Forecasting the Range-wide Status of Polar Bears at Selected Times in the 21st Century

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Abstract

To inform the U.S. Fish and Wildlife Service decision, whether or not to list polar bears as threatened under the Endangered Species Act (ESA), we forecast the status of the world's polar bear (*Ursus maritimus*) populations 45, 75 and 100 years into the future. We applied the best available information about predicted changes in sea ice in the 21st century to current knowledge of polar bear populations and their ecological relationships to the sea ice to understand how the range-wide population of polar bears might change. We combined the world's 19 polar bear subpopulations into 4 ecological regions based on current and projected sea ice conditions. These "ecoregions" are the (1) Seasonal Ice Ecoregion which includes Hudson Bay, and occurs mainly at the southern extreme of the polar bear range, (2) the Archipelago Ecoregion of the Canadian Arctic, (3) the Polar Basin Divergent Ecoregion where ice is formed and then advected away from near-shore areas, and (4) the Polar Basin Convergent Ecoregion where sea ice formed elsewhere tends to collect against the shore. We incorporated projections of future sea ice in each ecoregion, based on 10 general circulation models (GCMs), into two models of polar bear habitat and potential population response. First, we used a deterministic model of past, current, and future polar bear carrying capacity which assumed a linear relationship between bear density and annual average sea ice extent. Because this approach did not include seasonal changes in ice availability or other possible population stressors, it provided an optimistic view of the potential magnitude of and change in population carrying capacity by ecoregion and time step. Second, we developed a Bayesian network (BN) model structured around population stressors that could affect the factors considered in ESA decisions. The BN model combined empirical data, interpretations of data, and professional judgment into a probabilistic framework. Although BN models can be based on the collective judgment of multiple experts, time constraints in this project allowed input from only one expert. Therefore, we consider our BN model a prototype, and we provide guidance regarding next steps necessary to further refine the model. The BN model incorporated information about annual and seasonal sea ice trends as well as potential effects of other population stressors such has harvest, disease, predation, and effects of increasing human activity in the north due to ice retreat. Under both modeling approaches, polar bear populations were forecasted to decline throughout all of their range during the 21st century. In projections based upon ensemble mean ice predictions, the carrying capacity model forecasted potential extirpation of polar bears in the Polar Basin Divergent Ecoregion in 75 years. Projections using minimal ice levels forecasted potential extirpation in this ecoregion by year 45, whereas projections using maximal ice levels forecasted steady declines but not extirpation by year 100. Populations of polar bears in the other ecoregions were projected to decline at all time steps, with severity of decline dependent upon whether minimum, maximum or mean ice projections were used. Dominant outcomes of the BN model were for extinction of polar bear populations in the Seasonal Ice and Polar Basin Divergent Ecoregions by 45 years from present, and in the Polar Basin Convergent Ecoregion by 75 years from present. The BN model projected high non-zero

probabilities that Archipelago polar bears could occur at smaller numbers than now through the end of the century. Declines in ice habitat were the overriding factors determining all model outcomes. Although management of human activities could forestall extinction in the Archipelago and Polar Basin Convergent ecoregions, it could not qualitatively alter the prognosis of extinction for the Polar Basin Divergent and Seasonal Ecoregions. Similarly, model results indicated that sea ice conditions would have to be substantially better than even the most conservative GCM projections to result in a qualitatively different outcome for any of the ecoregions. Our modeling suggests that realization of the sea ice future which is currently projected, would mean loss of ≈ 2/3 of the world's current polar bear population by mid-century.

Introduction

Study Objective

Polar bears depend upon sea ice for access to their prey and for other aspects of their life history (Stirling and Øritsland 1995; Stirling and Lunn 1997; Amstrup 2003). Observed declines in sea ice availability have been associated with reduced body condition, reproduction, survival, and population size for polar bears in parts of their range (Stirling et al. 1999; Obbard et al. 2006; Stirling and Parkinson 2006; Regehr et al. 2007b). Observed (Comiso 2006) and projected (Holland et al. 2006) sea ice declines have led to the hypothesis that the future welfare of polar bears range-wide may be diminished, and to the U.S. Fish and Wildlife Service (FWS) proposal to list the polar bear as a threatened species under the Endangered Species Act (U.S. Fish and Wildlife Service 2007). The classification as a "threatened species" requires determination that it is likely the polar bear will become an endangered species within the "foreseeable future" throughout all or a significant portion of its range. An "endangered species" is any species that is in danger of extinction throughout all or a significant portion of its range. To help inform the final listing decision, the FWS requested that the U.S. Geological Survey (USGS) conduct additional analyses of polar bears and their sea ice habitats. Between February and August 2007, USGS and collaborators developed nine reports targeting specific questions considered especially informative to the final decision. This report, one of the nine, builds upon the other eight reports and uses other current information on polar bears to forecast the status of polar bears occurring in different parts of the Arctic at three future periods in the 21st-century.

We use the best available information and knowledge, including that derived from new studies requested by the FWS, to forecast the future status of polar bears in each of 4 ecoregions (Figure 1). We present our forecast in a "compared to now" setting where projections for the decade of 2045-2055, 2070-2080, and 2090-2100 are compared to the "present" period of 1996-2006. For added perspective we also look back to the decade of 1985-1995. Hence, we examined five time periods in total. Our view of the present and past are based on sea ice conditions derived from satellite data. Our future forecasts are based largely on information derived from general circulation model (GCM) projections of the extent and spatiotemporal distribution of sea ice.

Background biology

Polar bears occur throughout portions of the Northern Hemisphere where the sea is ice-covered for all or much of the year. Polar bear genetics indicate that the species branched off from brown bears (*Ursus arctos*) and invaded an open niche on the surface of the sea ice during maximal extent of the continental ice sheets in the very late Pleistocene. Molecular genetic techniques suggest this could have

occurred as long ago as 250,000 years (Amstrup 2003).Very few polar bear fossils are known, however, and those that have been discovered are relatively recent. They appear for the first time in the fossil record only 40 to 50 thousand years ago (Thenius 1953; Kurtén 1964). During their short evolutionary history, polar bears have diverged substantially from brown bears, apparently under selective pressures stemming from their specialization for capturing seals from the surface of the ice. Stanley (1979) described the many recently-evolved traits of polar bears as an example of "quantum speciation." The dearth of polar bear fossils reflects their specialty of living on the sea ice. Remains of dead animals on the sea ice would tend to accumulate on the sea floor rather than on land where they are more accessible to human discovery.

Since moving offshore, behavioral and physical adaptations have allowed polar bears to increasingly specialize at hunting seals from the surface of the ice (Stirling 1974; Smith 1980; Stirling and Øritsland 1995). Polar bears derive essentially all of their sustenance from marine mammal prey and have evolved a strategy designed to take advantage of the high fat content of marine mammals (Best 1984). Over half of the calories in a seal carcass are located in the layer of fat between the skin and underlying muscle (Stirling and McEwan 1975). Polar bears show their preference for fat by quickly removing the fat layer from beneath the skin after they catch a seal. The high fat intake that can be achieved by specializing on marine mammal prey has allowed polar bears to thrive in the harsh Arctic environment and to become the largest of the extant Ursids (Stirling and Derocher 1990; Amstrup 2003).

Over much of their range, polar bears are dependent on one species of seal, the ringed seal (*Phoca hispida*). Polar bears occasionally catch belugas (*Delphinapterus leucas*), narwhals (*Monodon monocerus*), walrus (*Odobenus rosmarus*), and harbor seals (*P. vitulina*) (Smith 1985; Calvert and Stirling 1990; Smith and Sjare 1990; Stirling and Øritsland 1995; Derocher et al. 2002). Walruses can be seasonally important in some parts of the polar bear range (Parovshchikov 1964; Ovsyanikov 1996). Bearded seals (*Erignathus barbatus*) can be a large part of their diet where they are common and are probably the second most common prey of polar bears (Derocher et al. 2002). Throughout most of their range, however, polar bears are most dependent upon ringed seals (Smith and Stirling 1975; Smith 1980). The relationship between ringed seals and polar bears is so close that the abundance of ringed seals in some areas appears to regulate the density of polar bears, while polar bear predation in turn, regulates density and reproductive success of ringed seals (Hammill and Smith 1991; Stirling and Øritsland 1995). Across much of the polar bear range, their dependence on ringed seals is close enough that the abundances of ringed seals can be estimated by knowing the abundances of polar bears (Stirling and Øritsland 1995; Kingsley 1998).

Polar bears rarely can catch seals on land or in open water (Furnell and Oolooyuk 1980); rather, they consistently catch seals and other marine mammals only at the air-ice-water interface. This dependence of polar bears on hunting at the ice surface, where aquatic mammals must come to breathe, is evident in the behavior of ringed seals. Steady predation pressure from polar bears over thousands of years has led ringed seals to use subnivian (below the snow) birthing lairs and to interrupt spring and summer basking with frequent periods of scanning their surroundings for bears. This is in contrast with Weddell seals (*Leptonychotes weddelli*), the southern hemisphere equivalent of ringed seals, which bask and give birth in the open (Stirling 1977) and can be approached by humans without reaction.

Although there are local exceptions, it appears that polar bears gain little overall benefit from alternate foods. Even in Hudson Bay where polar bears are forced onto land for

extended periods with access to a variety of foods including human refuse, little terrestrial food is incorporated into polar bear tissues (Ramsay and Hobson 1991). In short, maintenance of polar bear populations is dependent upon marine prey, largely ringed seals, and they are tied to the surface of the ice for effective access to those prey.

Polar bears occur in most ice-covered regions of the northern hemisphere, including the center of the polar basin (Stefansson 1921). They are not evenly dispersed throughout this area, however. Polar bears have been observed most frequently in shallow-water areas near shore and in other areas where currents and upwellings keep the winter ice cover from becoming too solidified. These shore leads and polynyas create a zone of active unconsolidated sea ice that is small in geographic area but contributes ~50% of the total productivity in Arctic waters (Sakshaug 2004). Polar bears, are most commonly observed in or near these near shore zones where ice is constantly moving, opening up and reconsolidating, rather than pelagic areas which are of lower productivity (Stirling and Smith 1975; Pomeroy 1997; Stirling 1997), and have been shown to focus their annual activity areas over these regions (Stirling et al. 1981; Amstrup and DeMaster 1988; Stirling 1990; Stirling and Øritsland 1995; Stirling and Lunn 1997; Amstrup et al. 2000, 2004a, 2005). Not surprisingly, ice over shallow waters less than 300m deep has now been shown to be the most preferred habitat of polar bears throughout the polar basin (Durner et al. 2007).

Given their wide geographic distribution, polar bears inhabit regions with very different sea ice conditions. The southern reaches of their range includes areas where sea ice is seasonal. There, polar bears are forced onto land where they are food deprived for extended periods each year. Polar bears of Hudson Bay are the best known example of this situation, but bears in Foxe Basin, Davis Strait, and Baffin Bay also are "stuck" on land for a portion of the year when the sea ice in their area melts entirely. Other polar bears live in some of the harshest and most northerly climes of the world where the ocean is ice-covered year-round. This includes northerly regions of the Canadian Arctic archipelago and northern Greenland (Jonkel et al. 1976). Others live in the pelagic regions of the polar basin where there are strong seasonal changes in the character of the ice. There polar bears historically have remained on the advancing and retreating ice pack throughout the year, despite the sometimes very long seasonal movements required to do so (Amstrup 1986; Amstrup and DeMaster 1988; Amstrup et al. 2000). For example, sea-ice extends as much as 400 km south of the Bering Strait that separates Asia from North America, and polar bears extend their range to the southernmost extreme of the ice (Ray 1971). Because sea ice disappears from most of the Bering and Chukchi seas in summer, however, polar bears occupying these areas must move as far as 1000 km northward to stay on the retreating ice (Garner et al. 1990, 1994). In the Chukchi Sea and elsewhere, polar bears spend their summers concentrated along the edge of the persistent pack ice. Significant northerly and southerly movements appear to be dependent upon seasonal melting and refreezing of ice near shore (Amstrup et al. 2000).

Telemetry data have shown that polar bears do not wander aimlessly on the ice, nor are they carried passively with the ocean currents as previously thought (Pedersen 1945). Rather, they occupy multi-annual activity areas from which they seldom leave. Tracking data show that polar bears use seasonally preferred or "core" regions every year, despite variation in annual activity area boundaries (Amstrup et al. 2000, 2001, 2004a, 2005). This suggests that activity areas of polar bears, when viewed over multi-year periods, could be called home ranges. All areas of the home range, however, will not be used each year. Sea-ice habitat quality varies temporally as well as geographically (Stirling and Smith 1975;

DeMaster et al. 1980; Ferguson et al. 1997, 1998, 2000a, 2000b; Amstrup et al. 2000). In areas where sea ice cover and character are seasonally dynamic, a large multi-year home range, of which only a portion may be used in any one season or year is an important part of the polar bear life history strategy. In other regions where ice is less dynamic, smaller and less variable activity areas are common (Messier et al. 1992; Ferguson et al. 2001).

The seasonal movement patterns of polar bears serve to emphasize the role of sea-ice in their life cycle. In the Beaufort Sea, the largest monthly activity areas and highest movement rates are during June-July and November-December. This matches the temporal patterns of ice melt and freeze in the area (Gloersen et al. 1992). Polar bears catch seals mainly by still-hunting (Stirling and Latour 1978). The dynamic summer and autumn ice must minimize predictability of seal hunting opportunity. Unpredictable ice distributions could require longer bear movements and larger bear activity areas during freeze-up and break-up. From May-August, measured net monthly movements of polar bears in the Beaufort Sea were significantly to the north for all bears, and in October they moved back to the south (Stirling 1990; Amstrup et al. 2000). October has historically been the month of freeze-up in the southern Beaufort Sea. In recent years, especially, October has been the first time in months when ice is available over the shallow water near-shore. Polar bears summering on the persistent pack ice quickly move into shallow water areas as soon as new ice forms in autumn, and they disperse easterly and westerly along near shore unconsolidated ice zones during winter. Mauritzen et al. (2001, 2002) also found movement patterns that were closely tied to seasonal ice cycles in other parts of the polar basin. Polar bears, in fact, have adapted their movement strategies to accommodate a broad range of sea ice characteristics (Messier et al. 1992; Ferguson et al. 1997, 1999).

The common denominator is that polar bears make seasonal movements to maximize their foraging time on sea ice that is suitable for hunting (Amstrup 2003). Polar bears appear to require relatively high concentrations of sea ice for effective hunting. Recent observations indicate that during most of the year, these preferred hunting habitats are sea-ice areas where the ice cover is $\geq$50% . (Stirling et al. 1999; Durner et al. 2004, 2006, 2007).

Methods

We took two approaches to forecast how the future range-wide population of polar bears might be different than it is now. Our first method provided estimates of the maximum potential sizes of polar bear populations based on climate modeling projections of the quantity of their habitat — but in the absence of effects of any additional stressors or knowledge about changes in habitat distribution. Our second method provided estimates of how the presence of multiple stressors, including changes in the quantity of sea ice as well as its spatiotemporal distribution, may affect polar bears.

The first approach was a deterministic calculation of polar bear habitat amount and carrying capacity in each ecoregion. We used estimated numbers of polar bears currently occupying each of the world's subpopulations, and the amount of sea-ice habitat currently in each area, to estimate the present-day polar bear density in each of 4 defined ecoregions (Figure 1). Then we multiplied the densities by the projected future (or empirically determined historic) amount of polar bear habitat in each ecoregion at various time periods, to derive the maximum potential number of bears that habitat could support. This is an estimate of polar bear carrying capacity, given the assumptions that current populations are at or near carrying capacity, that polar bear densities (number of bears per unit area) do not change, and that quality of the future habitat is equivalent to that at present. Of course, we recognize that such

calculations oversimplify the eventuality. Yet, these simple calculations provide approximate numerical references of polar bear numbers that help place other discussions of future change into perspective.

Our second approach, a Bayesian network (BN) population stressor model, addressed many shortcomings of the carrying capacity model by incorporating probabilistic calculations of potential effects from multiple stressors on polar bear populations. The BN model used the same projections of habitat change as in the carrying capacity model, but it also included seasonal habitat changes as well as anticipated likelihoods of changes in several other stressors (Figure 2). The BN model accommodated scenarios of whether availability of food for polar bears would likely change and whether bears might redistribute themselves because of changes in habitat. Also considered was whether changes in hunting, oil and gas development, contaminants, parasites, disease agents and other potential anthropogenic (human-caused) stressors could become more or less influential than they are now. The BN model parameterized knowledge about the effects of observed habitat changes on polar bear distribution, demography and physical condition. This included understandings gained from other studies by the USGS relative to the listing decision, and expert judgment on the effects of a variety of other factors which might alter the future for polar bears. Construction of the BN model allowed us to integrate qualitative judgments, regarding how polar bears interact with their environment, with quantitative habitat predictions in a synthetic model to provide relative probabilities of potential future outcomes. Forecasts of the future status of polar bears were based on comparisons between current and future sea ice, and on other salient changes in the polar bear's environment that may change as the ice diminishes. Current ice conditions were extracted from data sets derived from passive microwave satellite imagery, 1979 – 2006 (*http://nsidc.org/data/nsidc-0051.html*). Future ice conditions were extracted from GCM projections (https://esg.llnl.gov:8443). In addition to sea ice extent and distribution data from satellite images and GCMs, we used resource selection functions (RSFs) to identify preferred, optimal polar bear habitat. The RSFs allowed us to evaluate whether preferred sea ice habitats may change at different rates than the overall sea ice cover.

We made forecasts of the future for polar bears in each of four ecoregions. We defined the ecoregions based on observed and GCM-projected differences in sea ice, and how polar bears respond or may respond to those changes. In the following section, we provide detailed descriptions of the four polar bear ecoregions. Next, we describe the process we used to make projections of the amount and distribution of future sea ice habitat. Finally we provide details of the modeling methods we used to project the future status of polar bears.

Polar Bear Ecoregions

Polar bears are distributed throughout regions of the Arctic and subarctic where the sea is ice covered for large portions of the year. Although movements of individual polar bears overlap extensively, telemetry studies have demonstrated spatial segregation among groups or stocks of polar bears in different regions of their circumpolar range (Schweinsburg and Lee 1982; Amstrup 1986, 2000; Garner et al. 1990, 1994; Messier et al. 1992; Amstrup and Gardner 1994; Ferguson et al. 1999; Carmack and Chapman 2003). Patterns in spatial segregation suggested by telemetry data, along with information from survey and reconnaissance, marking and tagging studies, and traditional knowledge, have resulted in recognition of 19 partially discrete polar bear groups (Aars et al. 2006). There is considerable overlap in areas occupied by members of these groups (Amstrup et al. 2004a, 2005), and boundaries separating the groups are adjusted as new data are collected. Nonetheless, these boundaries are

thought to be ecologically meaningful, and the 19 units they describe and are managed as subpopulations (Figure 1).

In this report, we adhere largely to these group designations as they are used by International Union for the Conservation of Nature (IUCN) Polar Bear Specialist Group (PBSG) described in Aars et al. (2006). Our descriptions digress somewhat from those of the PBSG in regions of the polar basin where current knowledge of sea ice conditions and polar bear habitat preferences suggest that digression makes sense. We first redefined a Queen Elizabeth Islands subpopulation (QE). This subpopulation had historically been identified for the continental shelf region and inter-island channels between Prince Patrick Island and the northeast corner of Ellesmere Island. This unit was originally a geographic catchall population to account for the remainder of northern Canada (Aars et al. 2006). This area is characterized by heavy multi-year (old age) ice, except for a recurring lead system that runs along the Queen Elizabeth Islands from the northeastern Beaufort Sea to northern Greenland (Stirling 1980). Approximately 200 polar bears could be resident here and some bears from other regions have been recorded moving through the area (Durner and Amstrup 1995; Lunn et al. 1995). In 2003, the Canadian Polar Bear Technical Committee and the Canadian Polar Bear Administrative Committee agreed not to identify the QE subpopulation. Rather, they concluded it should be included as an undifferentiated portion of the central Arctic Basin (Lunn et al. 2006, page 101). Here, we reinstated QE as an important ecological unit. We also formally extended the QE boundary to include northern Greenland, based upon observed and predicted behavior of sea ice. Like the Northern Beaufort Sea subpopulation, QE occurs in a region of the polar basin that recruits ice as it is advected from other portions of the polar basin (Comiso 2002; Rigor and Wallace 2004; Belchansky et al. 2005; Holland et al. 2006; Durner et al. 2007; Ogi and Wallace 2007; Serreze et al. 2007).

We also do not incorporate the Arctic Basin subpopulation into our analyses. This subpopulation was defined by the IUCN in 2001 (Lunn et al. 2002) to recognize bears which may reside outside the territorial jurisdictions of the polar nations. The Arctic Basin region is characterized by very deep water which is known to be unproductive (Pomeroy 1997). Available data are conclusive that polar bears prefer sea-ice over shallow water (<300m deep) (Amstrup et al. 2000, 2004a; Durner et al. 2007), and it is thought that this preference reflects increased hunting opportunities over more productive waters. Indeed, polar bears from coastal regions will use the central Arctic Basin seasonally, but tracking studies indicate that few if any bears are year-round residents of the central Arctic Basin.

Although each of the areas where the 19 individual IUCN subpopulations occur have unique characteristics, we pooled them into four ecological regions (Figure 1). We defined "ecoregions" on the basis of observed temporal and spatial patterns of ice formation and ablation (melting or evaporation), observations of how polar bears respond to those patterns, and how general circulation models (GCMs) forecast future ice patterns. We defined these four ecoregions as: 1) Seasonal Ice (or Seasonal) Ecoregion; 2) the Canadian Arctic Archipelago (Archipelago Ecoregion); 3) the Polar Basin Divergent Ecoregion; and 4) the Polar Basin Convergent Ecoregion. Splitting the polar basin into 2 ecoregions was based upon their different patterns of sea ice formation, ablation and advection (transport by the wind or currents) (Rigor et al. 2002; Rigor and Wallace 2004; Maslanik et al. 2007; Meier et al. 2007; Ogi and Wallace 2007). The Polar Basin Divergent Ecoregion is characterized by extensive formation of annual sea ice which is then advected into the center of the polar basin or out of the polar basin through Fram Strait. The Polar Basin Divergent Ecoregion lies between ~127° W longitude and 10° E longitude

and includes the southern Beaufort, Chukchi, East Siberian-Laptev, Kara, and Barents seas. The Polar Basin Convergent Ecoregion is the remainder of the polar basin including the east Greenland Sea, the continental shelf areas adjacent to northern Greenland and the Queen Elizabeth Islands, and the northern Beaufort Sea (Figure 1).

Modeling

Overview

We projected the future status of polar bear populations in each of the four ecoregions, which collectively encompass the entire range of polar bear distributions range-wide. Both the carrying capacity and the BN models were applied to each of the four ecoregions at five time periods relative to present (years -10, 0, 45, 75, and 100). Analyses included historic and current habitat conditions from the satellite-observed ice data for years -10 and 0, and future habitat conditions from GCM ice projections for years 45, 75, and 100. Because multiple GCM model runs were not available, we did not have samples from which true process variation could be estimated. To capture the full range of variation, however, we developed estimates from: 1) the multi-model (ensemble) means of the 10 GCMs, 2) the GCM that projected the minimum ice extent, and 3) the GCM that projected the maximum ice extent—for each ecoregion in each time period. See DeWeaver (2007) and Durner et al. (2007) for a thorough discussion of the range in values among GCMs.

Sea-ice habitat variables

Our forecast of future carrying capacity of polar bears was based entirely on historic and current observations, and future GCM projections of future sea ice habitat for polar bears. Our BN model then incorporated changes in sea-ice habitat distribution as one of the "stressors" which might help predict the future of polar bears. Hence both approaches depended upon an assessment of polar bear habitat and projections of how future habitat might be different than now (Figure 2). For modeling, we needed consistent metrics of polar bear habitat that would facilitate temporal comparisons. We defined two such metrics: 1) polar bear habitat as simply the area of sea ice over the continental shelf; and 2) optimal sea ice habitat—defined as ice with characteristics shown to be preferred by polar bears through development and application of resource selections functions (RSFs).

Durner et al. (2007) used polar bear satellite tracking data and monthly ice concentration observations derived from passive microwave satellite imagery (Cavalieri et al. 1999) to develop RSFs that estimated relative probabilities of habitat use in the two pelagic ecoregions of the polar basin. RSFs were built only for the polar basin where radiolocation data had sufficient sample size. Durner et al. (2007) constructed four seasonal RSF models (winter, spring, summer, and autumn) using data collected during 1985–1995. Durner et al. (2007) then extrapolated the RSF models using sea ice projections from each of 10 GCMs (Table 1) that were selected for analysis because their 20th century simulations were better aligned with the observational ice record (DeWeaver 2007).

For each season, Durner et al. (2007) calculated the average 1985–1995 RSF threshold that separated the upper 20% from the lower 80% of the RSF-valued habitat area, and termed the upper 20% "optimal habitat" because those areas were occupied by over 70% of the bear locations. These 1985–1995 thresholds were used to extract the area of optimal habitat in all months of the 21st-century RSF extrapolations from all 10 GCMs. Using the 1985–1995 period to define the thresholds provided Durner et al. a foundation that allowed them to examine whether future ice projections indicated increases, decreases, or stability in the cumulative annual area of optimal polar bear

habitat.

We used three types of monthly maps from the Durner et al. (2007) study: 1) Arctic-wide observed sea ice concentrations (1979–2006); 2) Arctic-wide 21st-century sea ice projections by 10 GCMs; and 3) both observed and projected areas of optimal polar bear sea-ice habitat in the two pelagic polar basin ecoregions. From the observed and projected Arctic-wide sea ice concentration maps, we defined and extracted "total available ice habitat" as the annual 12-month sum of sea ice cover over the continental shelves of the two polar basin ecoregions. Ice cover was defined as the aerial extent (km^2) of all pixels with $\geq 50\%$ ice concentration. Since deep water is uncommon in the archipelago and seasonal ice ecoregions, we considered those entire areas to effectively reside over the continental shelf, meaning total ice habitat equated to total ice cover.

Other key sea ice factors of interest included how climate warming may change the duration and distance that ice retreats from the continental shelf regions. Using the observed and projected ice concentration maps, we extracted and summed the annual number of ice-free months in each ecoregion. An ice-free month occurred when the proportion of ice cover (defined above) over the continental shelf dropped below 50% of the total area (again, the archipelago and seasonal ecoregions were considered entirely shelf waters). In other words, we considered the availability of total ice habitat to be compromised if less than half of the continental shelf-waters were ice-covered; hence the respective month was classified as ice-free. Also for each year, for the month of minimum ice extent, we calculated the mean distance from every pixel in an ecoregion to the nearest ice-covered pixel.

We note that expressing changes in sea-ice habitat over time on the basis of annual km^2-months tends to minimize the potential effects of sea ice habitat changes projected for the future as well as those that have been observed may have on polar bears. Whereas the yearly average sea ice extent has declined at a rate of 3.6% per decade, the mean September sea ice extent has declined at a rate of 8.4% per decade (Meier et al. 2007). Further, all GCMs project extensive winter sea ice through the end of the 21st century in most ecoregions (Durner et al. 2007). Therefore the severity of summer periods of food deprivation may be hidden by extensive sea ice in winter. Although polar bears are well adapted to a feast and famine diet (Watts and Hansen 1987), there apparently are limits to their ability to sustain long periods of food deprivation (Regehr et al. 2007b). We recognize that our measure of change in km^2-months will be largely insensitive to seasonal effects.

We used the baseline period 1985-1995 to define high-value (optimal) habitat because during this early period of our studies, year-round polar bear movements were less restricted than they were in recent years when sea ice extent was more spatially reduced. The 4 seasonal RSF thresholds, derived from the 1985-1995 period, remained fixed for all time steps in our projections. Thus, when we extracted the area of optimal habitat from RSF maps generated from outputs of GCMs, the threshold values for optimal habitat were those observed in 1985-1995. This approach created a foundation that allowed us to examine whether future ice projections indicated increases, decreases, or stability in the cumulative annual area of optimal polar bear habitat relative to our earliest decade of empirical observations. Inherently, this approach assumes that polar bears in the future will select habitats in the same way they did between 1985-1995 despite seasonal changes in ice extent and distribution.

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Carrying Capacity Model

We developed deterministic calculations of polar bear carrying capacity for each combination of ecoregion, time step, and future minimum, maximum, and multi-model mean GCM projections. Deterministic projections were calculated in Microsoft Excel®. Calculations in the model components are described below.

Habitat amount

First, we compiled the amount of total ice habitat and optimal habitat from the observed sea ice record and from the GCM projections. Specifically, the total annual (Σ 12 months) habitat amount $H_{t,G}$ was expressed for each of the four ecoregions G and each of the five yearly time periods t as km^2-months. For the two polar basin ecoregions (where the RSF study was conducted) we subtracted the optimal habitat area from the estimates of total ice habitat to provide an area of non-optimal habitat.

Change in habitat amount

Despite overall agreement in the direction of change in sea ice extent, there is considerable variability among the GCMs in their simulations of present-day ice extent, as well as disparity with the observed sea ice record (Figure 3). These disparities reflect aspects of GCM model uncertainties that are introduced by many factors (DeWeaver 2007). Disparities of GCM model predictions with known conditions are not surprising because GCMs are constructed to emulate natural climate variability (Wang et al. 2007). Amounts of ice predicted by the GCM model might not perfectly match amount observed because the observed climate is but one realization of the possible modeled outcomes.

When comparing modeled futures to the present, it would make no sense to project the trends forward from a baseline that "could have been." Rather, the sensible approach is to use the GCM's projected rates of habitat change, and apply those rates of change to the actual observed baseline. To this end, we compared the habitat projections at each time step to each model's "time zero" value, and calculated the percent change in habitat projected by each model relative to itself. This calibrating or normalizing of the estimates of available habitat provided all model results with a common beginning or baseline value in year 0, and took full advantage of the rate of change projected by each model.

We calculated the percent change in habitat amount H at time t with respect to year 0, for each geographic region G, as

$$CH_{t,G} = 100 * \frac{(H_{t,G} - H_{0,G})}{H_{0,G}}.$$

One outcome of the calculation of $CH_{t,G}$ was that estimates at year 0 varied among GCM runs. Another outcome of these calculations is that compared to the observed ice extent, the GCM ensemble mean, and most individual models, overestimated ice extent in the study area in both the late-20th century simulations and the early-21st century projections. Furthermore, the recent rate of summer ice decline in the observed data shows a trajectory that is steeper than that of the GCM ensemble mean during the early 21st century. This is a reflection of Stroeve et al.'s (2007) conclusion that Arctic sea ice may be disappearing at a rate that is "faster than forecasted".

Our normalized $CH_{t,G}$ was further interpreted into categories of direction of change,

magnitude of change, and a composite summary of magnitude and direction. Direction was categorized into "contracting" if $CH_{t,G} < 0$ or "expanding or stable" if $CH_{t,G} \geq 0$. Magnitude was categorized into "fast" if $|CH_{t,G}| > 30.0$, "moderate" if $15.0 < |CH_{t,G}| \leq 30.0$, and "slow or none" if $|CH_{t,G}| < 15.0$. We also make available the specific results for $CH_{t,G}$ so that alternative cutoff values for such categories could be examined if desired. The summary category for habitat change was then based on the habitat change direction category and the magnitude category, as shown in Table 4.

Polar bear densities

We used the most recent estimated population size for each IUCN subpopulation (Aars et al. 2006, Table 5) to calculate polar bear densities. Because estimates were not provided for the East Greenland and Kara Sea subpopulations, we surmised numbers that seemed appropriate based upon the area of habitat and records of harvest where available. Accuracy of the year 0 density estimates is not critical because our goal was to express the relative changes that are likely to occur. In other words, although the numbers of bears in many of the world's subpopulations are poorly known, our projections of trends in those numbers in this model are valid to the extent that sea ice quantity alone determines polar bear carrying capacity.

We calculated polar bear densities based on observed total ice habitat in each of the four ecoregions. We also calculated polar bear densities based on optimal habitat in each of the two polar basin ecoregions. Following examples in the ecological literature, we refer to the densities estimated from total and optimal habitat as "crude" and "ecological," respectively (Rinkevich and Gutiérrez 1996; Diller and Thome 1999). We calculated densities as follows. First we tallied present-day (year 0) polar bear population sizes $N_{0,G}$ in each of the four ecoregions G. We then calculated polar bear densities as

$$D_G = \frac{H_{0,G}}{N_{0,G}},$$

expressed as habitat area (km^2-months x 1000) per bear, using the estimates of habitat at year 0 from satellite data. We expressed density in terms of habitat area per bear to avoid the excessively small values that would result from expressing density in terms of bears per area.

We calculated total densities based on total ice habitat area for the Seasonal and Archipelago ecoregions, and we calculated "ecological" and "crude" densities based on optimal habitat and and non-optimal habitat area, respectively, for the Polar Basin Divergent and Convergent ecoregions. Empirical observations indicated that polar bears spend 70% of their time in the portion of the habitat that we called optimal (Durner et al. 2007). We extrapolated this to mean that at any snapshot in time, 70% of the bears in the two polar basin ecoregions were within the identified optimal habitat. We used 70% to estimate an ecological density in the optimal habitat. The remaining 30% of bears in each ecoregion were assigned to the non-optimal habitat to calculate a crude density. All polar bear density calculations were based on year 0 numbers of bears and habitat area, and then applied to other past and future time periods. This assumed that densities are invariant over time in terms of describing potential carrying capacity levels.

Polar bear carrying capacity

We applied year 0 polar bear densities to habitat area in each time period to calculate polar bear carrying capacity $K_{t,G}$ for each combination of time period t, ecoregion G, and minimum, maximum, and ensemble mean GCM habitat values. The calculation was:

$$K_{t,G} = H_t / D_G.$$

We used the normalized percent change in habitat to derive values for available habitat at

each time step. This assured that our estimates of changes in carrying capacity coincided with the projected estimate of available habitat at each time step. Specifically, we calculated percent change $CK_{t,G}$ in $K_{t,G}$ from year 0 values, as

$$CK_{t,G} = 100 * \frac{(K_{t,G} - K_{0,G})}{K_{0,G}}.$$

This was done for all habitats in the Seasonal Ice and Archipelago ecoregions, and separately for optimal habitat and non-optimal habitat in the Divergent and Convergent ecoregions. We then applied each of the percent change values $CK_{t,G}$ to the estimate of carrying capacity at year 0 $K_{0,G}$ (based on the observed data), to recalculate a normalized value of carrying capacity as

$$K_{t,G}^{norm} = K_{0,G} * \left(1 + \frac{CK_{t,G}}{100}\right).$$

In this way, the values of normalized carrying capacity $K_{t,G}^{norm}$ can be compared over time periods (historic, current, and future) for each of the GCM model run scenarios (minimum, ensemble mean, and maximum) in parity.

Percent change in carrying capacity

We divided the values of change in carrying capacity $CK_{t,G}$ into categories of direction, magnitude, and composite outcomes. Direction was categorized into "decreasing" if $CK_{t,G} < 0$ or "stable or increasing" if $CK_{t,G} \geq 0$. Magnitude was categorized into "high" if $|CK_{t,G}| > 30.0$, "moderate" if $15.0 < |CK_{t,G}| \leq 30.0$, and "low to none" if $|CK_{t,G}| < 15.0$. We make available the specific results for $CK_{t,G}$ so alternative cutoff values can be examined if desired. The summary categories of carrying capacity change were then derived from the direction and magnitude categories, as shown in Table 6.

Assigning Status Categories Based on Carrying Capacity Change

We categorized outcomes of habitat change and carrying capacity change into 4 composite summary categories to describe the status of polar bear populations: enhanced, maintained, decreased, and toward extirpation (Table 2). The composite summary categories express very general classes of carrying capacity levels as compared with current levels, and basically constitute a simple rule set for expressing outcomes in ordinal scale classes. We provide categorical outcomes to depict future polar bear carrying capacity levels in a simple, understandable manner that is relatively insensitive to the accuracy of specific calculations or assumptions. We started these computations with the best estimates available of sea ice habitats and polar bear numbers, and we applied those estimates to the best available GCM projections.

As mentioned previously, many polar bear population estimates were crude, and the assumption that polar bear density would not change over time is almost certainly not valid. Collapsing the numerical outcomes of this process into intuitive categories of qualitative results, however, converts the actual numbers to only four general classes. The carrying capacity model is not a demographic model, nor is it an estimation of actual, expected population sizes of polar bears. It is a calculation only of possible carrying capacity and changes thereof, assuming no effects from anthropogenic stressors or environmental factors other than the losses of habitat forecasted by GCMs.

Bayesian Network Population Stressor Model

Our second method of forecasting the status of polar bears in the 21st century involved the development of a prototype Bayesian network (BN) model that accommodates the potential effects of multiple stressors on polar bear populations. Inputs to our BN model included

various categories of natural and anthropogenic stressors (Barrett 1981; Anderson et al. 2000), and key environmental factors that affect polar bear populations. Anthropogenic stressors included various human activities that could affect the distribution or abundance of polar bears, such as harvest, pollution, oil and gas development, shipping, direct bear-human interactions, and others. Natural stressors on polar bears included changes in the availability of primary and alternate prey and foraging areas, and occurrence of parasites, disease, and predation (Ramsay and Stirling 1984; Amstrup et al. 2006). Other key environmental factors included projected changes in total ice and optimal habitat, changes in the distance that ice retreats from traditional autumn or winter foraging areas, and changes in the number of months per year that ice is absent in the continental shelf regions. Collectively, the anthropogenic stressors, natural disturbances, and other key environmental factors were structured in a BN model in terms of how they affect polar bear demography and use of foraging areas, and ultimately, how they affect polar bear distribution and abundance.

Below, we provide a general description of BN models and their use in ecological applications. We then describe how we developed the population stressor model for polar bears, how results from the model were analyzed, how we analyzed the model results, and how we conducted sensitivity analyses.

What are Bayesian network models?

A Bayesian network is a graphical model that represents a set of variables that are linked by probabilities[1] (Neopolitan 2003; McCann et al. 2006). BNs are comprised of variable *nodes* and their *links*. Nodes can represent correlates or causal variables that affect some outcome of interest, and the links define which specific variables directly affect which other specific variables. A BN defines a causal web with probabilistic links, whereby specifying the conditions of some variables can predict the outcome of some other variables. In this way, BNs constitute what are called influence diagrams (Marcot et al. 2006). BNs provide an efficient way to represent and summarize understanding of a system, and can combine expert knowledge and empirical data into the same modeling structure. Crafting a BN allows one to better understand the relationships and sensitivities among the elements of the causal web, and to provide insights into the workings of the system that otherwise would not have been evident.

Each node in a BN model typically is depicted with two or more mutually exclusive states. BN nodes can represent categorical, ordinal, or continuous variable states or constant (scalar) values. Each node typically has an associated probability table that describes either its prior (unconditional) probabilities of each state for input nodes, or its conditional probabilities of each state for nodes that directly depend on other nodes (see Marcot et al. 2006) for a description of the underlying statistics). BNs are "solved" by specifying the values of input nodes and having the model calculate posterior probabilities of the outcome node(s) through standard "Bayesian learning," which is the application of Bayes' theorem (Jensen 2001; see also footnote 1).

Use of Bayesian networks in ecological modeling

[1] In BNs, input nodes contain unconditional prior probabilities of their states. The states are assumed to be mutually exclusive and the probabilities sum to one. Prior probabilities are distributed as discontinuous Dirichlet functions in the form of $D(x) = \lim_{m\to\infty}\lim_{n\to\infty}\cos^{2n}(m!\pi x)$, which is a multivariate, n-state generalization of the two-state Beta distribution with state probabilities being continuous within [0,1]. States S of output nodes contain posterior probabilities that are calculated conditional upon nodes H that directly affect them, using Bayes Theorem, as $P(S \mid H) = \frac{P(H \mid S)P(S)}{P(H)}$ (see Jensen 2001 and Marcot 2006 for further explanation of the statistical basis of BNs).

BNs are being increasingly used in ecological and natural resource modeling. Examples include use of BNs to model population viability of salmonid fishes (Lee and Rieman 1997), habitat restoration potential for rare wildlife species (Marcot et al. 2001; Wisdom et al. 2002), effects of habitat alteration on populations of native ungulates (McNay et al. 2006), and many other applications (Marcot 2007). BNs are useful for modeling systems where empirical data are lacking, but variable interactions and their uncertainties can be depicted based on expert judgment (Das 2000). They are also particularly useful in efforts to synthesize large amounts of divergent quantitative and qualitative information to answer "what if" kinds of questions. Their ability to examine "what if" questions has led to insights regarding the prognosis for how global warming may impact coral reefs, and the degree to which local management actions may be able to offset some effects of rising temperatures (Wooldridge and Done 2004; Wooldridge et al. 2005).

Structuring the Bayesian network population stressor model for polar bears

Developing a BN model entails depicting the "causal web" of interacting variables (nodes) in an influence diagram (that is, describing the general structure of the model), assigning states to each node, and assigning probabilities to each node that define the conditions under which each state would result. BNs can be built from a combination of empirical data and expert judgment, and can be built using commercially-available modeling shells. We used the modeling shell Netica® (Norsys, Inc.), and followed guidelines for developing BN models developed by Jensen (2001), Cain (2001) and Marcot et al. (2006).

The BN model we developed for polar bears depicted the potential population influences from multiple stressors and environmental conditions that were not captured in the simple carrying capacity model described earlier. Our BN stressor model was based on the knowledge of one polar bear expert (S. Amstrup) who established the model structure and probability tables according to expected influences among variables. B. Marcot served as a "knowledge engineer" or model engineer, and provided guidance to help structure the expert's knowledge into an appropriate BN format. An initial list of ecological correlates was compiled by the expert, which were then organized into an influence diagram (Figure 4). Through discussion and questioning, the model engineer guided the expert through several stages to a final structure. The interactive sessions were useful in exploring alternative means of depicting influences among variables, ways to summarize influences into categories of numerical and distribution responses which could be useful to managers, and ways of representing some variables with proxies.

The BN model structure was divided into three kinds of nodes: (1) input nodes that were the anthropogenic stressor or environmental variables and used unconditional probabilities to parameterize their states; (2) summary nodes that collected and summarized effects of multiple input nodes and used conditional probabilities to calculate their states; and (3) output nodes that represented numerical, distribution, and overall population responses to the suite of stressors and environmental conditions. The output nodes used Bayesian learning to calculate posterior probabilities of their final outcome states. Summary nodes in the model served to "gather" and depict the joint influence of several inputs, and constituted what are sometimes called latent variables in the ecological modeling literature (e.g., Bollen 1989). Including latent variable nodes in the BN model was also helpful in establishing probability tables in each node and for characterizing general categories of the input (stressor) nodes. We went through many iterations of the model structure to ensure that it responded to particular input conditions in ways that paralleled responses of polar bear

populations which have been observed, or for which there are strong prevailing hypotheses in the biological community.

The overall outcome of our BN model was a statement of the relative probabilities that the population in each ecoregion would be larger than now, same as now, smaller, rare, or extinct. The overall outcome was determined by nodes which summarized the likely numerical and distribution response of polar bears to projected changes in their environment. Responses of polar bears to projected habitat changes and other potential stressors could affect polar bear distribution or polar bear numbers independently in some cases, or they could affect both distribution and numbers simultaneously. Our approach allowed for independent or linked numerical and distributional responses. The factors influencing numerical and distribution responses were, in turn, further defined in terms of more specific human stressor, natural disturbance, or key environmental correlate variables (Figure 5).

Because our purpose was to inform the decision of whether to list polar bears as a threatened species, we designed the summary nodes in the BN model to include four of the five major listing factors used to determine a species' status according to the Endangered Species Act (U.S. Fish and Wildlife Service 2007). We included summary nodes for Factor A—habitat threats; Factor B—overutilization; Factor C—disease and predation; and Factor E—other natural or man-made factors. We did not include Factor D—inadequacy of existing regulatory mechanisms, because our model focused on ecosystem effects; however, regulatory aspects could be seamlessly added at a future time. Inclusion of these summary nodes recognized the listing factors as important potential stressors and also acknowledged the work done by the FWS during development of the proposal to list polar bears. Structuring the BN model in this way, therefore, helps assure its relevance to the listing process. This structure also anticipates that our BN stressor model could provide a foundation for a decision model specific to Endangered Species Act listing criteria for this species.

Parameterizing the Bayesian network model

Model input nodes were parameterized with data on ice extent, length of time that ice was projected to be away from identified foraging areas, and the distance of ice retreat from such areas (Table 3). Other nodes incorporated qualitative descriptions of possible states of important environmental correlates. Because we were interested in forecasting changes from current conditions, states of each node were expressed categorically as "compared to now." That is, they could be in a condition similar to present, they could be in better condition than present, or they could be in worse condition. We set prior probabilities of all input nodes to uniform distributions (complete uncertainty), but before the model was run, we specified the states that seemed most probable (Table 3).

States of environmental correlates were established under each combination of time step, ecoregion, and GCM model outputs. We parameterized the conditional probability tables to assure that node structures were specified in accordance with available polar bear data or expert understanding of data. After initially populating and inspecting the conditional probability tables, we used three different methods to arrive at final values: 1) sensitivity analyses of subparts of the model, 2) solving the model backwards by specifying outcome states and evaluating if the most likely input states that were returned were plausible according to what we know about polar bears now, and 3) running the model (and subparts) forward to ascertain if the summary and outcome nodes responded as expected given the states of the input nodes. These approaches constituted initial calibration of the model to the expert's knowledge about polar bears and how polar bears are likely to respond to various circumstances. In sum, the goals of this first-generation BN model were to ensure that input

conditions matched the current understanding of polar bear biology ecology and responses to observed changes, and that it responded to particular input conditions in ways that paralleled observed responses of polar bear populations.

As fully specified, the BN model included probability tables for each node (Figure 5, Appendix 2, 3). The BN model ultimately consisted of 38 nodes, 44 links, and 1,667 conditional probability values specified by the modelers. The model was solved for each combination of 4 ecoregions, 5 time periods, and 3 future GCM scenarios (ensemble mean, maximum, and minimum). Specifically, for each ecoregion and time period, the three future GCM scenarios were: 1) results projected by the ensemble mean of all 10 GCMs ; 2) results projected by the GCM that forecasted the greatest retention of sea ice; and 3) results projected by the GCM that forecasted the lowest retention of sea ice. Only one data source (the observed record of sea ice) was examined for the historic (1985-1995) and current (1996-2006) time periods. In total, we examined 44 unique combinations. We evaluated correlations among input nodes and between input and output nodes, to assure that colinearity among inputs was not unduly affecting outcome states.

The input data to run each combination were specified by summarizing the respective GCM-derived habitat variables, and by best professional judgment of polar bear expert S. Amstrup (Table 3). Because BN models combine expert judgment and interpretation with quantitative and qualitative empirical information, inputs from multiple experts are usually incorporated into the structure and parameterization of a "final" model. Due to time constraints, however, we were not able to seek and incorporate the input of multiple polar bear experts. Therefore, the model presented here should be viewed as a first-generation prototype. The model will be refined through formally developed processes (see Discussion) at a future time.

Bayesian network model output states

Principal results of the BN model are levels of relative probabilities for the potential states at outcome nodes. In the polar bear BN population stressor model, outcomes of greatest interest were 1) those related to listing factors used by the FWS, 2) the distribution responses, 3) numerical responses, and 4) the overall population response. We evaluated the BN outcomes in terms of the most probable outcome at each of the time steps, and the dispersion of probabilities among all outcomes. Probabilities are presented for each ecoregion and for each of the GCM scenarios we examined. We assessed results from the BN model in the statistical software package SYSTAT 11 (SYSTAT 2004).

We defined our principal outcome nodes (shown in Figure 5) and their possible states as follows:

Node C4: Numerical Response

This node represents the anticipated numerical response of polar bears in an ecoregion based upon the sum total of the identified factors which are likely to have affected numbers of polar bears in any particular area. Such factors include net reproduction as affected by ice habitat conditions, and influences of disease, predation, intentional takes, and human disturbances and stressors. Numerical response outcome states were defined as follows:

- increased density = polar bear density greater than that at Year 0 (year 2000); the density level could be determined empirically to be significantly greater than that at Year 0; density can be expressed in terms of number of polar bears per unit area of optimal habitat (thus expressing "ecological density") or of total (optimal plus suboptimal) habitat (thus expressing "crude density");
- same as now = polar bear density as above

but equivalent to the density at Year 0; the density level could be determined empirically to not be different from that at Year 0;

- reduced density = polar bear density less than that at Year 0 (year 2000) but greater than one-half of the density at Year 0; the density level could be determined empirically to be significantly less than that at Year 0 and also significantly greater than one-half of the density at Year 0;
- rare = polar bear density less than half of that at Year 0 (year 2000); the density level could be determined empirically to be significantly less than that one-half that at Year 0;
- absent = polar bears are not demonstrably present; polar bear density is not significantly different than zero.

Node C3: Distribution Response

This is the sum total of ecological and human factors that predict the future distribution of polar bears in the ecoregion. Distribution refers here to the *functional response* of polar bears (viz., movement and spatial redistribution of bears) to conditions of ice habitat quantity, quality, and temporal distribution; availability of prey and foraging areas; and human disturbances and stressors. Distribution response outcome states were defined as follows:

- same as now = polar bear distribution equivalent to that at Year 0; distribution could be determined empirically to not be different from that at Year 0;
- reduced but resident = a condition in which habitat or prey availability have changed in a way that would likely lead to a significantly reduced spatial distribution (e.g. due to avoidance of a human development, or sea ice is still present in the area but in more limited quantity). Bears would still occur in the area, but their spatial distribution would be more limited than at Year 0;
- transient visitors = a condition in which habitat or prey availability are seasonally limited or human activities have resulted in a situation where available ice is precluded from use by polar bears on a seasonal basis;
- extirpated = a condition in which habitat or prey availability have declined and human stressors have increased in such a way as to render the area essentially unusable by polar bears, and have lead to a complete or effective dearth of polar bears in the area.

Node D1: Overall Population Outcome

Overall population outcome refers to the collective influence of both numerical response and distribution response. It incorporates the full suite of effects from all anthropogenic stressors, natural disturbances, and environmental conditions on the expected occurrence and levels of polar bear populations in the ecoregion. Overall population outcome states were defined as follows:

- larger = polar bear populations have a numerical response greater than at present (Year 0) and a distribution response at least the same as at present (that is, able to use available habitat, to relocate if possible and needed, and to withstand anthropogenic stressors);
- same as now = polar bear populations have a numerical response essentially the same as at present (Year 0) and a distribution response at least the same as at present;
- smaller = polar bear populations have a reduced density and a distribution response the same as at present or reduced but resident; or have a density same as at present but occur as reduced but resident or transient visitors;
- rare = polar bears are numerically rare and

have a distribution response same as at present, or occur as reduced but resident or transient visitors; or have a reduced density and occur as transient visitors;

- extinct = polar bears are numerically absent or distributionally extirpated.

Here, the "extinct" state refers to conditions of: (1) complete absence of the species (N=0) from an ecoregion; or (2) numbers and distributions below a "quasi-extinction" level, that refers to a non-zero population level at or below which the population is near extinction (Ginzburg et al. 1982; Otway et al. 2004); or (3) functional extinction, that refers to being so scarce as to be near extinction and contributing negligibly to ecosystem processes (Sekercioglu et al. 2004; McConkey and Drake 2006).

Our final BN model was structured to make maximum use of the data and GCM outcomes describing observed and projected changes in the sea ice. Knowledge of polar bears, their dependence on sea ice, and the ways in which sea ice changes have been observed to affect polar bears, were used to populate the conditional probability tables. The BN model also incorporated professional judgment regarding how other ecological and human factors may change if sea ice changes occur as projected. Because our prototype model was parameterized by the best professional judgment of only one polar bear expert, it is reasonable to ask how robust the results might be to input probabilities which could vary among other experts. It also is appropriate to ask whether it is likely that future sea ice change, to which model outcomes are very sensitive, could fall into ranges that would result in qualitatively different outcomes than our BN model projects. Finally, it is appropriate to ask the extent to which model outcomes may be altered by active management of the states of nodes which represent variables which are under human control.

We addressed questions about the ability of changes in human activities to alter the BN output states by fixing inputs which humans could control and examining differences in the overall outcomes. We evaluated the extent to which sea ice projections would have to differ to make qualitative differences in outcomes by holding all non-ice variables at uniform priors and allowing ice variables only to vary at future time steps. Comparing those results to the range of ice conditions available from GCMs provides a sense of just how much the realized future ice conditions would have to change from those projected to make a difference in population outcomes. Finally, although we cannot second guess how other polar bear experts may recommend parameterizing and structuring the model, comparison of model runs with preset values provides some sense of how much differently the model would have to be parameterized to project patterns qualitatively different than those we observed.

After the BN population stressor model was finalized, we ran overall sensitivity analyses to determine the degree to which each input and summary variable influenced the population outcome variables. We used results of sensitivity analysis to determine the potential effect of each stressor variable on the anticipated polar bear numerical response, distribution response, and overall population outcome.

For discrete and categorical variables, sensitivity was calculated in the modeling shell Netica as the degree of entropy reduction (reduction in the disorder or variation) at one node relative to the information represented in other nodes of the model. That is, the sensitivity tests indicate how much of the variation in the node in question, is explained by each of the other nodes considered. That is, "node X explains this much of the variation in node Y." [See chapter 2 in Burnham and Anderson (1998) for a summary discussion of the entropy concept.] The degree of entropy reduction, I, is the expected reduction in mutual information of an output variable Q with q states due to a finding of an input variable F with f states. For discrete variables, I is measured in terms of

information bits and is calculated as:

$$I = H(Q) - H(Q \mid F) = \sum_q \sum_f \frac{P(q,f)\log_2[P(q,f)]}{P(q)P(f)}$$

where $H(Q)$ is the entropy of Q before new findings are applied to input node F, and $H(Q|F)$ is the entropy of Q after new findings are applied to F. In Netica, entropy reduction is also termed mutual information.

For continuous variables, sensitivity is calculated as variance reduction VR, which is the expected reduction in variation, $V(Q)$, of the expected real value of the output variable Q due to the value of input variable F, and is calculated as

$$VR = V(Q) - V(Q \mid F),$$

where

$$V(Q) = \sum_q P(q)[X_q - E(Q)]^2,$$

$$V(Q \mid F) = \sum_q P(q \mid f)[X_q - E(Q \mid f)]^2, \text{ and}$$

$$E(Q) = \sum_q P(q) X_q,$$

and where X_q is the numeric real value corresponding to state q, $E(Q)$ is the expected real value of Q before new findings are applied, $E(Q|F)$ is the expected real value of Q after new findings f are applied to F, and $V(Q)$ is the variance in the real value of Q before any new findings (Marcot et al. 2006)

The greater the values of I or VR, the greater is the influence of input variable F on output variable Q. In this way, we were able to assign an order to the potential influence of each input and summary node on the population outcome nodes, and thereby describe the overall sensitivity structure of the model.

Results

In this section we first present the projection of carrying capacities for polar bears in each ecoregion based on a presumed linear relationship between sea ice extent and polar bear numbers. That projection, which does not include seasonal changes in the sea ice, or other factors which could be population stressors, provides an upper bound on polar bear populations that could be supported by sea ice habitat available in the future. We next present projections based on the BN population stressor model. Because it incorporated many of the factors not included in the projection of carrying capacity, it provides a more thorough assessment of the future of polar bears in each ecoregion.

Forecasted 21st Century Polar Bear Carrying Capacity

Habitat area and change

Total habitat area, expressed as the annual sum of km^2-months of sea ice extent, was projected by the GCM models to be reduced (Figure 3) from present-day conditions, at each time step in each ecoregion and for all ecoregions combined (global). Proportional declines in available total habitat ranged from relatively modest (less than 15% decline from present) at year 45 in the Seasonal Ice Ecoregion, to large (more than 47% decline) by year 100 in the Polar Basin Divergent Ecoregion (Table 4, Figures 6, 7). For all combinations of time steps, GCM runs, and ecoregions, both total and optimal habitat were projected to be less abundant than present amounts (Table 4, Figures 6, 7). Globally, projected habitat declines were 24%, 18%, and 15% for the minimum, mean, and maximum GCM model inputs, respectively, by year 45. Equivalent global values at year 100 were 40%, 32%, and 23% for minimum, mean, and maximum ice projections, respectively. Using the satellite observed sea ice record, total habitat area during the previous decade (year -10) varied among ecoregions and was between 3% and 17% more abundant than at present. Globally, total habitat in the last decade was 7% more abundant than it is now (Figures 6, 7).

Polar bear carrying capacity

Current estimated polar bear densities ranged from a high of $0.923*10^3$ km^2-months per bear in the Polar Basin Convergent Ecoregion, to a low of $7.695*10^3$ km^2-months per bear in the non-optimal portion of the Polar Basin Divergent Ecoregion (Table 5). Estimates of polar bear carrying capacity ($K_{t,G}$) based upon these densities, as well as percent change in carrying capacity from present ($CK_{t,G}$), and carrying capacity normalized to present ($K_{t,G}^{norm}$), are presented in Table 6, and Figures 8 and 9. As with total habitat, total historical carrying capacity (year -10) ranged from 3 to 17% greater than at present in the Archipelago and Seasonal Ice Ecoregions, respectively, and 8% globally (Figure 9).

In the Seasonal Ice Ecoregion, we projected total carrying capacity to decline 7-10% from present levels by year 45, 21-32% by year 75, and 22-32% by year 100 (ranges of percentages depending on habitat amount predicted by the GCM maximum and GCM minimum results, respectively; Table 6, Figures 8, 9). In the Archipelago Ecoregion, we projected total carrying capacity to decline 3-14% from present levels by year 45, 18-21% by year 75, and 21-24% by year 100. In the Polar Basin Divergent Ecoregion, total carrying capacity dropped 19-35% from present levels by year 45, 29-43% by year 75, and 23-48% by year 100. In the Polar Basin Convergent Ecoregion, total carrying capacity ranged from -24% to +4% of present levels by year 45, and dropped 8-28% by year 75, and 3-31% by year 100.

For the two polar basin ecoregions, model data also were available on amount of optimal habitat and carrying capacity within optimal habitat (Tables 2,4; Figs. 7,8). In the Polar Basin Divergent Ecoregion, we projected carrying capacity of optimal habitat to drop 17-36% at year 45, 31-45% at year 75, and 21-49% at year 100, again because of relatively greater loss of optimal habitat. Conversely, the Polar Basin Convergent Ecoregion appeared to largely maintain non-optimal habitat, although there was considerable variation among models and time periods. The increasing proportion of non-optimal habitat along with corresponding increase in its carrying capacity (by as much as 49% by year 45 under the GCM maximum scenario), however, was insufficient to prevent overall declines in total carrying capacity, in most model runs. This was caused by strong declines in the carrying capacity of optimal habitat in latter years of the projections. Nonetheless, projected habitat losses in the Polar Basin Convergent Ecoregion were more modest and more variable among all model runs than in the Polar Basin Divergent Ecoregion. The optimal habitat-based carrying capacity showed declines ranging up to 31% loss by year 100, with no gains in any time period. In all ecoregions, trends consistently suggested moderate to large decreases in total carrying capacity by year 75, and moderate decreases in all ecoregions beginning in year 45. Globally, total carrying capacity across all ecoregions was projected to drop 10-22% from present levels by year 45, 22-32% from present levels by year 75, and 20-37% from present levels by year 100 (Figure 9).

Overall, total carrying capacity was projected to decrease at all time steps we examined in the 21st century. Models which projected minimal ice extent projected trends toward extirpation of bears from the Polar Basin Divergent Ecoregion by year 45 and from the Seasonal Ecoregion by year 75. Under ensemble mean ice conditions, we projected likely extirpation of bears in the Polar Basin Divergent Ecoregion by year 75 and in the Polar Basin Convergent Ecoregion by year 100 (Table 7).

Bayesian Network Model Forecast of the 21st Century Status of Polar Bears

Overall outcomes projected by our BN model which included the consideration of population stressors in addition to sea ice area effects were ranked according to relative

probability in Table 8. In all but the Archipelago Ecoregion, the dominant outcome state was "extinct" at all future time periods (Figure 10). Probabilities of the "extinct" state for future time periods varied from a low of 8% in the Archipelago Ecoregion at year 45 under the GCM maximum scenario, to a high of 87% in the Polar Basin Divergent Ecoregion at year 45 under the GCM minimum ice scenario (Table 8, Figure 11).

In the Archipelago Ecoregion, a smaller population was the dominant outcome at year 45 under all GCM scenarios, and at year 75 only for the GCM maximum scenario. Even in the Archipelago Ecoregion, "extinct" was sometimes the dominant outcome for other combinations of time periods and GCM modeling scenarios (Figure 10).

In the Seasonal and Polar Basin Divergent ecoregions, "extinct" was by far the most dominant outcome with very low probabilities forecast for all other outcome states in all time periods. The low probability afforded to outcome states other than extinct suggested a clear trend in these ecoregions toward probable extirpation by mid century. At year 45 in the Polar Basin Convergent Ecoregion, and at all future time steps in the Archipelago Ecoregion, considerable probability fell into outcome states other than extinct (Figure 10). Even when extinct was the most probable outcome, other outcomes sometimes had large non-zero probabilities.

The general trends of the overall population outcome (node D1) from the BN model (Table 8, Figure 10 and 11) can be viewed as follows. In each ecoregion, the polar bear population was very likely larger or at least incurred a far lower likelihood of multiple stressors in the past than compared to present. In the future, however, multiple stressors will likely play important and deleterious roles on all polar bear populations, even starting at year 45, and generally increase in their effect through year 100. Effects of multiple stressors appear to have a composite influence on the overall populations at more or less the same intensities regardless of the GCM modeling scenario (Table 8).

When the overall population outcome is broken down into its component influences, some further differences among ecoregions, time steps, and GCM modeling scenarios become apparent. For instance, there seems to be a greater adverse influence from future conditions on polar bear distribution response (node C3) than on polar bear numerical response (node C4) (Table 9). In part this is because of salient adverse future outcomes of habitat threats (node F2; Table 10) and foraging habitat distribution, especially in the Seasonal and Polar Basin Divergent ecoregions (Table 11). The BN model also represents worsening future conditions of natural disturbances including disease and predation (Table 12) and overall adverse influences on reproduction and vital rates (Table 13).

Sensitivity Structure of the Bayesian Network Population Stressor Model

We conducted 10 tests on the BN population stressor model to determine its sensitivity structure (Appendix 1). In general, the BN model seemed well balanced in terms of its underlying probability tables, in that sensitivity of the final outcome variable (node D1, overall population outcome) was distributed among all arms of the model. In other words, no single input variable or small clique of input variables unduly dominated the overall population outcome (see Appendix 1, sensitivity test 1).

Some 91% of the variation in overall population outcome (node D1) was explained by the top six variables (Appendix 1, Figure 12). Four of those top six variables were sea ice related, including our quantitative data on spatiotemporal change. The ecoregion of consideration and the level of intentional takes rounded-out the top six variables with influence on overall population outcome. In essence, ecoregion also is a habitat variable because ecoregions were specified on the basis of their

differences in sea ice. In that context, 5 of the top six variables explaining variation in overall outcome related to the nature of the sea ice.

The primary importance of sea ice change and lesser but complementary importance of anthropogenic stressors carried through to determinations of which FWS listing factors explained the most variation in overall outcome. Relative to the FWS listing factors, overall population outcome was by far most influenced by stressors related to Factor A (habitat threats). Influences from Factor B (overutilization), Factor E (other natural or man-made factors), and Factor C (disease and predation) provided progressively less influence (Appendix 1, sensitivity test 2).

Subsections of the BN model ("submodels") also were tested for sensitivity (Appendix 1, sensitivity tests 5-10). Notable among these tests was that foraging habitat value (node A, a composite "latent variable" created to summarize effects of several key environmental factors), was most sensitive to foraging habitat character, which is a subjective assessment of the quality of sea ice used for foraging by polar bears (Appendix 1, sensitivity test 8). Foraging habitat character (node S1) was included in the BN model to reflect observations that recent changes in the sea ice have included increased roughness and rafting among ice floes that are thought to reduce foraging effectiveness of polar bears (Stirling et al. 2008).

Discussion

We begin this section with a discussion of uncertainty as it pertains to our objectives and our outcomes. We follow a treatment of general uncertainty with a discussion of our carrying capacity model outcomes. Then, we describe the state of development in our BN polar bear population stressor model. That description includes identification of caveats regarding the current stage of development of the model and next steps necessary to address those caveats. Finally, we assess the BN model outcomes with regard to existing knowledge about polar bears and with respect to observed and projected changes in their sea ice habitats on which they depend.

Types and Implications of Uncertainty

Analyses in this report contain three main categories of uncertainty: (1) uncertainty in our understandings of the biological, ecological, and climatological systems; (2) uncertainty in the representation of those understandings in models and statistical descriptions; and (3) uncertainty in model predictions.

First, uncertainty in our understanding of complex ecosystems is virtually inevitable, particularly for one as extensive and remote as the circumpolar Arctic. We have however, incorporated a broad sweep of knowledge regarding polar bears and their environment which is available from published literature, from other reports informing the listing process, and from expert interpretations of that available information.

How to best represent our understanding of the system in models can be structured in various ways. In this report, we captured and represented expert understanding of polar bear habitats and populations in a manner that can be reviewed, tested, verified, calibrated, and amended as appropriate. We have attempted to open the "black box" so to speak, and fully expose all formulas and probabilities used in the polar bear carrying capacity and the BN population stressor models. We also used sensitivity testing to help convey the reliability of BN model depictions (Johnson and Gillingham 2004) (Appendix 1). After BN models of this type are modified through peer review, or revised with knowledge from more than one expert, any variation in resulting models can represent the divergence (or convergence) of expertise and judgment among multiple specialists.

Also included in the second category of uncertainty are uncertainties associated with

statistical estimation of parameters such as the extent of sea ice or size of polar bear populations. Statistical estimation typically includes systematic measurement error and random error, for example, as partitioned in general linear models and as may arise in classification functions such as assigning categories to map areas. In this case, we have minimal opportunity to address these estimation errors. The sea ice parameters we used in our polar bear models were derived from GCM outputs, which possess their own wide margins of uncertainty (DeWeaver 2007). Hence, the magnitude and distribution of errors associated with our sea ice parameters were unknown.

To compensate for these unknowns, we accommodated a broad range of sea ice uncertainties by analyzing the 10-member ensemble GCM mean, as well as the minimum and maximum GCM ice forecasts. In the case of polar bear population estimates, many are known so poorly that the best we have are educated guesses. Pooling subpopulations where numbers are merely guesses, with those where precise estimates are available, to gain a range-wide perspective prevents meaningful specific calculation and incorporation of error terms. We recognize that difficulty, but because our projections are expressed in the context of a comparison to present conditions, we largely avoid the issue. That is, whatever the population size is now, the future size is expressed relative to that and all errors are carried forward.

The third category of uncertainty pertains to model predictions. Predictions from models of species abundance and distribution can be subject to at least three sources of error: error due to spatial autocorrelation, dispersal and movement of organisms, and biotic and environmental interactions (Guisan et al. 2006). We addressed these error sources in the following ways. The estimates of ice habitat area were derived separately for each ecoregion from the GCM models because the ecoregions behave independently in terms of sea ice advection. The BN population stressor model accounted explicitly for potential movement of polar bears (e.g., use of alternative foraging areas) and for biotic and environmental interactions (as expressed in the conditional probability tables; see Appendix 3).

Deterministic models, such as the spreadsheet carrying capacity model, present calculations and predictions essentially as point values with no variance or error. In the absence of empirical measures of variation, one could presume a Gaussian error distribution around such calculated predictions. However, in our polar bear carrying capacity model there was no means of determining the magnitude of that error (nor did we have empirical estimates of variation surrounding polar bear population sizes by ecoregion). Hence, we did not attempt to estimate error levels for the carrying capacity calculations, although we acknowledge there is uncertainty surrounding those values.

Probabilistic or stochastic models, such as the BN population stressor model, can inherently display results as probabilities of various states or potential outcomes. The spread and magnitude of probability values across the outcome states in the BN model reflect the combination of uncertainties in states across all other variables, as reflected in each of their conditional probability tables. More sophisticated means of estimating variance of the probabilities of outcome states can also be undertaken (e.g. calculating their standard deviation and standard error from bootstrapping random subsets of the input values (Guisan and Zimmermann 2000) or from random subsets of simulated output cases). These additional steps are laborious, however, and better undertaken after the BN model has been through additional peer review and established as at least a *beta* level model (see below).

The spread of probabilities among the BN outcome states is itself an expression of uncertainty and important information for the decision-maker who may wish to weigh alternative outcomes in a risk assessment. When predictions result in high probability of one

population outcome state and low to zero probabilities of all other states, there is low overall uncertainty of predicted results, presuming that the other categories of uncertainty (in our understanding of the system and our representation of that understanding in the modeling) are taken into account. In some cases, however, the BN model predicts nearly equivalent probabilities of more than one population outcome state. In these cases, uncertainty of the outcomes is greater, and the decision-maker may wish to weigh the probabilities according to his or her risk attitude and decision criteria.

Finally, model uncertainty also entails addressing model credibility, acceptability, and appropriateness of the model structure. We made every effort to ensure that the model structure was appropriate and credible, and that the inputs were parameterized according to best available knowledge on polar bears and their environment. We have explored the logic and structure of our BN model through sensitivity analyses, running the model backwards from particular states to see if it returns us to the appropriate starting point, and performing particular "what if" experiments (e.g., by fixing values in some nodes and watching how values at other nodes respond). We are as confident as we can be at this point in model development that the model is performing correctly and providing outcomes that can be useful in qualitatively forecasting the potential future status of polar bears. Because the model has been structured and parameterized by only one polar bear expert, however, there are additional criteria of model validation that must be addressed through subsequent peer review and model revision (Marcot et al. 1983; Marcot 1990, 2006).

Forecasted 21st Century Polar Bear Carrying Capacity

All 10 of the GCMs we analyzed project a downward trend in sea ice extent in the 21st century (DeWeaver 2007). Those declines are paralleled by projected declines in both total and optimal polar bear habitat at all time steps (Figure 3, Durner et al. 2007). The wide range of outcomes in each region and time period represents the spread of values from the GCM model runs, even when normalized to present-day conditions. Despite the range of outcomes, however, declines in available polar bear habitat translate to lower carrying capacity for polar bears in all ecoregions at all future time steps (Figures 8, 9).

Our projected rates of decline in habitat and polar bear carrying capacity are generally slower than rates that have actually been observed during the past two decades. This is most notable in the Seasonal Ice Ecoregion where the rate of sea ice decline has been among the most profound of any in the Arctic (Meier et al. 2007). Yet, data derived from GCM forecasts appeared to suggest slow rates of future declines in the Seasonal Ecoregion (Figures 7, 9). This inconsistency in the Seasonal Ecoregion is apparently caused, at least in part, by some GCM projections that consistently put large amounts of sea ice over the continental shelf habitats in Davis Strait and Baffin Bay. Whereas the analyses of GCM outputs suggest decreases of 15-45% in sea ice cover in Hudson Bay through the next century, the same models forecast more ice remaining over the continental shelves of Davis Strait than was actually observed in that region between 1996 and 2006. Similarly, GCMs predict only a 7% decrease of sea ice in Baffin Bay by 2100. In contrast, satellite observations verify that Baffin Bay sea ice extent declined over 10% between the 1985-1995 period and the 1996-2006 period. Between those same periods the sea ice extent over the continental shelves of Davis Strait declined 51%.

The rapid rate of observed ice loss in the Seasonal Ice Ecoregion suggests that modeled persistence of ice there in the future is probably not realistic. This concept is corroborated by observations that show this ecoregion has seen

as much warming as almost any other location in the Arctic (Comiso and Parkinson 2004). If anything, sea ice declines in the Seasonal Ice Ecoregion are likely to be hastened in the future if temperatures continue to increase (Stirling and Parkinson 2006). Therefore, our projected gradual declines in polar bear carrying capacity in the Seasonal Ice Ecoregion are probably optimistic and biased on the high side.

In most other regions, the differences between observed and projected ice loss are smaller, but still variable. For example, the Polar Basin Divergent Ecoregion has seen a 4.5% loss in total habitat during the observational period. The ensemble mean forecast for ice loss in the ecoregion is 9% during the next 50 years and 26% by the end of the century. In contrast, individual IUCN subpopulation areas within the Polar Basin Divergent Ecoregion were forecast to have up to 95% decline in ice habitat. Nonetheless, the range of values in our projections appears to capture a general trend of large ice losses, large losses of optimal habitat, and large losses of carrying capacity for polar bears in the Polar Basin Divergent Ecoregion.

In contrast to the Seasonal and Polar Basin Divergent Ecoregions, we forecast more modest changes in habitat and polar bear carrying capacity for the Archipelago and Polar Basin Convergent Ecoregions. These more modest habitat losses appear consistent with modest losses during the observational period and with the forecasted changes in the individual IUCN subpopulation areas. These results parallel recent sea ice observations that show minimal declines in these ecoregions (Meier et al. 2007).

Although the pattern of projected carrying capacity varied greatly among regions, the bottom line was for an overall range-wide decline in polar bear carrying capacity of between 10% and 22% by year 45 and between 20% and 37% by year 100 (Table 6, Figure 9). The carrying capacity model forecasted that polar bears could be extirpated from the Polar Basin Divergent Ecoregion as early as year 45.

Projections from this modeling approach are deterministic projections based on current estimated densities of polar bears. They depend upon the extent of the sea ice and optimal sea ice habitat only and do not account for possible changes in relative carrying capacity as the amount of ice changes. For example, if thinner ice for shorter periods of time results in more insolation penetrating the water column and greater productivity of the remaining ice habitat, carrying capacity per unit area may rise. If on the other hand, declines in the areal extent of the under ice (epontic) community, which currently provides much of the productivity in Arctic seas (Sakshaug 2004) is not compensated by benefits of increased insolation, carrying capacity could decline. More open water in summer means more new ice forming in winter, which could increase brine expulsion (Fisher et al. 2006) with a variety of potential effects on epontic productivity. Even if overall productivity increases, if the character of the sea ice is dramatically different, polar bears may be ill-suited to forage there. The carrying capacity model cannot accommodate such scenarios, nor can it account for adverse effects of stressors other than changes in sea ice extent.

Just as the carrying capacity model cannot capture possible changes in marine productivity, it also cannot capture the importance of seasonal variation in sea ice. Durner et al. (2007) illustrated that although the annual trend in km2-months of optimal habitat is useful for comparing large scale patterns, it overlooks the importance of seasonal variation. Whereas the GCM ensemble forecasts a polar basin-wide decline of 36% in annually available optimal habitat, it suggests declines of nearly 80% during summer (Figure 13). This reflects the fact that all GCMs forecast sea ice will continue to cover the whole polar basin during the winter through most of the 21st century. So, the realized future changes in ice habitats are seasonally dependent. This is important because seasonal fluctuations in sea ice cover include changes in the location of sea ice as

well as its total quantity.

Among the most substantive spatial changes is the retreat of ice from the continental shelves of the polar basin (Comiso 2002; Rigor and Wallace 2004; Belchansky et al. 2005; Holland et al. 2006; Durner et al. 2007; Ogi and Wallace 2007; Serreze et al. 2007). Hence, not only is the sea ice declining in this region on an annual basis, there will be little or no ice in the region at all in summer. The continental shelves of the polar basin are far more productive than the deep polar basin regions offshore (Pomeroy 1997; Sakshaug 2004). Observations show that polar bears spend most of their time foraging on sea-ice over shallow water (<300m deep) (Amstrup et al. 2000, 2004a; Durner et al. 2007), where it is thought that they hunt most effectively (Stirling et al. 1981; Stirling 1997). Seasonal absence of sea ice from the shelf regions of the polar basin, therefore, can be expected to have a greater effect on foraging than the annual changes in sea ice quantity might suggest.

The length of time that ice is absent from important foraging areas is another variable that our carrying capacity model cannot accommodate. Polar bears are well adapted to survive periods of food deprivation. Those adaptations that have allowed them to successfully exploit the Seasonal Ice ecoregion (Watts and Hansen 1987). There, marine productivity is high enough that polar bears can gain sufficient mass before the ice melts to sustain a long summer and autumn fast.

The polar basin, in contrast to most of the seasonal ice regions, is relatively low in productivity (Sakshaug 2004). Whereas polar bears in the Seasonal Ecoregion reach peak body weights before the ice melts in summer; polar bears in the polar basin do not reach peak body weight until late autumn or early winter (Durner and Amstrup 1996). This suggests they have a different temporal pattern of weight gain to compensate for the relatively low productivity of the polar basin seas. Polar bears in the polar basin simply need more time to reach the weight necessary to survive the winter. Another indication of the low productivity, with which polar bears contend in the polar basin, is the observation that polar bears in the polar basin reach sexual maturity later in life than they do in other portions of their range. In the polar basin, polar bears produce their first young at age six. This is in contrast to much of the Canadian Arctic where they breed for the first time at age 4 and produce their first cubs at 5 years of age (Stirling et al. 1977, 1980, 1984; Ramsay and Stirling 1982, 1988; Furnell and Schweinsburg 1984; Amstrup 2003). Polar basin bears, therefore, may not be able to accommodate extended seasonal absence of sea ice from their preferred foraging habitats. Indeed, recent analyses suggest that the length of time that ice is absent from continental shelf foraging areas may be related to certain measures of physical stature and cub survival (Rode et al. 2007) as well as a predictor of survival (Hunter et al. 2007; Regehr et al. 2007a) in polar bears of the Beaufort Sea.

As noted earlier, most GCMs project that ice will return to much of the Arctic in winter, even late in the century. This fact is reflected in the relatively modest changes in sea ice extent we report on an annual basis--the seasonal absence is to great extent masked by the recurrence of ice in winter. Our carrying capacity model therefore does not account of these seasonal aspects of sea ice change. The impact of periods of food deprivation which are too long for polar bears to accommodate is just not represented by the changes in sea ice extent expressed as km2-months. This shortcoming is another reason that the carrying capacity model likely underestimates the effects future sea ice change will have on polar bears.

Even with all of the caveats that accompany the carrying capacity modeling, however, the conclusion that polar bear populations will face major declines over large portions of their current range seems sound if the sea ice declines as predicted. The carrying capacity model

suggests the greatest declines will be in the Polar Basin Divergent Ecoregion where extirpation could occur by mid-century and seems very likely by late-century. Using the recent observational sea ice record to qualify the carrying capacity projections for the Seasonal Ice Ecoregion, it seems more likely that extirpation will occur there despite the fact that that outcome was forecasted from only the GCM minimum ice projections. The carrying capacity model further suggests that polar bears, in reduced numbers, are likely to persist in the Polar Basin Convergent Ecoregion and the Archipelago Ecoregion through the end of the 21st century.

Bayesian Network Model Forecast of the 21st Century Status of Polar Bears

Next steps in the BN model development

Before we discuss outcomes of our BN model, we provide a detailed description of its current state of development and the next steps in that development. Because BN models combine expert judgment and interpretation with quantitative and qualitative empirical information, inputs from multiple experts (if available) are necessary before a model can be considered final. Due to time constraints, however, we were not able to seek and incorporate the input of multiple polar bear experts into our BN model. Therefore, the model presented here should be viewed as a first-generation "alpha" level prototype (Marcot et al. 2006). It captures and depicts judgment of one subject matter expert. It is therefore, in a general sense, an expert system (Martin et al. 2005; McCann et al. 2006), but still must be vetted through other polar bear experts.

The next model development steps, including the vetting necessary to advance development of our prototype "alpha" level model, have been described in detail by (Marcot et al. 2006), and include:

- further peer review of the alpha model by other subject-matter experts;
- reconciliation of the peer reviews by the initial expert, and updating the model to a *beta* level that incorporates the reviews;
- testing of the beta level model for accuracy with existing data (e.g., determining if it matches historic or current known conditions); and
- updating the model to the next "*gamma*" level with existing data, or even to a *delta* level through incorporation of additional validation data from new field work or new analyses if available.

Throughout this process, sensitivity testing can be used to verify model performance and structure. This framework has been used successfully for developing a number of BN models of rare species of plants and animals (Marcot et al. 2001, 2006; Raphael et al. 2001; Marcot 2006).

The next step in the development process of the polar bear BN population stressor model is the review of the current prototype by peers--in this case by other polar bear experts. The process of review of the model by other polar bear experts is akin to the peer review of a manuscript sent to a journal. The initial model engineer can serve as an "editor" to present the alpha-level model to one or more other experts in the field; to elicit and compile their critique and comments on overall model structure (the variable used and their connections) and probabilities; and then to return to the initial expert with the reviews. The review by peers could result in revision of the alpha-level model, producing a variant(s) of the model that more adequately represents the reviewer's own expert knowledge and judgment. The initial expert develops a "reconciliation" of the reviews that annotates how each review comment was addressed in modifying the model (or not). The result is modification, or perhaps retention, of the alpha-level model structure, to produce the beta-level model which incorporates inputs from more than one expert.

Model variants that may have emerged in the review process would represent the range of expert opinions and experiences, and this range could be important information for decision-making.

Further advancing of the model beyond a beta-level, depends on whether new analysis results or new empirical data are available. Because BN models are best viewed as working tools useful to project outcomes, and to guide monitoring and data collection this becomes an interactive process. The model sensitivities can indicate which monitoring efforts will provide the information most useful to future decisions. The full model or portions of the model can be tested for performance against new data generated by that monitoring. The model is then validated and updated. This advantage of the BN modeling approach which allows new field data or new empirical observations to be incorporated into the model as they come along, allows for continual tests of model performance and provide new inputs which can be, in turn, used to improve model performance. Every new piece or data and new relevant observation allows further refinement of the performance of the model (Marcot 2006).

Because these additional steps in development of our prototype model have not yet been completed, it is important to view probabilities of outcome states in terms of their general direction and overall magnitudes rather than focusing on the exact numerical probabilities of the outcomes. When predictions result in high probability of one population outcome state and low or zero probabilities of all other states, there is low overall uncertainty of predicted results. When projected probabilities of various states are more equally distributed, however, careful consideration should be given to large nonzero probabilities representing particular outcomes even if those probabilities are not the largest. Consistency of pattern among scenarios (e.g., different GCM runs) also is important to note. If the most probable outcome has a much higher probability than all of the other states, and if the pattern across time frames and GCM models is consistent, it is most likely important to note that outcome and pattern. If on the other hand, probabilities are more uniformly spread among different states, and if the pattern varies among scenarios, the importance of the most probable outcome may not be as great. This approach takes advantage of the information available from the model while recognizing that it is still in development. It also conforms to the concept of viewing the model as a tool describing relative probabilistic relationships among major levels of population response under multiple stressors.

BN model projected outcomes

In the BN model, for each scenario run, the spread of population outcome probabilities (or at least non-zero possibilities) represented how individual uncertainties propagate and compound across multiple stressors. Beyond year 45, "extinct" was the most probable state into which polar bear populations in all ecoregions moved, except those in the Archipelago Ecoregion (Figure 10, Table 8). Distribution changes driven by changes in the sea ice appeared to be a major factor leading to these predictions. The sea ice extents of the Polar Basin Divergent Ecoregion and Seasonal Ice Ecoregion have declined more rapidly than other places in the Arctic (Meier et al. 2007). The loss of sea ice habitats in the Polar Basin Divergent Ecoregion is projected to continue, and possibly to accelerate (Holland et al. 2006; Stroeve et al. 2007; Durner et al. 2007). Because polar bears are tied to the sea ice for obtaining food, major changes in the quantity of and distribution of sea ice must result in similar changes in polar bear distribution. In this sense, our carrying capacity model incorporates an element of foraging efficiency, even though it cannot directly account for other potential stressors per se.

The BN model suggested that polar bear

populations in the Seasonal Ice Ecoregion moved into the extinct category rapidly in contrast to outcomes projected by the carrying capacity model. This may have been because the BN model incorporated aspects of the spatiotemporal distribution of the sea ice that are consistent with recent analyses (Hunter et al. 2007; Regehr et al. 2007a) suggesting that long periods without ice habitats over continental shelf foraging areas may be associated with decreased survival of polar bears. In addition to variables representing the availability of sea ice over the continental shelves, our BN model incorporated other potential stressors not included in our projection of carrying capacity which could have resulted in the different forecasts for the Seasonal Ice Ecoregion. The BN model projection for the Seasonal Ice Ecoregion also seems more in line with the observational record (Stirling and Parkinson 2006; Meier et al. 2007) and provides added cause for reconsideration of the results of the carrying capacity model in the Seasonal Ice Ecoregion.

Overall outcomes projected for polar bears appeared to be driven more by distributional effects than numerical effects. The most probable outcomes for Factor A (Habitat Threats) of the Proposal to list polar bears as a threatened species were "major restriction" (Table 10). Numerical responses of polar bears to future circumstances were forecast to be more modest than changes in distribution. In all regions, reduced density was the most probable outcome (Table 9). One way to interpret that outcome may be that where habitat remains, polar bears will remain even if in reduced numbers. This is consistent with our BN model results suggesting that polar bear populations may remain in the Archipelago Ecoregion at least into the middle of the 21st century. Corresponding with our carrying capacity projection, declines in distribution and number are likely to be faster and more profound in the Polar Basin Divergent Ecoregion and the Seasonal Ecoregion than elsewhere. Importantly, our results suggest that a core of polar bear habitat and some number of polar bears is likely to persist in and around the Archipelago Ecoregion at least into mid century.

Sensitivity analyses

Sensitivity analyses offer an opportunity to interpret model outcomes at every level. The overall population outcome was most sensitive to change in habitat quantity (node B) and temporal habitat availability (node C). The other major habitat variable, change in distance between ice and the continental shelf (node N) was the 6th most influential factor on the overall population outcome. Change in distance between ice and the continental shelf may have been ranked much lower than the other two quantitative sea ice variables because it was a measurement which only applied to the two polar basin ecoregions. This variable was not calculated in the Archipelago or Seasonal Ice Ecoregions because waters there are all (or essentially all) over the continental shelf. Nonetheless, the combination of these three habitat variables explained 64% of the uncertainty in the overall population outcome. Ecoregion was the 3rd most influential node on overall outcome. We constructed the model recognizing that the four ecoregions differed in the nature of the sea ice which occurred there and in how polar bears utilize that ice. The fact that ecoregion explained 15% of the variation in overall population outcome is further evidence of the importance of sea ice habitat and its regional differences, to polar bear responses to projected habitat change. This is an important result helpful in understanding that, for example, polar bears appear to be facing much greater restriction in the Polar Basin Divergent and Seasonal Ice ecoregions than they do elsewhere.

Another habitat variable, "sea ice character" (node S1), was ranked 5th among variables having influence on the overall population

outcome. This qualitative variable relating to sea ice character was included to allow for the fact that in addition to changes in quantity and distribution of sea ice, more subtle changes in the sea ice could affect polar bears. For example, longer open water periods and warmer winters have resulted in thinner ice in the polar basin region (Lindsay and Zhang 2005; Holland et al. 2006; Belchansky et al. 2008). Fischbach et al. (2007) hypothesized that thinning and the associated greater extent of marginal ice stability in autumn has resulted in reduced sea ice denning among polar bears of the southern Beaufort Sea.

Observations during polar bear field work suggest that the thinning of the sea ice also has resulted in increased roughness and rafting among ice floes. Compared to the thicker ice that dominated the polar basin decades ago, thinner ice is more easily deformed, even late in the winter. Although highly deformed ice composed of blocks of thin and rafted ice may be satisfactory for seals, they may not be well suited to polar bear foraging. These changes appear to reduce foraging effectiveness of polar bears and it is suspected the changes in ice conditions may have contributed to recent cannibalism and other unusual foraging behaviors (Stirling et al. 2008).

Recognizing these recent observations of nutritionally stressed individuals prompted us to include the "sea ice character" variable to qualitatively summarize a variety of changes in sea ice which may affect polar bears. States for this variable were entered based upon the observations that habitat quality already had been changing in a negative way in the Polar Basin Divergent Ecoregion. States, however, were entered differently to reflect that warming which has caused thinning of ice in the polar basin, could actually improve habitat for polar bears in other ecoregions. That flexible parameterization resulted in this variable explaining 6% of the variation in overall population outcome. The sensitivity of overall population outcome to this node confirms that the nature of the sea ice as well as its spatiotemporal distribution will continue to have an important influence on the future of polar bears.

The 4th ranked potential stressor to which overall population outcome was sensitive was intentional takes. Historically, the direct killing of polar bears by humans, for subsistence or for sport, has been the biggest challenge to polar bear welfare (Amstrup 2003). Our model suggests that harvest of polar bears remains an important factor in their population dynamics, as sea ice retreats. Retreating sea ice will make the arctic habitats of polar bears more accessible and it is likely to result in increased numbers of bears occupying terrestrial habitats, at least seasonally. These factors will increase the potential vulnerability of bears to direct human kills. As the regions of the Arctic, which are currently unsettled due to the harshness of the climate, become warmer, human settlements and developments are likely to expand into them. This will increase the likelihood of takes in areas where direct mortalities by humans had not previously been an issue. The fact that intentional takes ranked so importantly in our outcomes suggests that of the potential human effects on polar bears, management of hunting will continue to be important (but see below).

The remainder of the variables ranking in the top ten with regard to their influence on overall population outcome were bear-human interactions (node B1), parasites and disease (node T), and hydrocarbon contamination (node R4). Although these and the remainder of the variables which exerted influence on overall outcome cumulatively explained only 9% of the variation in outcome, some of them result directly from human behavior. Hence, noting their influence may be of management value. Bear-human interactions, number 7 on the list of factors to which overall outcome was sensitive, are likely to increase as bears lose their traditional sea ice habitats. Our direct observations indicate these interactions already are increasing in Alaska as larger numbers of

bears remain on land in summer. Longer summers They also have increased in frequency in portions of the Seasonal Ice Ecoregion where increased periods of ice absence have resulted in more bears in poor condition appearing in settlements as they apparently seek alternate foods (Regehr et al. 2007b). According to our model, management of bear-human interactions could influence the future status of polar bears at least on the local level.

The influence of parasites and disease agents, number 8 on the sensitivity list, on polar bears would likely increase if the climate continues to warm. Historically, polar bears have had few parasite and disease agents with which to contend (Amstrup 2003) but this may change as warming continues. Parasitic agents which have developmental stages outside the bodies of warm-blooded hosts (e.g., nematodes) will likely benefit from the warmer and wetter weather forecast for the Arctic (Macdonald et al. 2005). Improved conditions for such parasites already have had significant impacts on some terrestrial mammals (Kutz et al. 2001, 2004). Bacterial parasites also are likely to benefit from a warmer and wetter Arctic. In general, the distribution and abundance of a variety of pathogens is dependent upon climate influences (Dobson and Carper 1993; Powell et al. 1996; Cook et al. 1998). Although increases in disease and parasite agents have not yet been reported in polar bears, a warming climate has been associated with increases in pathogens in a variety of other marine organisms (Kuiken et al. 2006). Similar increases in disease and parasite agents in the polar bear's environment are anticipated, however, if temperatures continue to warm as projected.

Human activities related to oil and gas exploration and development are very likely to increase with disappearance of sea ice from many northern areas. At the same time, less sea ice will facilitate offshore developments. More offshore development will increase the probability of hydrocarbon discharges into polar bear environments (Stirling 1990). The record of over 30 years of oil and gas development in Alaska suggests that with proper management, potential negative effects of these activities on polar bears can be minimized (Amstrup 1993, 2000, 2003; Amstrup et al. 2004b). Increases in marine developments, however, and the associated increases in shipping (etc.) will require new monitoring methods and may require increased diligence to maintain the positive track record. Hence, restricted sea ice could lead to greater probabilities of localized contaminant discharges.

Long range marine and atmospheric transport of contaminants also is likely to increase (Macdonald et al. 2003, 2005). Increased rainfall in northern regions already has increased river discharges into the arctic seas. Many of these north flowing rivers originate in heavily industrialized regions and carry heavy contaminant burdens (Macdonald et al. 2005). Considering the potential for increases in both local and long range transport of contaminants to the arctic, with warmer climate and less sea ice, the influence these activities have on polar bears is likely to increase.

Strength of evidence of BN model projections

The overall outcomes projected by our BN population stressor model are consistent with conclusions of the International Union for the Conservation of Nature (IUCN) polar bear specialist group (PBSG) which recommended, based mainly on projected changes in sea ice, that polar bears should be reclassified as vulnerable (Aars et al. 2006). It is also consistent with the increasing volume of data confirming negative relationships between polar bear welfare and sea ice decline (Stirling and Derocher 1993; Stirling et al. 1999, 2007, 2008; Ainley et al. 2003; Derocher et al. 2004; Ferguson et al. 2005; Aars et al. 2006; Amstrup et al. 2006; Stirling and Parkinson 2006; Hunter et al. 2007). In summary, our prototype BN

population stressor model projects that sea ice and sea ice related factors will be the dominant driving force affecting future distributions and numbers of polar bears through the 21st century. Our model also projects that if sea ice patterns change as projected by currently available climate models, polar bears will be absent from 2 major portions of their range by mid century.

Despite caveats regarding the early stage of development of our BN model, there are reasons, in addition to its consistency with the conventional wisdom of the polar bear community, to believe the directions and general magnitudes of its outcomes are reasonable. Sea ice related variables, including our 3 nodes (B, C, and N) which were derived from GCM outputs, were in the top 6 variables to which overall outcome was sensitive, and explained 70% of the variation in that outcome (Figure 12, Appendix 1). This, while appearing to corroborate the well established link between polar bears and sea ice, prompted us to ask 2 questions. First, is there is anything that humans could do, short of bringing back more ice, that would qualitatively alter our projected outcomes. Second, how much different would sea ice need to be to cause a qualitative change in our overall outcomes.

Could on the ground management affect our outcomes?--To address the first question, we fixed the input states for all nodes over which humans might be able to exert control (e.g., harvest, contaminants, oil and gas development) first to same as now, and then to improved conditions as compared to now. We reran the BN population stressor model under both conditions for other nodes and at all future time periods and with all 3 GCM scenarios for sea ice.

Despite fixing human influences, outcomes of these runs were not qualitatively different from previous runs for the Polar Basin Divergent and Seasonal Ecoregions. Projected probabilities of extinction were lower at every time step, but the most probable outcome state for these two ecoregions was still "extinct" at nearly every time step and for every GCM scenario. The only exception to this statement was for the Seasonal Ecoregion at year 45, the most probable outcome from the maximum ice GCM scenario being "smaller" rather than "extinct." In that case, however, the probability of extinct was just slightly below that of smaller. Probabilities of extinction in these two fixed runs of the model were lower at each time step and for each GCM scenario than during the general runs of the model (Figure 14), indicating that more probability was being spread across other outcome states (Table 14). However, at all time steps (except for year 45 in the Seasonal Ice Ecoregion), the predicted probability of extinction was around twice that of any other outcome state. The conclusion for the Seasonal Ice and Polar Basin Divergent Ecoregions is that management of localized human activities can have no qualitative effect on the future of polar bears in the Seasonal Ice and Polar Basin Divergent Ecoregions if sea ice continues to decline as projected. Polar bears of both ecoregions are projected to move toward extinction by 45 years from now.

There were greater differences between our fixed runs and our general runs in the other ecoregions. The most probable outcome state for the Archipelago Ecoregion was smaller at all time steps and for all GCM scenarios when human factors were set to same as now. When human factors were set to fewer than now, the most probable state of the Archipelago Ecoregion was same as now through the 45 year time step and smaller thereafter. Probabilities of other outcome states in the Archipelago Ecoregion were rather evenly distributed on either side of the "smaller" outcome (Table 14). Probabilities of extinction were substantially lower than in our general model runs when human influences were either same as now or better then now, and with the GCM maximum scenario they were essentially 0 through year 75 (Figure 14). Also, there was even a relatively large probability of increase in some of the runs. This indicates that management of human

factors could be important for polar bears in the Archipelago Ecoregion.

In the Polar Basin Convergent Ecoregion, "smaller" rather than "extinct" was the most probable outcome at year 45 for all GCM scenarios when human factors were either same as now or improved. Under the scenario where human factors were fixed as fewer in the Polar Basin Convergent Ecoregion, "smaller" was the most probable outcome through year 75 in the maximum GCM scenario. Probabilities of extinction were lower (Figure 14), and probabilities were spread through other outcome states. Unlike the Archipelago Ecoregion, however, extinct was the most probable outcome at most time steps for the majority of GCM scenarios (Table 14, Figure 14).

The conclusion from these fixed runs of the model is that management of human activities has the potential to qualitatively improve the welfare of polar bears in the Archipelago Ecoregion through the 21st century and in Polar Basin Convergent Ecoregion through mid-century. Conversely, it appears that there is little that management of localized human activities can do, assuming spatiotemporal extent of the sea ice continues to decline as expected, to qualitatively improve the outcomes projected for polar bears in the Polar Basin Divergent and Seasonal Ice Ecoregions. Polar bears in those two ecoregions, which include approximately 2/3 of the current range-wide population, are projected to become extinct by mid century regardless of local management actions that would eliminate or mitigate anthropogenic stressors.

Could future sea ice be different enough to affect outcomes?--Fixing the effects in our model, which humans might be able to manage, illustrated that sea ice effects prevail in determining the future of polar bears, and that only in some regions could those effects be compensated by on the ground human activities. But what would it take in the way of different sea ice projections to qualitatively change our forecasted population outcomes? To answer that question we must turn to the presumptions built into our model.

We populated the conditional probability tables, in nodes of our model which reflect sea ice extent and distribution, in recognition of the established reliance of polar bears on the surface of the sea ice (Table 3, Appendix 3). Evidence for the polar bear's reliance on sea ice is replete. Although they are opportunistic and will take terrestrial foods, including human refuse, when available, and may benefit from such activity (Lunn and Stirling 1985; Derocher et al. 1993), polar bears are largely dependent on the productivity of the marine environment. Refuse, for example, is of limited availability throughout the polar bear range, and could at best benefit relatively few individuals. Also, polar bears are poorly equipped to consume and digest most plant parts (Chapin et al. 2006), and they are, for the most part, inefficient in preying on terrestrial animals (Brook and Richardson 2002; Stempniewicz 2006). Perhaps most importantly, polar bears have evolved a strategy designed to take advantage of the high fat content of marine mammals (Best 1984). Available terrestrial foods are, with few exceptions, not rich enough or cannot be gathered efficiently enough to support polar bears, which are the largest of the bears, in any numbers (Welch et al. 1997; Rode et al. 2001; Robbins et al. 2004). Although there are localized exceptions, polar bears appear to gain little overall benefit at the population level, from alternate foods (Ramsay and Hobson 1991). Polar bears, it appears, are obligately dependent on the surface of the sea ice for capture of the prey necessary to maintain their populations.

Based upon this well established reliance on sea ice for foraging we assumed that continued declines, in regions where sea ice declines already have had significant deleterious effects, would be negative for polar bears and we built that assumption into the conditional probability tables of our models. We also assumed that in some ecoregions, polar bears might benefit from

changes in the sea ice - at least temporarily - or would at least not be as greatly affected as in other regions. We built that assumption into our models as well. These assumptions, in short, mean that if sea ice continues to decline it ultimately will have a negative effect on polar bears but that those effects will not be equal in all ecoregions nor will they occur at the same times in all regions.

So, the question "how would the ice need to change in order to produce outcomes qualitatively different than our current model outcomes (Table 8 and figures 10 and 11)" is reasonable. We explored this question in our BN model by setting the values for all non-ice inputs to uniform prior probabilities. That is we didn't make any assumptions about whether they would change in ways that were better or worse for polar bears. We assumed complete uncertainty with regard to future food availability, oil and gas activity, contaminants and disease etc. Then, we ran the model to determine how changes in the sea ice states alone, specified by our ensemble of GCMs, given complete uncertainty with regard to all else, would affect our outcomes.

This exercise illustrated that for the Seasonal Ice Ecoregion, and the Polar Basin Divergent Ecoregion, sea ice would have to decline substantially less than is predicted by our maximum ice GCM scenario to make any qualitative difference in our outcomes. At all time steps and for all GCM runs, the most probable outcome is "extinct" (Figure 14), and by far the greatest probability falls into the extinct state (Table 15). The most probable outcome in the Polar Basin Convergent Ecoregion also is "extinct" at all time steps under this fixed modeling situation. Overall probabilities of extinction are lower, and more probability is forecast for other outcome states, but extinction holds more than twice the probability of any other state at all time frames. We do not know just how much more ice it would take to prevent this outcome, but it would need to be much more than any of our models suggest if it were to result in a qualitative improvement of the general model outcome.

Even in the Archipelago Ecoregion there is no substantial change. There, the most probable outcomes are in the same patterns as in our general model runs. The difference is that the probability of extinct is slightly lower in most cases, and more probability is spread throughout other possible states.

In conclusion, to see any qualitative change in the probability of extinction in any of the ecoregions, even in year 45, sea ice projections would need to leave more sea ice than the maximum GCM projection we used. This eventuality may be unlikely in light of the fact, as shown in Figures 3, 6, and 7, that most sea ice models tended to predict more ice than there actually was during the observational record between 1979 and present (Durner et al. 2007; Stroeve et al. 2007). It also may seem unlikely in light of recent observations. As of 23 August 2007 declines in Arctic sea ice extent in 2007 have set a new record for the available time series from 1979-2006. This record minimum is 400,000 km^2 below the previous record which occurred in 2005 (National Snow and Ice Data Center, *http://nsidc.org/news/press/2007_seaice minimum/20070810_index.html*). Because this new record has occurred 25-83 days before the summer melt season will end in different parts of the polar basin (Stroeve et al. 2006), much more melting and greater sea ice reduction seems likely. The more rapid decline in observed sea ice than in modeled sea ice (Stroeve et al. 2007) appears to be continuing. By exploring outcomes of our BN model by fixing certain parameters, we determined that future sea ice would have to be more extensive, at all time steps, than is projected by our most conservative models (the models forecasting the most sea ice remaining). But, the sea ice in 2007 already has declined below the level projected for mid century by the 4 most conservative models in our ensemble (Figure 15). This seems to be compelling evidence that we are not likely to see more ice than our models have suggested

at any of the future time steps we evaluated.

Another aspect of the 2007 summer ice melt is pertinent to our discussion. Our analyses of GCM outputs has suggested that sea ice is likely to remain in the Archipelago Ecoregion through the end of the century. Based upon this projection, our carrying capacity model and our BN model both suggested that the Archipelago Ecoregion would provide refuge to polar bears well into the century. The southern portion of the Archipelago Ecoregion, however, was clear of sea ice by 23 August 2007 (Figure 15). This recent observation then calls into question a main conclusion of our modeling effort: that polar bears in the Archipelago Ecoregion may be insulated from sea ice change for many decades. True, this is just one yearly data point. But it is a data point that fits a recent pattern of sea ice declining at an accelerating rate that is faster than sea ice forecasters have projected. And, it is one piece of evidence suggesting that it may not be at all reasonable to expect that future spatiotemporal distribution of sea ice will exceed the maximum values projected by our model ensemble.

We do not know how other polar bear experts might differ in how they would structure and parameterize a BN polar bear population stressor model. Several factors, however, suggest that a polar bear model would have to be structured and parameterized very differently to project qualitatively different outcomes. First, the great sensitivity in our model to sea ice habitat changes is consistent with hypothesized effects of global warming on polar bears (Derocher et al. 2004). Second, this sensitivity to sea ice change parallels recent observations of how decreasing spatiotemporal distribution of sea ice has affected polar bears (Stirling et al. 1999, 2007; Hunter et al. 2007; Regehr et al. 2007a, 2007b; Rode et al. 2007). Third, it appears that future sea ice patterns would have to be fundamentally different than is projected for the apparent direction in polar bear populations we project to be altered. Finally, with sea ice trends continuing to decline at rates that are faster than forecast, the relationship of polar bears to sea ice change would have to be fundamentally different than the range-wide body of polar bear data suggests it is. All of these would have to be very different for trends in polar bears distrubution and numbers to take a fundamentally different path than our BN model projects.

In short, although it is highly likely that other polar bear experts might structure a model differently and populate conditional probability tables differently than we have, it seems unlikely that those differences would be great enough to make a qualitative difference in the outcomes projected by our prototype model.

Conclusion

We took two approaches to forecast the range-wide future status of polar bears. First, we built a simple deterministic model of future polar bear carrying capacity. This model depended on a linear relationship between sea ice area and polar bear density. It was easy to understand and provided some sense of how numbers of polar bears might change over time in different regions of the Arctic. However, because it only addressed annual average sea ice extent, the carrying capacity model could not account for contribution of changes in the nature or spatiotemporal distribution of sea ice. It also could not account for other population stressors which could accompany changes in the sea ice and which could exacerbate the effects due to habitat loss. Hence, this simple deterministic model provided a conservative outlook for polar bears. Second, we built a Bayesian network population stressor (BN) model. This model incorporated changes in spatiotemporal distribution of sea ice as well as other potential population stressors which the deterministic carrying capacity model did not include. The BN model incorporated quantitative information regarding changes in habitat as well as qualitative information regarding other potential stressors in a

probabilistic setting. The BN model had the ability to more thoroughly assess the extent of changes which might occur and to describe outcome states in terms of their relative probabilities.

Our forecasts suggested that declines in the spatiotemporal distribution of sea ice habitat along with other potential stressors will severely impact future polar bear populations. Outcomes varied geographically and by time step, and included the following:

1. Polar bear populations in the Polar Basin Divergent and Seasonal Ice ecoregions will most likely be extirpated by mid century. Approximately 2/3 of the world's current polar bear population resides in the combined area of these two ecoregions.
2. Polar bear populations in the Archipelago Ecoregion appear likely to persist through the middle of the century. Some modeling scenarios suggest persistence of polar bears in this ecoregion toward the end of the century. The number of bears in this ecoregion will likely be less than at present due to the reduced amount of habitat and other factors.
3. Polar bears in the Polar Basin Convergent Ecoregion may persist through mid-century, but they most probably will be extirpated at and beyond year 75.
4. A declining habitat base, coinciding with FWS Listing Factor A (habitat threats), was the overriding factor in forecasts of declining numbers and distribution of polar bears.
5. Other factors which correspond with FWS listing Factors B, C, and E, and which could result in additional population stress on polar bears, are likely to exacerbate effects of habitat loss.
6. Management of localized human activities such as hunting, release of contaminants, and direct bear-human interactions etc., qualitatively increased the probability of persistence of polar bears in the Archipelago ecoregion through the end of the century and increased the probability that polar bears could persist in the Polar Basin Convergent Ecoregion through mid-century.
7. Management of localized human activities did not appear able to change the probability of extinction in the Polar Basin Divergent or Seasonal Ice ecoregions in any qualitative way. Holding all model inputs for localized human activities to represent fewer impacts than now made no qualitative change in the probability of extinction.
8. Because recently observed declines in sea ice extent continue to outpace most GCM projections, more extensive sea ice seems an increasingly unlikely future. Yet, to qualitatively alter outcomes projected by our models and head off the projected loss of 2/3 of the world's current polar bears, future sea ice would have to be far more extensive than is projected by even conservative General Circulation Models.

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Table 1. Ten IPCC AR-4 GCMs whose sea ice simulations and projections were used to define ice covariates for polar bear RSF models: IPCC model ID, country of origin, approximate grid resolution (degrees), forcing scenario, and the number of runs used for the polar bear studies.

We treated the mean of the 8 ncar_ccsm3_0 model runs as a single output to be consistent with the other models which had only one run.

MODEL ID	Country	Grid Resolution (lat x lon)	Forcing Scenario	Number of Runs
ncar_ccsm3_0	USA	1.0 x 1.0	20c3m	8
			SRES A1B	8
cccma_cgcm3_1	Canada	3.8 x 3.8	20c3m	1
			SRES A1B	1
cnrm_cm3	France	1.0 x 2.0	20c3m	1
			SRES A1B	1
gfdl_cm2_0	USA	0.9 x 1.0	20c3m	1
			SRES A1B	1
giss_aom	USA	3.0 x 4.0	20c3m	1
			SRES A1B	1
ukmo_hadgem1	UK	0.8 x 1.0	20c3m	1
			SRES A1B	1
ipsl_cm4	France	1.0 x 2.0	20c3m	1
			SRES A1B	1
miroc3_2_medres	Japan	1.0 x 1.4	20c3m	1
			SRES A1B	1
miub_echo_g	Germany/Korea	1.5 x 2.8	20c3m	1
			SRES A1B	1
mpi_echam5	Germany	1.0 x 1.0	20c3m	1
			SRES A1B	1

Table 2. Composite summary categories of polar bear carrying capacity change from present levels, based on categories of composite habitat change and composite carrying capacity change.

Composite habitat change summary category	Composite carrying capacity change summary category	Composite summary category of carrying capacity change
Expanding fast	Increasing high	Enhanced
Expanding fast	Increasing moderate	Enhanced
Expanding fast	Stable	Enhanced
Expanding moderate	Increasing high	Enhanced
Expanding moderate	Increasing moderate	Enhanced
Expanding moderate	Stable	Enhanced
Stable	Decreasing high	Decreased
Stable	Decreasing moderate	Decreased
Stable	Decreasing low	Decreased
Stable	Increasing high	Enhanced
Stable	Increasing moderate	Enhanced
Stable	Stable	Maintained
Contracting slow	Decreasing high	Decreased
Contracting slow	Decreasing moderate	Decreased
Contracting slow	Decreasing low	Decreased
Contracting slow	Stable	Decreased
Contracting moderate	Decreasing high	Toward extirpation
Contracting moderate	Decreasing moderate	Decreased
Contracting moderate	Decreasing low	Decreased
Contracting moderate	Stable	Decreased
Contracting fast	Decreasing high	Toward extirpation
Contracting fast	Decreasing moderate	Toward extirpation
Contracting fast	Decreasing low	Decreased
Contracting fast	Stable	Decreased

Table 3. Input data used in the Bayesian network population stressor model (Figure 5).

Data for model node B was derived from the spreadsheet carrying capacity model (Table 6); data for model nodes C and N were derived from the global circulation model (GCM) results; and data for all other model nodes were specified as best professional judgment by one polar bear expert (S. Amstrup).

	BBN node name	B	C	N	S1	M	R3	R2	F
	Variable name	Foraging habitat quantity change	Foraging habitat absence change	Shelf distance change	Foraging habitat character	Geographic area	Alternative prey availability	Relative ringed seal availability	Alternative regions available
	Unit of measure	% change from "now"	# of Months Different than now	km	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	any value < or = +20%	any value > or = -1	any value > or = -200	more_optimal same_as_now less_optimal	Polar_Basin_Divergent Polar_Basin_Convergent Archipelago Seasonal_Ice	increase same_as_now decrease	increase same_as_now decrease	Yes No
Time Period	**Basis**								
				Seasonal Ice Ecoregion					
Year -10	Satellite data	17.14%	-0.7	*	more_optimal	Seasonal_Ice	decrease	increase	Yes
Year 0	Satellite data	0.00%	0.0	*	same_as_now	Seasonal_Ice	same_as_now	same_as_now	Yes
Year 45	GCM minimum	-10.36%	1.0	*	same_as_now	Seasonal_Ice	decrease	decrease	Yes
Year 75	GCM minimum	-31.89%	2.5	*	less_optimal	Seasonal_Ice	decrease	decrease	Yes
Year 100	GCM minimum	-32.11%	2.7	*	less_optimal	Seasonal_Ice	decrease	decrease	Yes
Year 45	Ensemble mean	-14.62%	1.0	*	same_as_now	Seasonal_Ice	decrease	decrease	Yes
Year 75	Ensemble mean	-25.75%	1.6	*	less_optimal	Seasonal_Ice	decrease	decrease	Yes
Year 100	Ensemble mean	-27.83%	1.8	*	less_optimal	Seasonal_Ice	decrease	decrease	Yes
Year 45	GCM maximum	-6.71%	0.7	*	same_as_now	Seasonal_Ice	decrease	decrease	Yes
Year 75	GCM maximum	-21.16%	1.3	*	same_as_now	Seasonal_Ice	decrease	decrease	Yes
Year 100	GCM maximum	-21.69%	1.7	*	same_as_now	Seasonal_Ice	decrease	decrease	Yes

Table 3. continued.

	BBN node name	J1	B1	R1	J	R4	T1	E	T	T2
	Variable name	Tourism	Bear-human interactions	Oil & gas activity	Shipping	Hydrocarbons / oil spill	Contaminants	Intentional takes	Parasites & disease	Predation
	Unit of measure	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	increased same_as_now decreased	increased same_as_now decreased	increase no_change decrease	increased same_as_now	increased_occurrence same_as_now decreased_occurrence	elevated same_as_now reduced	increased same_as_now decreased	influential not	influential not
Time period	**Basis**									
Seasonal Ice Ecoregion										
Year -10	Satellite data	decreased	decreased	no_change	same_as_now	same_as_now	reduced	decreased	not	not
Year 0	Satellite data	same_as_now	same_as_now	no_change	same_as_now	same_as_now	same_as_now	same_as_now	not	not
Year 45	GCM minimum	increased	increased	no_change	increased	same_as_now	elevated	decreased	influential	influential
Year 75	GCM minimum	increased	increased	no_change	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	GCM minimum	increased	increased	no_change	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	Ensemble mean	increased	increased	no_change	increased	same_as_now	elevated	decreased	influential	influential
Year 75	Ensemble mean	increased	increased	no_change	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	Ensemble mean	increased	increased	no_change	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	GCM maximum	increased	increased	no_change	increased	same_as_now	elevated	decreased	influential	influential
Year 75	GCM maximum	increased	increased	no_change	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	GCM maximum	increased	increased	no_change	increased	increased_occurrence	elevated	decreased	influential	influential

Table 3 continued.

	BBN node name	B	C	N	S1	M	R3	R2	F
	Variable name	Foraging habitat quantity change	Foraging habitat absence change	Shelf distance change	Foraging habitat character	Geographic area	Alternative prey availability	Relative ringed seal availability	Alternative regions available
	Unit of measure	% change from "now"	# of Months Different than now	km	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	any value < or = +20%	any value > or = -1	any value > or = -200	more_optimal same_as_now less_optimal	Polar_Basin_Divergent Polar_Basin_Convergent Archipelago Seasonal_Ice	increase same_as_now decrease	increase same_as_now decrease	Yes No
Time Period	Basis								
Archipelago Ecoregion									
Year -10	Satellite data	3.21%	-0.5	*	less_optimal	Archipelago	same_as_now	decrease	No
Year 0	Satellite data	0.00%	0.0	*	same_as_now	Archipelago	same_as_now	same_as_now	No
Year 45	GCM minimum	-13.79%	1.1	*	more_optimal	Archipelago	increase	increase	No
Year 75	GCM minimum	-20.71%	2.0	*	same_as_now	Archipelago	decrease	decrease	No
Year 100	GCM minimum	-24.30%	2.3	*	same_as_now	Archipelago	decrease	decrease	No
Year 45	Ensemble mean	-11.93%	1.5	*	more_optimal	Archipelago	increase	increase	No
Year 75	Ensemble mean	-20.06%	2.4	*	same_as_now	Archipelago	increase	decrease	No
Year 100	Ensemble mean	-22.16%	2.5	*	same_as_now	Archipelago	decrease	decrease	No
Year 45	GCM maximum	-3.43%	0.0	*	more_optimal	Archipelago	increase	increase	No
Year 75	GCM maximum	-18.02%	2.7	*	more_optimal	Archipelago	increase	increase	No
Year 100	GCM maximum	-20.85%	2.3	*	same_as_now	Archipelago	decrease	decrease	No

Table 3 continued.

	BBN node name	J1	B1	R1	J	R4	T1	E	T	T2
	Variable name	Tourism	Bear-human interactions	Oil & gas activity	Shipping	Hydrocarbons / oil spill	Contaminants	Intentional takes	Parasites & disease	Predation
	Unit of measure	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	increased same_as_now decreased	increased same_as_now decreased	increase no_change decrease	increased same_as_now	increased_occurrence same_as_now decreased_occurrence	elevated same_as_now reduced	increased same_as_now decreased	influential not	influential not
Time period	**Basis**									
Archipelago Ecoregion										
Year -10	Satellite data	decreased	increased	no_change	same_as_now	same_as_now	reduced	same_as_now	not	not
Year 0	Satellite data	same_as_now	same_as_now	no_change	same_as_now	same_as_now	same_as_now	same_as_now	not	not
Year 45	GCM minimum	increased	increased	no_change	same_as_now	same_as_now	elevated	increased	influential	not
Year 75	GCM minimum	increased	increased	increase	increased	increased_occurrence	elevated	same_as_now	influential	influential
Year 100	GCM minimum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	Ensemble mean	increased	increased	no_change	same_as_now	same_as_now	elevated	increased	influential	not
Year 75	Ensemble mean	increased	increased	increase	same_as_now	increased_occurrence	elevated	same_as_now	influential	influential
Year 100	Ensemble mean	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	GCM maximum	increased	increased	no_change	same_as_now	same_as_now	elevated	increased	influential	not
Year 75	GCM maximum	increased	increased	increase	same_as_now	increased_occurrence	elevated	increased	influential	not
Year 100	GCM maximum	increased	increased	increase	same_as_now	increased_occurrence	elevated	decreased	influential	influential

Table 3 continued.

	BBN node name	B	C	N	S1	M	R3	R2	F
	Variable name	Foraging habitat quantity change	Foraging habitat absence change	Shelf distance change	Foraging habitat character	Geographic area	Alternative prey availability	Relative ringed seal availability	Alternative regions available
	Unit of measure	% change from "now"	# of Months Different than now	km	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	any value < or = +20%	any value > or = -1	any value > or = -200	more_optimal same_as_now less_optimal	Polar_Basin_Divergent Polar_Basin_Convergent Archipelago Seasonal_Ice	increase same_as_now decrease	increase same_as_now decrease	Yes No
Time Period	**Basis**								
Polar Basin Divergent Ecoregion									
Year -10	Satellite data	5.33%	-0.3	-83	more_optimal	Polar_Basin_Divergent	same_as_now	increase	Yes
Year 0	Satellite data	0.00%	0.0	0	same_as_now	Polar_Basin_Divergent	same_as_now	same_as_now	Yes
Year 45	GCM minimum	-36.15%	2.1	1359	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 75	GCM minimum	-44.64%	2.9	2006	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 100	GCM minimum	-49.46%	3.2	2177	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 45	Ensemble mean	-19.31%	1.8	631	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 75	Ensemble mean	-31.68%	2.6	1034	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 100	Ensemble mean	-35.77%	3.0	1275	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 45	GCM maximum	-16.68%	2.2	234	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 75	GCM maximum	-31.16%	2.4	233	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes
Year 100	GCM maximum	-21.33%	2.7	315	less_optimal	Polar_Basin_Divergent	same_as_now	decrease	Yes

Table 3 continued.

	BBN node name	J1	B1	R1	J	R4	T1	E	T	T2
	Variable name	Tourism	Bear-human interactions	Oil & gas activity	Shipping	Hydrocarbons / oil spill	Contaminants	Intentional takes	Parasites & disease	Predation
	Unit of measure	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	increased same_as_now decreased	increased same_as_now decreased	increase no_change decrease	increased same_as_now	increased_occurrence same_as_now decreased_occurrence	elevated same_as_now reduced	increased same_as_now decreased	influential not	influential not
Time period	**Basis**									
Polar Basin Divergent Ecoregion										
Year -10	Satellite data	decreased	decreased	decrease	same_as_now	same_as_now	reduced	decreased	not	not
Year 0	Satellite data	same_as_now	same_as_now	no_change	same_as_now	same_as_now	same_as_now	same_as_now	not	not
Year 45	GCM minimum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 75	GCM minimum	decreased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	GCM minimum	decreased	increased	decrease	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	Ensemble mean	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 75	Ensemble mean	same_as_now	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	Ensemble mean	decreased	increased	decrease	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	GCM maximum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 75	GCM maximum	same_as_now	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	GCM maximum	same_as_now	increased	decrease	increased	increased_occurrence	elevated	decreased	influential	influential

Table 3 continued.

	BBN node name	B	C	N	S1	M	R3	R2	F
	Variable name	Foraging habitat quantity change	Foraging habitat absence change	Shelf distance change	Foraging habitat character	Geographic area	Alternative prey availability	Relative ringed seal availability	Alternative regions available
	Unit of measure	% change from "now"	# of Months Different than now	km	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	any value < or = +20%	any value > or = -1	any value > or = -200	more_optimal same_as_now less_optimal	Polar_Basin_Divergent Polar_Basin_Convergent Archipelago Seasonal_Ice	increase same_as_now decrease	increase same_as_now decrease	Yes No
Time Period	Basis								
Polar Basin Convergent Ecoregion									
Year -10	Satellite data	4.34%	-0.5	-41	same_as_now	Polar_Basin_Convergent	same_as_now	same_as_now	No
Year 0	Satellite data	0.00%	0.0	0	same_as_now	Polar_Basin_Convergent	same_as_now	same_as_now	No
Year 45	GCM minimum	-1.77%	0.9	831	same_as_now	Polar_Basin_Convergent	increase	same_as_now	No
Year 75	GCM minimum	-23.19%	1.9	1542	less_optimal	Polar_Basin_Convergent	decrease	decrease	No
Year 100	GCM minimum	-30.33%	2.5	1478	less_optimal	Polar_Basin_Convergent	decrease	decrease	No
Year 45	Ensemble mean	-13.85%	2.0	464	same_as_now	Polar_Basin_Convergent	increase	increase	No
Year 75	Ensemble mean	-22.65%	3.0	847	less_optimal	Polar_Basin_Convergent	decrease	same_as_now	No
Year 100	Ensemble mean	-25.02%	3.3	795	less_optimal	Polar_Basin_Convergent	decrease	decrease	No
Year 45	GCM maximum	-24.28%	2.9	334	same_as_now	Polar_Basin_Convergent	increase	increase	No
Year 75	GCM maximum	-30.23%	3.5	434	less_optimal	Polar_Basin_Convergent	increase	increase	No
Year 100	GCM maximum	-31.20%	3.7	510	less_optimal	Polar_Basin_Convergent	decrease	same_as_now	No

Table 3 continued.

	BBN node name	J1	B1	R1	J	R4	T1	E	T	T2
	Variable name	Tourism	Bear-human interactions	Oil & gas activity	Shipping	Hydrocarbons / oil spill	Contaminants	Intentional takes	Parasites & disease	Predation
	Unit of measure	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state	discrete state
	Allowable values	increased same_as_now decreased	increased same_as_now decreased	increase no_change decrease	increased same_as_now	increased_occurrence same_as_now decreased_occurrence	elevated same_as_now reduced	increased same_as_now decreased	influential not	influential not
Time period	**Basis**									
Polar Basin Convergent Ecoregion										
Year -10	Satellite data	decreased	decreased	decrease	same_as_now	same_as_now	reduced	same_as_now	not	not
Year 0	Satellite data	same_as_now	same_as_now	no_change	same_as_now	same_as_now	same_as_now	same_as_now	not	not
Year 45	GCM minimum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 75	GCM minimum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	GCM minimum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	Ensemble mean	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 75	Ensemble mean	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	Ensemble mean	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 45	GCM maximum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 75	GCM maximum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential
Year 100	GCM maximum	increased	increased	increase	increased	increased_occurrence	elevated	decreased	influential	influential

Table 4. Amount, percent change, and summary of change in polar bear habitat forecasted by the deterministic polar bear carrying capacity model.

x = not calculated or data not available.

		Habitat amount (km^2-months x 1000)			% change in habitat from year 0		Change in Total Habitat from Year 0		
Time Period	Data basis	Total habitat	RSF habitat	Non-RSF habitat	RSF habitat	Total habitat	Direction[1]	Magnitude[2]	Summary
Seasonal Ice Ecoregion									
Year -10	Satellite data	16,258.70	x	x	x	17%	Expanding or stable	Moderate	Expanding moderate
Year 0	Satellite data	13,879.60	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 0	GCM minimum	11,217.33	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM minimum	10,054.93	x	x	x	-10%	Contracting	Slow to none	Contracting slow
Year 75	GCM minimum	7,640.68	x	x	x	-32%	Contracting	Fast	Contracting fast
Year 100	GCM minimum	7,615.55	x	x	x	-32%	Contracting	Fast	Contracting fast
Year 0	Ensemble mean	16,340.56	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	Ensemble mean	13,952.36	x	x	x	-15%	Contracting	Slow to none	Contracting slow
Year 75	Ensemble mean	12,132.32	x	x	x	-26%	Contracting	Moderate	Contracting moderate
Year 100	Ensemble mean	11,793.25	x	x	x	-28%	Contracting	Moderate	Contracting moderate
Year 0	GCM maximum	20,178.76	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM maximum	18,823.83	x	x	x	-7%	Contracting	Slow to none	Contracting slow
Year 75	GCM maximum	15,909.29	x	x	x	-21%	Contracting	Moderate	Contracting moderate
Year 100	GCM maximum	15,802.26	x	x	x	-22%	Contracting	Moderate	Contracting moderate

[1] Direction was categorized into "contracting" if $CH_{t,G} < 0$ or "expanding or stable" if $CH_{t,G} \geq 0$.

[2] Magnitude was categorized into "fast" if $|CH_{t,G}| > 30.0$, "moderate" if $15.0 < |CH_{t,G}| \leq 30.0$, and "slow or none" if $|CH_{t,G}| < 15.0$.

Table 4 continued.

		Habitat amount (km^2-months x 1000)			% change in habitat from year 0		Change in Total Habitat from Year 0		
Time Period	Data basis	Total habitat	RSF habitat	Non-RSF habitat	RSF habitat	Total habitat	Direction	Magnitude	Summary
Archipelago Ecoregion									
Year -10	Satellite data	6,903.69	x	x	x	3%	Expanding or stable	Slow to none	Stable
Year 0	Satellite data	6,689.17	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 0	GCM minimum	5,784.55	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM minimum	4,986.82	x	x	x	-14%	Contracting	Slow to none	Contracting slow
Year 75	GCM minimum	4,586.46	x	x	x	-21%	Contracting	Moderate	Contracting moderate
Year 100	GCM minimum	4,378.68	x	x	x	-24%	Contracting	Moderate	Contracting moderate
Year 0	Ensemble mean	7,158.84	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	Ensemble mean	6,305.10	x	x	x	-12%	Contracting	Slow to none	Contracting slow
Year 75	Ensemble mean	5,722.95	x	x	x	-20%	Contracting	Moderate	Contracting moderate
Year 100	Ensemble mean	5,572.14	x	x	x	-22%	Contracting	Moderate	Contracting moderate
Year 0	GCM maximum	8,298.05	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM maximum	8,013.84	x	x	x	-3%	Contracting	Slow to none	Contracting slow
Year 75	GCM maximum	6,802.87	x	x	x	-18%	Contracting	Moderate	Contracting moderate
Year 100	GCM maximum	6,568.13	x	x	x	-21%	Contracting	Moderate	Contracting moderate
Polar Basin Divergent Ecoregion									
Year -10	Satellite data	35,066.08	12,253.30	22,812.78	5%	4%	Expanding or stable	Slow to none	Stable
Year 0	Satellite data	33,563.40	11,633.44	21,929.96	0%	0%	Expanding or stable	Slow to none	Stable
Year 0	GCM minimum	31,741.23	11,032.20	20,709.03	0%	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM minimum	21,207.61	7,043.79	14,163.82	-36%	-33%	Contracting	Fast	Contracting fast
Year 75	GCM minimum	18,503.41	6,107.96	12,395.45	-45%	-42%	Contracting	Fast	Contracting fast
Year 100	GCM minimum	16,871.39	5,575.40	11,295.99	-49%	-47%	Contracting	Fast	Contracting fast
Year 0	Ensemble mean	38,753.63	12,560.31	26,193.32	0%	0%	Expanding or stable	Slow to none	Stable
Year 45	Ensemble mean	30,582.79	10,135.02	20,447.77	-19%	-21%	Contracting	Moderate	Contracting moderate
Year 75	Ensemble mean	26,399.58	8,580.94	17,818.64	-32%	-32%	Contracting	Fast	Contracting fast
Year 100	Ensemble mean	24,992.14	8,067.62	16,924.52	-36%	-36%	Contracting	Fast	Contracting fast
Year 0	GCM maximum	45,672.05	14,591.97	31,080.08	0%	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM maximum	36,092.83	12,158.61	23,934.22	-17%	-21%	Contracting	Moderate	Contracting moderate
Year 75	GCM maximum	33,664.81	10,045.76	23,619.05	-31%	-26%	Contracting	Moderate	Contracting moderate
Year 100	GCM maximum	34,293.06	11,479.88	22,813.18	-21%	-25%	Contracting	Moderate	Contracting moderate

Table 4 continued.

		Habitat amount (km^2-months x 1000)			% change in habitat from year 0		Change in Total Habitat from Year 0		
Time Period	Data basis	Total habitat	RSF habitat	Non-RSF habitat	RSF habitat	Total habitat	Direction	Magnitude	Summary
Polar Basin Convergent Ecoregion									
Year -10	Satellite data	6,063.56	5,440.34	623.22	4%	4%	Expanding or stable	Slow to none	Stable
Year 0	Satellite data	5,823.36	5,214.13	609.23	0%	0%	Expanding or stable	Slow to none	Stable
Year 0	GCM minimum	4,945.44	4,136.50	808.94	0%	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM minimum	4,424.39	4,063.23	361.16	-2%	-11%	Contracting	Slow to none	Contracting slow
Year 75	GCM minimum	4,042.15	3,177.04	865.11	-23%	-18%	Contracting	Moderate	Contracting moderate
Year 100	GCM minimum	3,539.31	2,881.99	657.32	-30%	-28%	Contracting	Moderate	Contracting moderate
Year 0	Ensemble mean	6,305.23	5,158.01	1,147.22	0%	0%	Expanding or stable	Slow to none	Stable
Year 45	Ensemble mean	5,334.67	4,443.39	891.28	-14%	-15%	Contracting	Moderate	Contracting moderate
Year 75	Ensemble mean	4,739.31	3,989.57	749.74	-23%	-25%	Contracting	Moderate	Contracting moderate
Year 100	Ensemble mean	4,566.56	3,867.34	699.22	-25%	-28%	Contracting	Moderate	Contracting moderate
Year 0	GCM maximum	7,068.41	6,023.03	1,045.38	0%	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM maximum	6,115.28	4,560.71	1,554.57	-24%	-13%	Contracting	Slow to none	Contracting slow
Year 75	GCM maximum	5,538.43	4,202.23	1,336.20	-30%	-22%	Contracting	Moderate	Contracting moderate
Year 100	GCM maximum	5,625.88	4,143.95	1,481.93	-31%	-20%	Contracting	Moderate	Contracting moderate
Global (all ecoregions combined)									
Year -10	Satellite data	64,292.03	x	x	x	7%	Expanding or stable	Slow to none	Stable
Year 0	Satellite data	59,955.53	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 0	GCM minimum	53,688.55	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM minimum	40,673.75	x	x	x	-24%	Contracting	Moderate	Contracting moderate
Year 75	GCM minimum	34,772.70	x	x	x	-35%	Contracting	Fast	Contracting fast
Year 100	GCM minimum	32,404.93	x	x	x	-40%	Contracting	Fast	Contracting fast
Year 0	Ensemble mean	68,558.26	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	Ensemble mean	56,174.92	x	x	x	-18%	Contracting	Moderate	Contracting moderate
Year 75	Ensemble mean	48,994.16	x	x	x	-29%	Contracting	Moderate	Contracting moderate
Year 100	Ensemble mean	46,924.09	x	x	x	-32%	Contracting	Fast	Contracting fast
Year 0	GCM maximum	81,217.27	x	x	x	0%	Expanding or stable	Slow to none	Stable
Year 45	GCM maximum	69,045.78	x	x	x	-15%	Contracting	Slow to none	Contracting slow
Year 75	GCM maximum	61,915.40	x	x	x	-24%	Contracting	Moderate	Contracting moderate
Year 100	GCM maximum	62,289.33	x	x	x	-23%	Contracting	Moderate	Contracting moderate

Table 5. Numbers and densities of polar bears by ecoregion, based on habitat amount at year 0 (Table 4).

x = not calculated or data not available.

Ecoregion	Numbers of polar bears	Polar bear density (km^2-months x 1000 per bear)		
		Crude density, based on non-RSF habitat	Ecological density, based on RSF habitat	Total density, based on total habitat
Seasonal Ice	7800	x	x	1.779
Archipelago	5000	x	x	1.338
Polar Basin Divergent	9500	7.695	1.749	x
Polar Basin Convergent	2200	0.923	3.386	x

Table 6. Polar bear carrying capacity forecast for each ecoregion, time period, and modeling basis, by the deterministic polar bear carrying capacity model.

x = not calculated or data not available.

		Carrying capacity (K) expressed as polar bear population size (no. bears), not normalized to year 0				% change in carrying capacity from year 0				Carrying capacity normalized to year 0		Change in total carrying capacity from year 0		
Time Period	Data basis	Based on all habitat	Based on RSF habitat	Based on non-RSF habitat	TOTAL	Based on all habitat	Based on RSF habitat	Based on non-RSF habitat	TOTAL	Based on RSF habitat	TOTAL	Direction[4]	Magnitude[5]	Summary
Seasonal Ice Ecoregion														
Year -10	Satellite data	9,137	x	x	9,137	17%	x	x	17%	x	9,137	stab_incr	moderate	Increasing moderate
Year 0	Satellite data	7,800	x	x	7,800	0%	x	x	0%	x	7,800	stab_incr	Low to none	Stable
Year 0	GCM minimum	6,304	x	x	6,304	0%	x	x	0%	x	7,800	stab_incr	Low to none	Stable
Year 45	GCM minimum	5,651	x	x	5,651	-10%	x	x	-10%	x	6,992	Decreasing	Low to none	Decreasing low
Year 75	GCM minimum	4,294	x	x	4,294	-32%	x	x	-32%	x	5,313	Decreasing	high	Decreasing high
Year 100	GCM minimum	4,280	x	x	4,280	-32%	x	x	-32%	x	5,295	Decreasing	high	Decreasing high
Year 0	Ensemble mean	9,183	x	x	9,183	0%	x	x	0%	x	7,800	stab_incr	Low to none	Stable
Year 45	Ensemble mean	7,841	x	x	7,841	-15%	x	x	-15%	x	6,660	Decreasing	Low to none	Decreasing low
Year 75	Ensemble mean	6,818	x	x	6,818	-26%	x	x	-26%	x	5,791	Decreasing	moderate	Decreasing moderate
Year 100	Ensemble mean	6,628	x	x	6,628	-28%	x	x	-28%	x	5,629	Decreasing	moderate	Decreasing moderate
Year 0	GCM maximum	11,340	x	x	11,340	0%	x	x	0%	x	7,800	stab_incr	Low to none	Stable
Year 45	GCM maximum	10,579	x	x	10,579	-7%	x	x	-7%	x	7,276	Decreasing	Low to none	Decreasing low
Year 75	GCM maximum	8,941	x	x	8,941	-21%	x	x	-21%	x	6,150	Decreasing	moderate	Decreasing moderate
Year 100	GCM maximum	8,880	x	x	8,880	-22%	x	x	-22%	x	6,108	Decreasing	moderate	Decreasing moderate

[4] Direction was categorized into "decreasing" if $CK_{t,G} < 0$ or "stable or increasing" if $CK_{t,G} \geq 0$.

[5] Magnitude was categorized into "high" if $|CK_{t,G}| > 30.0$, "moderate" if $15.0 < |CK_{t,G}| \leq 30.0$, and "low to none" if $|CK_{t,G}| < 15.0$.

Table 6 continued.

Time Period	Data basis	Carrying capacity (K) expressed as polar bear population size (no. bears), not normalized to year 0				% change in carrying capacity from year 0				Carrying capacity normalized to year 0		Change in total carrying capacity from year 0		
		Based on all habitat	Based on RSF habitat	Based on non-RSF habitat	TOTAL	Based on all habitat	Based on RSF habitat	Based on non-RSF habitat	TOTAL	Based on RSF habitat	TOTAL	Direction	Magnitude	Summary
Archipelago Ecoregion														
Year -10	Satellite data	5,160	x	x	5,160	3%	x	x	3%	x	5,160	stab_incr	Low to none	Stable
Year 0	Satellite data	5,000	x	x	5,000	0%	x	x	0%	x	5,000	stab_incr	Low to none	Stable
Year 0	GCM minimum	4,324	x	x	4,324	0%	x	x	0%	x	5,000	stab_incr	Low to none	Stable
Year 45	GCM minimum	3,728	x	x	3,728	-14%	x	x	-14%	x	4,310	Decreasing	Low to none	Decreasing low
Year 75	GCM minimum	3,428	x	x	3,428	-21%	x	x	-21%	x	3,964	Decreasing	Moderate	Decreasing moderate
Year 100	GCM minimum	3,273	x	x	3,273	-24%	x	x	-24%	x	3,785	Decreasing	Moderate	Decreasing moderate
Year 0	Ensemble mean	5,351	x	x	5,351	0%	x	x	0%	x	5,000	Stable-Incr	Low to none	Stable
Year 45	Ensemble mean	4,713	x	x	4,713	-12%	x	x	-12%	x	4,404	Decreasing	Low to none	Decreasing low
Year 75	Ensemble mean	4,278	x	x	4,278	-20%	x	x	-20%	x	3,997	Decreasing	Moderate	Decreasing moderate
Year 100	Ensemble mean	4,165	x	x	4,165	-22%	x	x	-22%	x	3,892	Decreasing	Moderate	Decreasing moderate
Year 0	GCM maximum	6,203	x	x	6,203	0%	x	x	0%	x	5,000	Stable-Incr	Low to none	Stable
Year 45	GCM maximum	5,990	x	x	5,990	-3%	x	x	-3%	x	4,829	Decreasing	Low to none	Decreasing low
Year 75	GCM maximum	5,085	x	x	5,085	-18%	x	x	-18%	x	4,099	Decreasing	Moderate	Decreasing moderate
Year 100	GCM maximum	4,910	x	x	4,910	-21%	x	x	-21%	x	3,958	Decreasing	Moderate	Decreasing moderate
Polar Basin Divergent Ecoregion														
Year -10	Satellite data	x	7,004	2,965	9,969	x	5%	4%	5%	7,004	9,969	Stable-Incr	Low to none	Stable
Year 0	Satellite data	x	6,650	2,850	9,500	x	0%	0%	0%	6,650	9,500	Stable-Incr	Low to none	Stable
Year 0	GCM minimum	x	6,306	2,691	8,998	x	0%	0%	0%	6,650	9,500	Stable-Incr	Low to none	Stable
Year 45	GCM minimum	x	4,026	1,841	5,867	x	-36%	-32%	-35%	4,246	6,195	Decreasing	High	Decreasing high
Year 75	GCM minimum	x	3,491	1,611	5,102	x	-45%	-40%	-43%	3,682	5,387	Decreasing	High	Decreasing high
Year 100	GCM minimum	x	3,187	1,468	4,655	x	-49%	-45%	-48%	3,361	4,915	Decreasing	High	Decreasing high
Year 0	Ensemble mean	x	7,180	3,404	10,584	x	0%	0%	0%	6,650	9,500	Stable-Incr	Low to none	Stable
Year 45	Ensemble mean	x	5,793	2,657	8,451	x	-19%	-22%	-20%	5,366	7,585	Decreasing	Moderate	Decreasing moderate
Year 75	Ensemble mean	x	4,905	2,316	7,221	x	-32%	-32%	-32%	4,543	6,481	Decreasing	High	Decreasing high
Year 100	Ensemble mean	x	4,612	2,199	6,811	x	-36%	-35%	-36%	4,271	6,114	Decreasing	High	Decreasing high
Year 0	GCM maximum	x	8,341	4,039	12,380	x	0%	0%	0%	6,650	9,500	Stable-Incr	Low to none	Stable
Year 45	GCM maximum	x	6,950	3,110	10,061	x	-17%	-23%	-19%	5,541	7,720	Decreasing	Moderate	Decreasing moderate
Year 75	GCM maximum	x	5,742	3,070	8,812	x	-31%	-24%	-29%	4,578	6,762	Decreasing	Moderate	Decreasing moderate
Year 100	GCM maximum	x	6,562	2,965	9,527	x	-21%	-27%	-23%	5,232	7,311	Decreasing	Moderate	Decreasing moderate

Table 6 continued.

Time Period	Data basis	Carrying capacity (K) expressed as polar bear population size (no. bears), not normalized to year 0				% change in carrying capacity from year 0				Carrying capacity normalized to year 0		Change in total carrying capacity from year 0		
		Based on all habitat	Based on RSF habitat	Based on non-RSF habitat	TOTAL	Based on all habitat	Based on RSF habitat	Based on non-RSF habitat	TOTAL	Based on RSF habitat	TOTAL	Direction	Magnitude	Summary
Polar Basin Convergent Ecoregion														
Year -10	Satellite data	x	1,607	675	2,282	x	4%	2%	4%	1,607	2,282	Stable-Incr	Low to none	Stable
Year 0	Satellite data	x	1,540	660	2,200	x	0%	0%	0%	1,540	2,200	Stable-Incr	Low to none	Stable
Year 0	GCM minimum	x	1,222	876	2,098	x	0%	0%	0%	1,540	2,200	Stable-Incr	Low to none	Stable
Year 45	GCM minimum	x	1,200	391	1,591	x	-2%	-55%	-24%	1,513	1,669	Decreasing	Moderate	Decreasing moderate
Year 75	GCM minimum	x	938	937	1,876	x	-23%	7%	-11%	1,183	1,967	Decreasing	Low to none	Decreasing low
Year 100	GCM minimum	x	851	712	1,563	x	-30%	-19%	-25%	1,073	1,639	Decreasing	Moderate	Decreasing moderate
Year 0	Ensemble mean	x	1,523	1,243	2,766	x	0%	0%	0%	1,540	2,200	Stable-Incr	Low to none	Stable
Year 45	Ensemble mean	x	1,312	966	2,278	x	-14%	-22%	-18%	1,327	1,812	Decreasing	Moderate	Decreasing moderate
Year 75	Ensemble mean	x	1,178	812	1,991	x	-23%	-35%	-28%	1,191	1,583	Decreasing	Moderate	Decreasing moderate
Year 100	Ensemble mean	x	1,142	757	1,900	x	-25%	-39%	-31%	1,155	1,511	Decreasing	High	Decreasing high
Year 0	GCM maximum	x	1,779	1,132	2,911	x	0%	0%	0%	1,540	2,200	Stable-Incr	Low to none	Stable
Year 45	GCM maximum	x	1,347	1,684	3,031	x	-24%	49%	4%	1,166	2,290	Stable-Incr	Low to none	Stable
Year 75	GCM maximum	x	1,241	1,448	2,689	x	-30%	28%	-8%	1,074	2,032	Decreasing	Low to none	Decreasing low
Year 100	GCM maximum	x	1,224	1,605	2,829	x	-31%	42%	-3%	1,060	2,138	Decreasing	Low to none	Decreasing low
Global (all ecoregions combined)														
Year -10	Satellite data	x	x	x	26,548	x	x	x	8%	x	26,548	Stable-Incr	Low to none	Stable
Year 0	Satellite data	x	x	x	24,500	x	x	x	0%	x	24,500	Stable-Incr	Low to none	Stable
Year 0	GCM minimum	x	x	x	21,723	x	x	x	0%	x	24,500	Stable-Incr	Low to none	Stable
Year 45	GCM minimum	x	x	x	16,837	x	x	x	-22%	x	18,989	Decreasing	Moderate	Decreasing moderate
Year 75	GCM minimum	x	x	x	14,700	x	x	x	-32%	x	16,579	Decreasing	High	Decreasing high
Year 100	GCM minimum	x	x	x	13,771	x	x	x	-37%	x	15,531	Decreasing	High	Decreasing high
Year 0	Ensemble mean	x	x	x	27,884	x	x	x	0%	x	24,500	Stable-Incr	Low to none	Stable
Year 45	Ensemble mean	x	x	x	23,283	x	x	x	-17%	x	20,457	Decreasing	Moderate	Decreasing moderate
Year 75	Ensemble mean	x	x	x	20,307	x	x	x	-27%	x	17,843	Decreasing	Moderate	Decreasing moderate
Year 100	Ensemble mean	x	x	x	19,503	x	x	x	-30%	x	17,136	Decreasing	High	Decreasing high
Year 0	GCM maximum	x	x	x	32,834	x	x	x	0%	x	24,500	Stable-Incr	Low to none	Stable
Year 45	GCM maximum	x	x	x	29,661	x	x	x	-10%	x	22,132	Decreasing	Low to none	Decreasing low
Year 75	GCM maximum	x	x	x	25,526	x	x	x	-22%	x	19,047	Decreasing	Moderate	Decreasing moderate
Year 100	GCM maximum	x	x	x	26,146	x	x	x	-20%	x	19,510	Decreasing	Moderate	Decreasing moderate

Table 7. Overall summary of change in total polar bear carrying capacity from present levels (based on applying results of carrying capacity calculations in Table 6 to the rule set in Table 2).

Time Period	Data basis	Overall Summary
Seasonal Ice Ecoregion		
Year -10	Satellite data	enhanced
Year 0	Satellite data	maintained
Year 0	GCM minimum	maintained
Year 45	GCM minimum	decreased
Year 75	GCM minimum	toward extirpation
Year 100	GCM minimum	toward extirpation
Year 0	Ensemble mean	maintained
Year 45	Ensemble mean	decreased
Year 75	Ensemble mean	decreased
Year 100	Ensemble mean	decreased
Year 0	GCM maximum	maintained
Year 45	GCM maximum	decreased
Year 75	GCM maximum	decreased
Year 100	GCM maximum	decreased
Archipelago Ecoregion		
Year -10	Satellite data	maintained
Year 0	Satellite data	maintained
Year 0	GCM minimum	maintained
Year 45	GCM minimum	decreased
Year 75	GCM minimum	decreased
Year 100	GCM minimum	decreased
Year 0	Ensemble mean	maintained
Year 45	Ensemble mean	decreased
Year 75	Ensemble mean	decreased
Year 100	Ensemble mean	decreased
Year 0	GCM maximum	maintained
Year 45	GCM maximum	decreased
Year 75	GCM maximum	decreased
Year 100	GCM maximum	decreased

Table 7 continued.

Time Period	Data basis	Overall Summary
Polar Basin Divergent Ecoregion		
Year -10	Satellite data	maintained
Year 0	Satellite data	maintained
Year 0	GCM minimum	maintained
Year 45	GCM minimum	toward extirpation
Year 75	GCM minimum	toward extirpation
Year 100	GCM minimum	toward extirpation
Year 0	Ensemble mean	maintained
Year 45	Ensemble mean	decreased
Year 75	Ensemble mean	toward extirpation
Year 100	Ensemble mean	toward extirpation
Year 0	GCM maximum	maintained
Year 45	GCM maximum	decreased
Year 75	GCM maximum	decreased
Year 100	GCM maximum	decreased
Polar Basin Convergent Ecoregion		
Year -10	Satellite data	maintained
Year 0	Satellite data	maintained
Year 0	GCM minimum	maintained
Year 45	GCM minimum	decreased
Year 75	GCM minimum	decreased
Year 100	GCM minimum	decreased
Year 0	Ensemble mean	maintained
Year 45	Ensemble mean	decreased
Year 75	Ensemble mean	decreased
Year 100	Ensemble mean	toward extirpation
Year 0	GCM maximum	maintained
Year 45	GCM maximum	decreased
Year 75	GCM maximum	decreased
Year 100	GCM maximum	decreased
Global (all ecoregions combined)		
Year -10	Satellite data	maintained
Year 0	Satellite data	maintained
Year 0	GCM minimum	maintained
Year 45	GCM minimum	decreased
Year 75	GCM minimum	toward extirpation
Year 100	GCM minimum	toward extirpation
Year 0	Ensemble mean	maintained
Year 45	Ensemble mean	decreased
Year 75	Ensemble mean	decreased
Year 100	Ensemble mean	toward extirpation
Year 0	GCM maximum	maintained
Year 45	GCM maximum	decreased
Year 75	GCM maximum	decreased
Year 100	GCM maximum	decreased

Table 8. Results of the Bayesian network population stressor model, showing the most probable outcome state, and probabilities of each state (larger, same as now, smaller, rare, and extinct), for overall population outcome (node D1; see Figure 5).

		Node D1: Overall Population Outcome					
Time period	Basis	Most probable outcome	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)
Seasonal Ice Ecoregion							
Year -10	Satellite data	larger	93.92%	5.75%	0.30%	0.02%	0.00%
Year 0	Satellite data	same_as_now	21.85%	43.72%	18.98%	8.37%	7.07%
Year 45	GCM minimum	extinct	0.05%	0.61%	9.79%	12.36%	77.19%
Year 75	GCM minimum	extinct	0.00%	0.09%	3.48%	8.28%	88.15%
Year 100	GCM minimum	extinct	0.00%	0.09%	3.48%	8.28%	88.15%
Year 45	Ensemble mean	extinct	0.05%	0.61%	9.79%	12.36%	77.19%
Year 75	Ensemble mean	extinct	0.00%	0.09%	3.48%	8.28%	88.15%
Year 100	Ensemble mean	extinct	0.00%	0.09%	3.48%	8.28%	88.15%
Year 45	GCM maximum	extinct	0.24%	2.20%	24.37%	19.35%	53.85%
Year 75	GCM maximum	extinct	0.01%	0.18%	5.17%	9.52%	85.11%
Year 100	GCM maximum	extinct	0.01%	0.18%	5.17%	9.52%	85.11%
Archipelago Ecoregion							
Year -10	Satellite data	same_as_now	22.51%	34.73%	31.48%	8.72%	2.56%
Year 0	Satellite data	larger	69.48%	29.26%	1.06%	0.19%	0.00%
Year 45	GCM minimum	smaller	4.57%	12.93%	51.34%	20.60%	10.56%
Year 75	GCM minimum	extinct	0.89%	3.16%	32.07%	19.34%	44.54%
Year 100	GCM minimum	extinct	1.38%	4.65%	33.38%	19.51%	41.07%
Year 45	Ensemble mean	smaller	4.57%	12.93%	51.34%	20.60%	10.56%
Year 75	Ensemble mean	extinct	1.05%	3.34%	32.25%	26.07%	37.30%
Year 100	Ensemble mean	extinct	1.38%	4.65%	33.38%	19.51%	41.07%
Year 45	GCM maximum	smaller	5.83%	15.93%	52.35%	18.01%	7.88%
Year 75	GCM maximum	smaller	4.42%	12.40%	49.36%	22.96%	10.85%
Year 100	GCM maximum	extinct	1.38%	4.65%	33.38%	19.51%	41.07%

Table 8 continued.

Time period	Basis	Node D1: Overall Population Outcome					
		Most probable outcome	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)
Polar Basin Divergent Ecoregion							
Year -10	Satellite data	larger	99.78%	0.22%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	24.16%	56.60%	13.36%	4.73%	1.14%
Year 45	GCM minimum	extinct	0.00%	0.00%	2.86%	10.58%	86.55%
Year 75	GCM minimum	extinct	0.00%	0.00%	3.07%	10.91%	86.02%
Year 100	GCM minimum	extinct	0.00%	0.00%	3.88%	12.23%	83.89%
Year 45	Ensemble mean	extinct	0.00%	0.18%	6.16%	13.34%	80.33%
Year 75	Ensemble mean	extinct	0.00%	0.00%	2.86%	10.58%	86.55%
Year 100	Ensemble mean	extinct	0.00%	0.00%	3.88%	12.23%	83.89%
Year 45	GCM maximum	extinct	0.00%	0.18%	6.16%	13.34%	80.33%
Year 75	GCM maximum	extinct	0.00%	0.07%	4.46%	12.00%	83.47%
Year 100	GCM maximum	extinct	0.00%	0.09%	5.73%	13.84%	80.33%
Polar Basin Convergent Ecoregion							
Year -10	Satellite data	larger	98.39%	1.61%	0.00%	0.00%	0.00%
Year 0	Satellite data	larger	71.69%	27.49%	0.63%	0.19%	0.00%
Year 45	GCM minimum	extinct	0.26%	2.30%	27.98%	31.59%	37.87%
Year 75	GCM minimum	extinct	0.00%	0.39%	9.68%	13.24%	76.70%
Year 100	GCM minimum	extinct	0.00%	0.39%	9.68%	13.24%	76.70%
Year 45	Ensemble mean	extinct	0.48%	2.72%	29.27%	32.46%	35.06%
Year 75	Ensemble mean	extinct	0.00%	0.27%	8.40%	15.10%	76.23%
Year 100	Ensemble mean	extinct	0.02%	0.44%	9.49%	12.75%	77.30%
Year 45	GCM maximum	extinct	0.14%	1.24%	21.15%	30.71%	46.77%
Year 75	GCM maximum	extinct	0.02%	0.46%	12.64%	24.46%	62.41%
Year 100	GCM maximum	extinct	0.02%	0.44%	10.51%	16.52%	72.52%

Table 9. Results of the Bayesian network population stressor model, showing the most probable outcome states, and probabilities of each state, for the distribution response and numerical response outcomes (nodes C3, C4; see Figure 5).

		Node C3: Distribution Response					Node C4: Numerical Response					
Time period	Basis	Most probable outcome	P(C3= same as now)	P(C3= reduced but resident)	P(C3= transient visitors)	P(C3= extirpated)	Most probable outcome	P(C4= increased density)	P(C4= same as now)	P(C4= reduced density)	P(C4= rare)	P(C4= absent)
					Seasonal Ice Ecoregion							
Year -10	Satellite data	same_as_now	99.79%	0.21%	0.00%	0.00%	increased_density	93.93%	5.83%	0.24%	0.00%	0.00%
Year 0	Satellite data	same_as_now	72.47%	11.59%	8.88%	7.07%	same_as_now	21.90%	47.20%	30.90%	0.00%	0.00%
Year 45	GCM minimum	extirpated	4.69%	8.13%	14.51%	72.68%	reduced_density	0.09%	1.40%	56.27%	28.38%	13.87%
Year 75	GCM minimum	extirpated	0.94%	1.66%	12.70%	84.70%	reduced_density	0.01%	0.27%	53.42%	30.54%	15.76%
Year 100	GCM minimum	extirpated	0.94%	1.66%	12.70%	84.70%	reduced_density	0.01%	0.27%	53.42%	30.54%	15.76%
Year 45	Ensemble mean	extirpated	4.69%	8.13%	14.51%	72.68%	reduced_density	0.09%	1.40%	56.27%	28.38%	13.87%
Year 75	Ensemble mean	extirpated	0.94%	1.66%	12.70%	84.70%	reduced_density	0.01%	0.27%	53.42%	30.54%	15.76%
Year 100	Ensemble mean	extirpated	0.94%	1.66%	12.70%	84.70%	reduced_density	0.01%	0.27%	53.42%	30.54%	15.76%
Year 45	GCM maximum	extirpated	14.83%	20.97%	16.84%	47.35%	reduced_density	0.35%	4.54%	60.26%	23.40%	11.44%
Year 75	GCM maximum	extirpated	1.96%	3.52%	13.30%	81.22%	reduced_density	0.02%	0.57%	53.88%	30.03%	15.50%
Year 100	GCM maximum	extirpated	1.96%	3.52%	13.30%	81.22%	reduced_density	0.02%	0.57%	53.88%	30.03%	15.50%
					Archipelago Ecoregion							
Year -10	Satellite data	same_as_now	71.72%	18.29%	8.74%	1.25%	same_as_now	24.36%	41.18%	31.17%	2.19%	1.09%
Year 0	Satellite data	same_as_now	99.40%	0.43%	0.18%	0.00%	increased_density	69.49%	29.41%	1.11%	0.00%	0.00%
Year 45	GCM minimum	same_as_now	56.09%	16.39%	24.50%	3.03%	reduced_density	5.36%	15.63%	63.62%	8.32%	7.07%
Year 75	GCM minimum	extirpated	23.49%	25.05%	16.32%	35.14%	reduced_density	1.14%	4.99%	55.92%	21.22%	16.73%
Year 100	GCM minimum	extirpated	23.49%	25.05%	16.32%	35.14%	reduced_density	1.76%	7.92%	62.24%	18.53%	9.56%
Year 45	Ensemble mean	same_as_now	56.09%	16.39%	24.50%	3.03%	reduced_density	5.36%	15.63%	63.62%	8.32%	7.07%
Year 75	Ensemble mean	transient_visitors	24.66%	17.46%	32.64%	25.25%	reduced_density	1.34%	5.39%	56.47%	20.58%	16.23%
Year 100	Ensemble mean	extirpated	23.49%	25.05%	16.32%	35.14%	reduced_density	1.76%	7.92%	62.24%	18.53%	9.56%
Year 45	GCM maximum	same_as_now	61.02%	15.59%	21.31%	2.08%	reduced_density	6.81%	18.88%	62.63%	6.32%	5.37%
Year 75	GCM maximum	same_as_now	51.08%	16.90%	28.65%	3.37%	reduced_density	5.36%	15.63%	63.62%	8.32%	7.07%
Year 100	GCM maximum	extirpated	23.49%	25.05%	16.32%	35.14%	reduced_density	1.76%	7.92%	62.24%	18.53%	9.56%

Table 9 continued.

Time period	Basis	Node C3: Distribution Response					Node C4: Numerical Response					
		Most probable outcome	P(C3= same as now)	P(C3= reduced but resident)	P(C3= transient visitors)	P(C3= extirpated)	Most probable outcome	P(C4= increased density)	P(C4= same as now)	P(C4= reduced density)	P(C4= rare)	P(C4= absent)
Polar Basin Divergent Ecoregion												
Year -10	Satellite data	same_as_now	100.00%	0.00%	0.00%	0.00%	increased_density	99.78%	0.22%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	85.66%	8.37%	4.82%	1.14%	same_as_now	24.16%	59.71%	16.12%	0.00%	0.00%
Year 45	GCM minimum	extirpated	0.00%	0.00%	18.00%	82.00%	reduced_density	0.00%	0.00%	53.00%	31.00%	16.00%
Year 75	GCM minimum	extirpated	0.00%	0.30%	18.27%	81.43%	reduced_density	0.00%	0.00%	53.33%	30.91%	15.76%
Year 100	GCM minimum	extirpated	0.00%	1.50%	19.35%	79.15%	reduced_density	0.00%	0.00%	54.65%	30.55%	14.80%
Year 45	Ensemble mean	extirpated	2.14%	2.99%	19.98%	74.89%	reduced_density	0.00%	0.56%	53.90%	30.04%	15.51%
Year 75	Ensemble mean	extirpated	0.00%	0.00%	18.00%	82.00%	reduced_density	0.00%	0.00%	53.00%	31.00%	16.00%
Year 100	Ensemble mean	extirpated	0.00%	1.50%	19.35%	79.15%	reduced_density	0.00%	0.00%	54.65%	30.55%	14.80%
Year 45	GCM maximum	extirpated	2.14%	2.99%	19.98%	74.89%	reduced_density	0.00%	0.56%	53.90%	30.04%	15.51%
Year 75	GCM maximum	extirpated	1.02%	1.50%	19.04%	78.44%	reduced_density	0.00%	0.26%	53.42%	30.55%	15.77%
Year 100	GCM maximum	extirpated	1.11%	3.30%	20.44%	75.15%	reduced_density	0.00%	0.27%	55.35%	30.02%	14.35%
Polar Basin Convergent Ecoregion												
Year -10	Satellite data	same_as_now	100.00%	0.00%	0.00%	0.00%	increased_density	98.39%	1.61%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	99.40%	0.43%	0.18%	0.00%	increased_density	71.69%	27.65%	0.66%	0.00%	0.00%
Year 45	GCM minimum	transient_visitors	17.71%	14.07%	40.63%	27.59%	reduced_density	0.31%	5.23%	60.81%	22.19%	11.45%
Year 75	GCM minimum	extirpated	4.72%	8.32%	15.48%	71.48%	reduced_density	0.00%	1.27%	55.04%	28.82%	14.87%
Year 100	GCM minimum	extirpated	4.72%	8.32%	15.48%	71.48%	reduced_density	0.00%	1.27%	55.04%	28.82%	14.87%
Year 45	Ensemble mean	transient_visitors	18.56%	13.79%	42.66%	24.99%	reduced_density	0.69%	6.01%	61.31%	21.10%	10.89%
Year 75	Ensemble mean	extirpated	3.53%	5.29%	20.93%	70.24%	reduced_density	0.00%	0.95%	54.53%	29.37%	15.16%
Year 100	Ensemble mean	extirpated	4.55%	8.08%	15.05%	72.32%	reduced_density	0.04%	1.34%	55.08%	28.72%	14.82%
Year 45	GCM maximum	transient_visitors	11.44%	10.51%	41.88%	36.17%	reduced_density	0.23%	3.51%	58.19%	25.11%	12.96%
Year 75	GCM maximum	extirpated	5.32%	5.39%	36.12%	53.17%	reduced_density	0.05%	1.58%	55.44%	28.31%	14.61%
Year 100	GCM maximum	extirpated	4.80%	7.22%	21.82%	66.16%	reduced_density	0.05%	1.42%	55.19%	28.59%	14.75%

Table 10. Results of the Bayesian network population stressor model, showing the most probable outcome states, and probabilities of each state, for habitat threats and director mortalities summary variables (nodes F2 and A1; see Fig. 5).

		Node F2: Factor A: Habitat Threats					Node A1: Factor B: Direct Mortalities			
Time period	Basis	Most probable outcome	P(F2= improve-ment)	P(F2= no effect)	P(F2= minor restriction)	P(F2= major restriction)	Most probable outcome	P(A1= fewer)	P(A1= same as now)	P(A1= more)
					Seasonal Ice Ecoregion					
Year -10	Satellite data	improvement	94.60%	5.00%	0.40%	0.00%	fewer	100.00%	0.00%	0.00%
Year 0	Satellite data	no_effect	26.41%	36.84%	23.02%	13.72%	same_as_now	0.00%	100.00%	0.00%
Year 45	GCM minimum	major_restriction	0.08%	2.00%	16.64%	81.28%	same_as_now	0.00%	62.60%	37.40%
Year 75	GCM minimum	major_restriction	0.00%	0.00%	4.72%	95.28%	same_as_now	0.00%	60.00%	40.00%
Year 100	GCM minimum	major_restriction	0.00%	0.00%	4.72%	95.28%	same_as_now	0.00%	60.00%	40.00%
Year 45	Ensemble mean	major_restriction	0.08%	2.00%	16.64%	81.28%	same_as_now	0.00%	62.60%	37.40%
Year 75	Ensemble mean	major_restriction	0.00%	0.00%	4.72%	95.28%	same_as_now	0.00%	60.00%	40.00%
Year 100	Ensemble mean	major_restriction	0.00%	0.00%	4.72%	95.28%	same_as_now	0.00%	60.00%	40.00%
Year 45	GCM maximum	major_restriction	0.40%	9.68%	43.60%	46.32%	same_as_now	0.00%	62.60%	37.40%
Year 75	GCM maximum	major_restriction	0.00%	0.08%	9.60%	90.32%	same_as_now	0.00%	60.00%	40.00%
Year 100	GCM maximum	major_restriction	0.00%	0.08%	9.60%	90.32%	same_as_now	0.00%	60.00%	40.00%
					Archipelago Ecoregion					
Year -10	Satellite data	no_effect	39.00%	44.60%	16.40%	0.00%	same_as_now	4.80%	53.00%	42.20%
Year 0	Satellite data	improvement	88.56%	10.43%	1.01%	0.00%	same_as_now	0.00%	100.00%	0.00%
Year 45	GCM minimum	no_effect	32.48%	41.28%	22.30%	3.94%	more	0.00%	0.00%	100.00%
Year 75	GCM minimum	minor_restriction	4.08%	24.32%	40.32%	31.28%	more	0.00%	30.00%	70.00%
Year 100	GCM minimum	minor_restriction	4.08%	24.32%	40.32%	31.28%	same_as_now	0.00%	60.00%	40.00%
Year 45	Ensemble mean	no_effect	32.48%	41.28%	22.30%	3.94%	more	0.00%	0.00%	100.00%
Year 75	Ensemble mean	minor_restriction	4.96%	25.44%	39.84%	29.76%	more	0.00%	30.00%	70.00%
Year 100	Ensemble mean	minor_restriction	4.08%	24.32%	40.32%	31.28%	same_as_now	0.00%	60.00%	40.00%
Year 45	GCM maximum	improvement	41.92%	38.40%	17.06%	2.62%	more	0.00%	0.00%	100.00%
Year 75	GCM maximum	no_effect	32.48%	41.28%	22.30%	3.94%	more	0.00%	0.00%	100.00%
Year 100	GCM maximum	minor_restriction	4.08%	24.32%	40.32%	31.28%	same_as_now	0.00%	60.00%	40.00%

Table 10 continued.

Time period	Basis	Node F2: Factor A: Habitat Threats					Node A1: Factor B: Direct Mortalities			
		Most probable outcome	P(F2= improve-ment)	P(F2= no effect)	P(F2= minor restriction)	P(F2= major restriction)	Most probable outcome	P(A1= fewer)	P(A1= same as now)	P(A1= more)
Polar Basin Divergent Ecoregion										
Year -10	Satellite data	improvement	99.68%	0.32%	0.00%	0.00%	fewer	100.00%	0.00%	0.00%
Year 0	Satellite data	no_effect	30.20%	47.24%	20.54%	2.02%	same_as_now	0.00%	100.00%	0.00%
Year 45	GCM minimum	major_restriction	0.00%	0.00%	0.00%	100.00%	same_as_now	0.00%	60.00%	40.00%
Year 75	GCM minimum	major_restriction	0.00%	0.00%	0.00%	100.00%	same_as_now	0.00%	60.60%	39.40%
Year 100	GCM minimum	major_restriction	0.00%	0.00%	0.00%	100.00%	same_as_now	0.00%	63.00%	37.00%
Year 45	Ensemble mean	major_restriction	0.00%	0.36%	9.80%	89.84%	same_as_now	0.00%	60.00%	40.00%
Year 75	Ensemble mean	major_restriction	0.00%	0.00%	0.00%	100.00%	same_as_now	0.00%	60.00%	40.00%
Year 100	Ensemble mean	major_restriction	0.00%	0.00%	0.00%	100.00%	same_as_now	0.00%	63.00%	37.00%
Year 45	GCM maximum	major_restriction	0.00%	0.36%	9.80%	89.84%	same_as_now	0.00%	60.00%	40.00%
Year 75	GCM maximum	major_restriction	0.00%	0.00%	5.08%	94.92%	same_as_now	0.00%	60.00%	40.00%
Year 100	GCM maximum	major_restriction	0.00%	0.00%	5.08%	94.92%	same_as_now	0.00%	63.60%	36.40%
Polar Basin Convergent Ecoregion										
Year -10	Satellite data	improvement	97.48%	2.52%	0.00%	0.00%	fewer	100.00%	0.00%	0.00%
Year 0	Satellite data	improvement	88.56%	10.43%	1.01%	0.00%	same_as_now	0.00%	100.00%	0.00%
Year 45	GCM minimum	minor_restriction	1.10%	14.38%	48.19%	36.32%	same_as_now	0.00%	60.00%	40.00%
Year 75	GCM minimum	major_restriction	0.00%	0.00%	23.60%	76.40%	same_as_now	0.00%	60.00%	40.00%
Year 100	GCM minimum	major_restriction	0.00%	0.00%	23.60%	76.40%	same_as_now	0.00%	60.00%	40.00%
Year 45	Ensemble mean	minor_restriction	1.25%	15.49%	49.10%	34.16%	same_as_now	0.00%	60.00%	40.00%
Year 75	Ensemble mean	major_restriction	0.00%	0.00%	17.65%	82.35%	same_as_now	0.00%	60.00%	40.00%
Year 100	Ensemble mean	major_restriction	0.00%	0.24%	22.16%	77.60%	same_as_now	0.00%	60.00%	40.00%
Year 45	GCM maximum	major_restriction	0.29%	4.22%	45.49%	50.00%	same_as_now	0.00%	60.00%	40.00%
Year 75	GCM maximum	major_restriction	0.00%	0.58%	25.18%	74.24%	same_as_now	0.00%	60.00%	40.00%
Year 100	GCM maximum	major_restriction	0.00%	0.35%	23.13%	76.52%	same_as_now	0.00%	60.00%	40.00%

Table 11. Results of the Bayesian network population stressor model, showing the most probable outcome states, and probabilities of each state, for changes in foraging habitat distribution (node D; see Figure 5).

		Node D: Change in Foraging Habitat Distribution					
Time period	Basis	Most probable outcome	P(D= improved availability)	P(D= same as now)	P(D= reduced availability)	P(D= greatly reduced availability)	P(D= unavailable)
		Seasonal Ice Ecoregion					
Year -10	Satellite data	same_as_now	50.00%	50.00%	0.00%	0.00%	0.00%
Year 0	Satellite data	reduced_avail	0.00%	20.00%	60.00%	20.00%	0.00%
Year 45	GCM minimum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 75	GCM minimum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 100	GCM minimum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 45	Ensemble mean	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 75	Ensemble mean	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 100	Ensemble mean	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 45	GCM maximum	reduced_avail	0.00%	20.00%	60.00%	20.00%	0.00%
Year 75	GCM maximum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 100	GCM maximum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
		Archipelago Ecoregion					
Year -10	Satellite data	same_as_now	0.00%	100.00%	0.00%	0.00%	0.00%
Year 0	Satellite data	improved_availability	60.00%	40.00%	0.00%	0.00%	0.00%
Year 45	GCM minimum	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 75	GCM minimum	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 100	GCM minimum	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 45	Ensemble mean	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 75	Ensemble mean	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 100	Ensemble mean	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 45	GCM maximum	improved_availability	60.00%	40.00%	0.00%	0.00%	0.00%
Year 75	GCM maximum	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%
Year 100	GCM maximum	same_as_now	40.00%	60.00%	0.00%	0.00%	0.00%

Table 11 continued.

		Node D: Change in Foraging Habitat Distribution					
Time period	Basis	Most probable outcome	P(D= improved availability)	P(D= same as now)	P(D= reduced availability)	P(D= greatly reduced availability)	P(D= unavailable)
		Polar Basin Divergent Ecoregion					
Year -10	Satellite data	improved_availability	100.00%	0.00%	0.00%	0.00%	0.00%
Year 0	Satellite data	reduced_avail	0.00%	20.00%	80.00%	0.00%	0.00%
Year 45	GCM minimum	unavailable	0.00%	0.00%	0.00%	20.00%	80.00%
Year 75	GCM minimum	unavailable	0.00%	0.00%	0.00%	20.00%	80.00%
Year 100	GCM minimum	unavailable	0.00%	0.00%	0.00%	0.00%	100.00%
Year 45	Ensemble mean	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 75	Ensemble mean	unavailable	0.00%	0.00%	0.00%	20.00%	80.00%
Year 100	Ensemble mean	unavailable	0.00%	0.00%	0.00%	0.00%	100.00%
Year 45	GCM maximum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 75	GCM maximum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
Year 100	GCM maximum	Gr_reduced_avail	0.00%	0.00%	20.00%	40.00%	40.00%
		Polar Basin Convergent Ecoregion					
Year -10	Satellite data	improved_availability	100.00%	0.00%	0.00%	0.00%	0.00%
Year 0	Satellite data	improved_availability	60.00%	40.00%	0.00%	0.00%	0.00%
Year 45	GCM minimum	reduced_avail	0.00%	20.00%	80.00%	0.00%	0.00%
Year 75	GCM minimum	reduced_avail	0.00%	0.00%	100.00%	0.00%	0.00%
Year 100	GCM minimum	reduced_avail	0.00%	0.00%	100.00%	0.00%	0.00%
Year 45	Ensemble mean	reduced_avail	0.00%	30.00%	70.00%	0.00%	0.00%
Year 75	Ensemble mean	reduced_avail	0.00%	0.00%	70.00%	30.00%	0.00%
Year 100	Ensemble mean	reduced_avail	0.00%	20.00%	60.00%	20.00%	0.00%
Year 45	GCM maximum	reduced_avail	0.00%	30.00%	70.00%	0.00%	0.00%
Year 75	GCM maximum	reduced_avail	0.00%	20.00%	60.00%	20.00%	0.00%
Year 100	GCM maximum	reduced_avail	0.00%	20.00%	60.00%	20.00%	0.00%

Table 12. Results of the Bayesian network population stressor model, showing the most probable outcome states, and probabilities of each state, for disease/predation and other disturbance factors variables (nodes A4, A6; see Figure 5).

		Node A4: Factor C: Disease, predation			Node A6: Factor E: Other factors (natural or man-made)				
Time period	Basis	Most probable outcome	P(A4= same as now)	P(A4= worse)	Most probable outcome	P(A6= improve-ment)	P(A6= no effect)	P(A6= minor restriction)	P(A6= major restriction)
Seasonal Ice Ecoregion									
Year -10	Satellite data	same_as_now	100.00%	0.00%	improvement	84.80%	15.20%	0.00%	0.00%
Year 0	Satellite data	same_as_now	100.00%	0.00%	no_effect	0.00%	100.00%	0.00%	0.00%
Year 45	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	13.00%	87.00%
Year 75	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 45	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	13.00%	87.00%
Year 75	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 45	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	13.00%	87.00%
Year 75	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Archipelago Ecoregion									
Year -10	Satellite data	same_as_now	100.00%	0.00%	major_restriction	4.80%	20.00%	34.80%	40.40%
Year 0	Satellite data	same_as_now	100.00%	0.00%	no_effect	0.00%	100.00%	0.00%	0.00%
Year 45	GCM minimum	worse	30.00%	70.00%	major_restriction	0.00%	0.00%	28.00%	72.00%
Year 75	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 45	Ensemble mean	worse	30.00%	70.00%	major_restriction	0.00%	0.00%	28.00%	72.00%
Year 75	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 45	GCM maximum	worse	30.00%	70.00%	major_restriction	0.00%	0.00%	28.00%	72.00%
Year 75	GCM maximum	worse	30.00%	70.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%

Table 12 continued.

Time period	Basis	Node A4: Factor C: Disease, predation			Node A6: Factor E: Other factors (natural or man-made)				
		Most probable outcome	P(A4= same as now)	P(A4= worse)	Most probable outcome	P(A6= improve-ment)	P(A6= no effect)	P(A6= minor restriction)	P(A6= major restriction)
Polar Basin Divergent Ecoregion									
Year -10	Satellite data	same_as_now	100.00%	0.00%	improvement	100.00%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	100.00%	0.00%	no_effect	0.00%	100.00%	0.00%	0.00%
Year 45	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 75	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	3.00%	97.00%
Year 100	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	15.00%	85.00%
Year 45	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 75	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	15.00%	85.00%
Year 45	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 75	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	18.00%	82.00%
Polar Basin Convergent Ecoregion									
Year -10	Satellite data	same_as_now	100.00%	0.00%	improvement	100.00%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	100.00%	0.00%	no_effect	0.00%	100.00%	0.00%	0.00%
Year 45	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 75	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM minimum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 45	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 75	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	Ensemble mean	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 45	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 75	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%
Year 100	GCM maximum	worse	0.00%	100.00%	major_restriction	0.00%	0.00%	0.00%	100.00%

Table 13. Results of the Bayesian network population stressor model, showing the most probable outcome states, and probabilities of each state, for reproduction and vital rates (nodes U, L2; see Figure 5).

		Node U: Reproduction				Node L2: Vital Rates			
Time period	Basis	Most probable outcome	P(U= increased)	P(U= same as now)	P(U= decreased)	Most probable outcome	P(L2 =improve)	P(L2= same as now)	P(L2= decline)
				Seasonal Ice Ecoregion					
Year -10	Satellite data	increased	59.68%	33.42%	6.90%	improve	92.53%	7.00%	0.47%
Year 0	Satellite data	same_as_now	25.59%	41.59%	32.82%	same_as_now	27.38%	41.72%	30.90%
Year 45	GCM minimum	decreased	1.78%	23.47%	74.75%	decline	0.25%	7.04%	92.71%
Year 75	GCM minimum	decreased	0.38%	20.76%	78.87%	decline	0.03%	1.47%	98.50%
Year 100	GCM minimum	decreased	0.38%	20.76%	78.87%	decline	0.03%	1.47%	98.50%
Year 45	Ensemble mean	decreased	1.78%	23.47%	74.75%	decline	0.25%	7.04%	92.71%
Year 75	Ensemble mean	decreased	0.38%	20.76%	78.87%	decline	0.03%	1.47%	98.50%
Year 100	Ensemble mean	decreased	0.38%	20.76%	78.87%	decline	0.03%	1.47%	98.50%
Year 45	GCM maximum	decreased	5.67%	30.90%	63.43%	decline	1.01%	22.54%	76.45%
Year 75	GCM maximum	decreased	0.78%	21.57%	77.65%	decline	0.05%	3.07%	96.87%
Year 100	GCM maximum	decreased	0.78%	21.57%	77.65%	decline	0.05%	3.07%	96.87%
				Archipelago Ecoregion					
Year -10	Satellite data	same_as_now	34.41%	45.14%	20.44%	same_as_now	39.94%	47.09%	12.97%
Year 0	Satellite data	increased	57.07%	34.96%	7.96%	improve	86.86%	12.04%	1.11%
Year 45	GCM minimum	same_as_now	30.18%	43.98%	25.84%	same_as_now	33.47%	45.72%	20.80%
Year 75	GCM minimum	decreased	10.62%	36.67%	52.71%	decline	5.17%	35.07%	59.76%
Year 100	GCM minimum	decreased	10.62%	36.67%	52.71%	decline	5.17%	35.07%	59.76%
Year 45	Ensemble mean	same_as_now	30.18%	43.98%	25.84%	same_as_now	33.47%	45.72%	20.80%
Year 75	Ensemble mean	decreased	11.35%	37.15%	51.50%	decline	6.07%	35.97%	57.96%
Year 100	Ensemble mean	decreased	10.62%	36.67%	52.71%	decline	5.17%	35.07%	59.76%
Year 45	GCM maximum	same_as_now	35.03%	43.12%	21.85%	improve	42.54%	41.66%	15.80%
Year 75	GCM maximum	same_as_now	30.18%	43.98%	25.84%	same_as_now	33.47%	45.72%	20.80%
Year 100	GCM maximum	decreased	10.62%	36.67%	52.71%	decline	5.17%	35.07%	59.76%

Table 13 continued.

Time period	Basis	Node U: Reproduction				Node L2: Vital Rates			
		Most probable outcome	P(U= increased)	P(U= same as now)	P(U= decreased)	Most probable outcome	P(L2 =improve)	P(L2= same as now)	P(L2= decline)
				Polar Basin Divergent Ecoregion					
Year -10	Satellite data	increased	90.93%	9.07%	0.00%	improve	99.72%	0.28%	0.00%
Year 0	Satellite data	same_as_now	10.57%	77.96%	11.47%	same_as_now	30.20%	53.67%	16.12%
Year 45	GCM minimum	decreased	0.00%	0.00%	100.00%	decline	0.00%	0.00%	100.00%
Year 75	GCM minimum	decreased	0.00%	0.00%	100.00%	decline	0.00%	0.00%	100.00%
Year 100	GCM minimum	decreased	0.00%	0.00%	100.00%	decline	0.00%	0.00%	100.00%
Year 45	Ensemble mean	decreased	0.00%	1.28%	98.72%	decline	0.00%	3.09%	96.91%
Year 75	Ensemble mean	decreased	0.00%	0.00%	100.00%	decline	0.00%	0.00%	100.00%
Year 100	Ensemble mean	decreased	0.00%	0.00%	100.00%	decline	0.00%	0.00%	100.00%
Year 45	GCM maximum	decreased	0.00%	1.28%	98.72%	decline	0.00%	3.09%	96.91%
Year 75	GCM maximum	decreased	0.00%	0.61%	99.39%	decline	0.00%	1.44%	98.56%
Year 100	GCM maximum	decreased	0.00%	0.61%	99.39%	decline	0.00%	1.44%	98.56%
				Polar Basin Convergent Ecoregion					
Year -10	Satellite data	increased	100.00%	0.00%	0.00%	improve	97.98%	2.02%	0.00%
Year 0	Satellite data	increased	68.30%	31.34%	0.36%	improve	89.62%	9.73%	0.66%
Year 45	GCM minimum	decreased	0.15%	30.35%	69.49%	decline	0.91%	27.51%	71.58%
Year 75	GCM minimum	decreased	0.00%	22.83%	77.17%	decline	0.00%	7.04%	92.96%
Year 100	GCM minimum	decreased	0.00%	22.83%	77.17%	decline	0.00%	7.04%	92.96%
Year 45	Ensemble mean	decreased	7.45%	40.74%	51.81%	decline	2.03%	29.91%	68.06%
Year 75	Ensemble mean	decreased	0.00%	22.12%	77.88%	decline	0.00%	5.26%	94.74%
Year 100	Ensemble mean	decreased	1.82%	32.73%	65.45%	decline	0.13%	7.24%	92.63%
Year 45	GCM maximum	decreased	4.58%	36.77%	58.65%	decline	0.68%	18.32%	81.00%
Year 75	GCM maximum	decreased	2.13%	33.19%	64.68%	decline	0.16%	8.51%	91.33%
Year 100	GCM maximum	decreased	1.92%	32.88%	65.20%	decline	0.14%	7.65%	92.21%

Table 14. Projected outcomes from Bayesian network population stressor model showing probabilities of overall outcome states resulting when all human factors were fixed at 'same as now' or 'fewer than now.'

		"Influence Run" #1						"Influence Run" #2					
		Outcome forcing Node A1 = "same as now" and Node A6 = "no effect", for Years 45, 75, 100						Outcome forcing Node A1 = "fewer" and Node A6 = "improvement", for Years 45, 75, 100					
		Node D1: Overall Population Outcome						Node D1: Overall Population Outcome					
Time period	Basis	most-prob D1	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)	most-prob D1	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)
Seasonal Ice Ecoregion													
Year -10	Satellite data	larger	93.92%	5.75%	0.30%	0.02%	0.00%	larger	93.92%	5.75%	0.30%	0.02%	0.00%
Year 0	Satellite data	same_as_now	21.85%	43.72%	18.98%	8.37%	7.07%	same_as_now	21.85%	43.72%	18.98%	8.37%	7.07%
Year 45	GCM minimum	extinct	0.10%	1.46%	22.80%	21.20%	54.40%	extinct	0.11%	8.43%	31.70%	14.00%	45.80%
Year 75	GCM minimum	extinct	0.01%	0.24%	16.20%	20.20%	63.30%	extinct	0.01%	3.89%	27.90%	14.70%	53.50%
Year 100	GCM minimum	extinct	0.01%	0.52%	18.60%	18.70%	62.20%	extinct	0.10%	4.98%	28.10%	13.30%	53.50%
Year 45	Ensemble mean	extinct	0.10%	1.46%	22.80%	21.20%	54.40%	extinct	0.11%	8.43%	31.70%	14.00%	45.80%
Year 75	Ensemble mean	extinct	0.01%	0.24%	16.20%	20.20%	63.30%	extinct	0.01%	3.89%	27.90%	14.70%	53.50%
Year 100	Ensemble mean	extinct	0.01%	0.24%	16.20%	20.20%	63.30%	extinct	0.01%	3.89%	27.90%	14.70%	53.50%
Year 45	GCM maximum	smaller	0.45%	5.16%	39.50%	22.80%	32.00%	smaller	0.46%	21.10%	40.30%	11.90%	26.30%
Year 75	GCM maximum	extinct	0.02%	0.52%	18.50%	20.80%	60.20%	extinct	0.02%	5.20%	29.50%	14.50%	50.80%
Year 100	GCM maximum	extinct	0.02%	0.52%	18.50%	20.80%	60.20%	extinct	0.02%	5.20%	29.50%	14.50%	50.80%
Archipelago Ecoregion													
Year -10	Satellite data	same_as_now	22.51%	34.73%	31.48%	8.72%	2.56%	same_as_now	22.51%	34.73%	31.48%	8.72%	2.56%
Year 0	Satellite data	larger	69.48%	29.26%	1.06%	0.19%	0.00%	larger	69.48%	29.26%	1.06%	0.19%	0.00%
Year 45	GCM minimum	smaller	19.70%	29.40%	39.70%	8.90%	2.26%	same_as_now	24.30%	44.10%	25.40%	4.62%	1.55%
Year 75	GCM minimum	smaller	2.54%	10.10%	46.40%	19.00%	22.00%	smaller	2.55%	31.80%	38.50%	9.30%	17.80%
Year 100	GCM minimum	smaller	2.54%	10.10%	46.40%	19.00%	22.00%	smaller	2.55%	31.80%	38.50%	9.30%	17.80%
Year 45	Ensemble mean	smaller	19.70%	29.40%	39.70%	8.90%	2.26%	same_as_now	24.30%	44.10%	25.40%	4.62%	1.55%
Year 75	Ensemble mean	smaller	2.99%	10.50%	46.50%	23.50%	16.50%	smaller	2.99%	32.10%	38.90%	13.20%	12.70%
Year 100	Ensemble mean	smaller	2.54%	10.10%	46.40%	19.00%	22.00%	smaller	2.55%	31.80%	38.50%	9.30%	17.80%
Year 45	GCM maximum	smaller	25.10%	29.90%	36.80%	6.72%	1.55%	same_as_now	30.00%	42.10%	23.40%	3.43%	1.03%
Year 75	GCM maximum	smaller	19.70%	29.40%	39.70%	8.90%	2.26%	same_as_now	24.30%	44.10%	25.40%	4.62%	1.55%
Year 100	GCM maximum	smaller	2.54%	10.10%	46.40%	19.00%	22.00%	smaller	2.55%	31.80%	38.50%	9.30%	17.80%

Table 14 continued.

		"Influence Run" #1						"Influence Run" #2					
		Outcome forcing Node A1 = "same as now" and Node A6 = "no effect", for Years 45, 75, 100						Outcome forcing Node A1 = "fewer" and Node A6 = "improvement", for Years 45, 75, 100					
		Node D1: Overall Population Outcome						Node D1: Overall Population Outcome					
Time period	Basis	most-prob D1	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)	most-prob D1	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)
Polar Basin Divergent Ecoregion													
Year -10	Satellite data	larger	99.78%	0.22%	0.00%	0.00%	0.00%	larger	99.78%	0.22%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	24.16%	56.60%	13.36%	4.73%	1.14%	same_as_now	24.16%	56.60%	13.36%	4.73%	1.14%
Year 45	GCM minimum	extinct	0.00%	0.00%	15.90%	25.30%	58.80%	extinct	0.00%	2.70%	29.20%	19.10%	49.00%
Year 75	GCM minimum	extinct	0.00%	0.00%	15.90%	25.30%	58.80%	extinct	0.00%	2.70%	29.20%	19.10%	49.00%
Year 100	GCM minimum	extinct	0.00%	0.00%	15.90%	25.30%	58.80%	extinct	0.00%	2.70%	29.20%	19.10%	49.00%
Year 45	Ensemble mean	extinct	0.00%	0.53%	20.10%	26.00%	53.40%	extinct	0.00%	5.28%	31.90%	18.50%	44.30%
Year 75	Ensemble mean	extinct	0.00%	0.00%	15.90%	25.30%	58.80%	extinct	0.00%	2.70%	29.20%	19.10%	49.00%
Year 100	Ensemble mean	extinct	0.00%	0.00%	15.90%	25.30%	58.80%	extinct	0.00%	2.70%	29.20%	19.10%	49.00%
Year 45	GCM maximum	extinct	0.00%	0.53%	20.10%	26.00%	53.40%	extinct	0.00%	5.28%	31.90%	18.50%	44.30%
Year 75	GCM maximum	extinct	0.00%	0.22%	18.00%	25.70%	56.10%	extinct	0.00%	3.91%	30.60%	18.80%	46.70%
Year 100	GCM maximum	extinct	0.00%	0.22%	18.00%	25.70%	56.10%	extinct	0.00%	3.91%	30.60%	18.80%	46.70%
Polar Basin Convergent Ecoregion													
Year -10	Satellite data	larger	98.39%	1.61%	0.00%	0.00%	0.00%	larger	98.39%	1.61%	0.00%	0.00%	0.00%
Year 0	Satellite data	larger	71.69%	27.49%	0.63%	0.19%	0.00%	larger	71.69%	27.49%	0.63%	0.19%	0.00%
Year 45	GCM minimum	smaller	0.46%	6.31%	44.10%	30.70%	18.40%	smaller	0.46%	24.70%	43.20%	17.80%	13.80%
Year 75	GCM minimum	extinct	0.00%	1.13%	24.60%	22.30%	51.90%	extinct	0.00%	8.56%	33.90%	14.00%	43.50%
Year 100	GCM minimum	extinct	0.00%	1.13%	24.60%	22.30%	51.90%	extinct	0.00%	8.56%	33.90%	14.00%	43.50%
Year 45	Ensemble mean	smaller	0.95%	7.12%	44.70%	30.40%	16.80%	smaller	0.96%	26.10%	42.70%	17.80%	12.50%
Year 75	Ensemble mean	extinct	0.00%	0.82%	23.00%	26.10%	50.00%	extinct	0.00%	6.98%	33.90%	17.70%	41.50%
Year 100	Ensemble mean	extinct	0.04%	1.24%	24.30%	22.10%	52.40%	extinct	0.04%	8.54%	33.40%	14.00%	44.00%
Year 45	GCM maximum	smaller	0.28%	3.47%	37.70%	34.60%	24.00%	smaller	0.29%	16.70%	43.30%	21.40%	18.30%
Year 75	GCM maximum	rare	0.05%	1.38%	28.50%	35.60%	34.50%	smaller	0.05%	9.12%	39.40%	24.30%	27.10%
Year 100	GCM maximum	extinct	0.04%	1.28%	25.60%	26.40%	46.60%	extinct	0.05%	8.73%	35.40%	17.30%	38.50%

Table 15. Projected outcomes from Bayesian network population stressor model showing probabilities of overall outcome states resulting when all human factors were fixed at uniform.

This means we made no assumptions about whether human factors would have more or less influences on polar bears in the future. We allowed total uncertainty in these nodes.

		"Influence Run" #3					
		Outcome forcing all input nodes to uniform (default prior) probabilities, except ice nodes N, B & C, and Ecoregion node M, for Years 45, 75, 100					
		Node D1: Overall Population Outcome					
Time period	Basis	most-prob D1	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)
		Seasonal Ice Ecoregion					
Year -10	Satellite data	larger	93.92%	5.75%	0.30%	0.02%	0.00%
Year 0	Satellite data	same_as_now	21.85%	43.72%	18.98%	8.37%	7.07%
Year 45	GCM minimum	extinct	0.25%	2.61%	14.70%	13.30%	69.10%
Year 75	GCM minimum	extinct	0.05%	1.42%	11.90%	12.70%	74.00%
Year 100	GCM minimum	extinct	0.05%	1.42%	11.90%	12.70%	74.00%
Year 45	Ensemble mean	extinct	0.25%	2.61%	14.70%	13.30%	69.10%
Year 75	Ensemble mean	extinct	0.05%	1.42%	11.90%	12.70%	74.00%
Year 100	Ensemble mean	extinct	0.05%	1.42%	11.90%	12.70%	74.00%
Year 45	GCM maximum	extinct	1.06%	7.63%	27.20%	16.50%	47.60%
Year 75	GCM maximum	extinct	0.05%	1.42%	11.90%	12.70%	74.00%
Year 100	GCM maximum	extinct	0.05%	1.42%	11.90%	12.70%	74.00%
		Archipelago Ecoregion					
Year -10	Satellite data	same_as_now	22.51%	34.73%	31.48%	8.72%	2.56%
Year 0	Satellite data	larger	69.48%	29.26%	1.06%	0.19%	0.00%
Year 45	GCM minimum	smaller	6.34%	17.20%	39.80%	15.30%	21.40%
Year 75	GCM minimum	extinct	2.86%	12.50%	34.00%	16.00%	34.60%
Year 100	GCM minimum	extinct	2.86%	12.50%	34.00%	16.00%	34.60%
Year 45	Ensemble mean	smaller	6.34%	17.20%	39.80%	15.30%	21.40%
Year 75	Ensemble mean	extinct	2.86%	12.50%	34.00%	16.00%	34.60%
Year 100	Ensemble mean	extinct	2.86%	12.50%	34.00%	16.00%	34.60%
Year 45	GCM maximum	smaller	8.55%	19.90%	41.60%	13.70%	16.20%
Year 75	GCM maximum	smaller	6.34%	17.20%	39.80%	15.30%	21.40%
Year 100	GCM maximum	extinct	2.86%	12.50%	34.00%	16.00%	34.60%

Table 15 continued.

		"Influence Run" #3					
		Outcome forcing all input nodes to uniform (default prior) probabilities, except ice nodes N, B & C, and Ecoregion node M, for Years 45, 75, 100					
		Node D1: Overall Population Outcome					
Time period	Basis	most-prob D1	P(D1= larger)	P(D1= same as now)	P(D1= smaller)	P(D1= rare)	P(D1= extinct)
Polar Basin Divergent Ecoregion							
Year -10	Satellite data	larger	99.78%	0.22%	0.00%	0.00%	0.00%
Year 0	Satellite data	same_as_now	24.16%	56.60%	13.36%	4.73%	1.14%
Year 45	GCM minimum	extinct	0.00%	0.59%	8.78%	11.30%	79.30%
Year 75	GCM minimum	extinct	0.00%	0.53%	8.53%	11.20%	79.70%
Year 100	GCM minimum	extinct	0.00%	0.53%	8.53%	11.20%	79.70%
Year 45	Ensemble mean	extinct	0.17%	2.47%	14.70%	13.50%	69.20%
Year 75	Ensemble mean	extinct	0.00%	0.59%	8.78%	11.30%	79.30%
Year 100	Ensemble mean	extinct	0.00%	0.53%	8.53%	11.20%	79.70%
Year 45	GCM maximum	extinct	0.17%	2.47%	14.70%	13.50%	69.20%
Year 75	GCM maximum	extinct	0.03%	1.36%	11.80%	12.70%	74.10%
Year 100	GCM maximum	extinct	0.03%	1.36%	11.80%	12.70%	74.10%
Polar Bear Convergent Ecoregion							
Year -10	Satellite data	larger	98.39%	1.61%	0.00%	0.00%	0.00%
Year 0	Satellite data	larger	71.69%	27.49%	0.63%	0.19%	0.00%
Year 45	GCM minimum	extinct	0.91%	8.60%	30.20%	17.50%	42.80%
Year 75	GCM minimum	extinct	0.14%	4.15%	22.60%	17.40%	55.70%
Year 100	GCM minimum	extinct	0.14%	4.15%	22.60%	17.40%	55.70%
Year 45	Ensemble mean	extinct	1.31%	9.28%	30.90%	17.30%	41.20%
Year 75	Ensemble mean	extinct	0.10%	3.16%	18.80%	15.70%	62.30%
Year 100	Ensemble mean	extinct	0.34%	4.29%	21.10%	16.00%	58.30%
Year 45	GCM maximum	extinct	0.46%	5.31%	24.10%	17.00%	53.10%
Year 75	GCM maximum	extinct	0.34%	4.29%	21.10%	16.00%	58.30%
Year 100	GCM maximum	extinct	0.34%	4.29%	21.10%	16.00%	58.30%

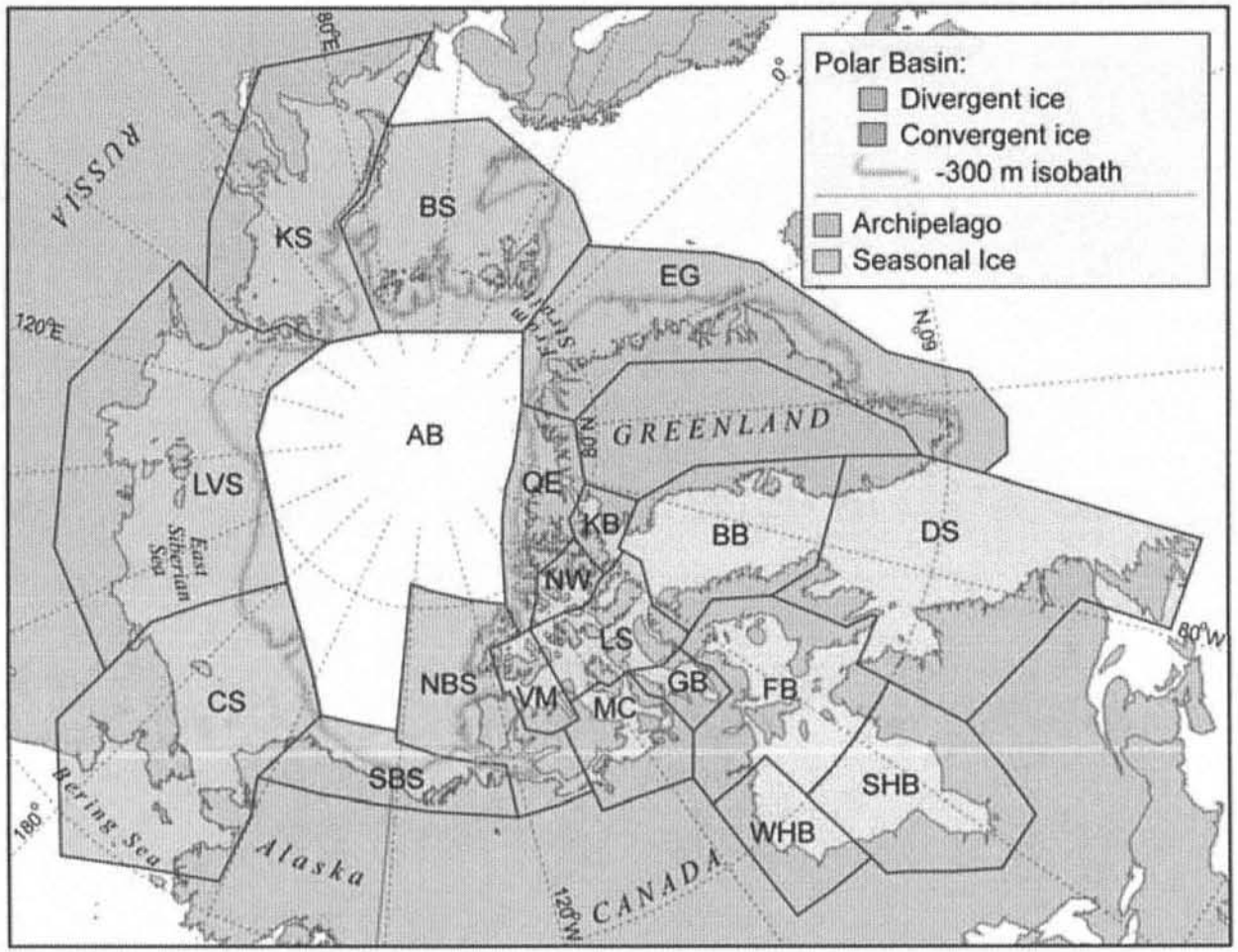


Figure 1. Map of four polar bear ecoregions to which we refer in this report. Ecoregions were established by grouping recognized subpopulations which share seasonal patterns of ice motion and distribution.

The polar basin Divergent Ice Ecoregion (purple) includes: Southern Beaufort Sea (SBS), Chukchi Sea (CS), Laptev Sea (LVS), Kara Sea (KS), and the Barents Sea (BS). The polar basin Convergent Ice Ecoregion (blue) includes: East Greenland (EG), Queen Elizabeth (QE), Northern Beaufort Sea (NBS). The Seasonal Ice Ecoregion (Green) includes: Southern Hudson Bay (SHB), Western Hudson Bay (WHB), Foxe Basin (FB), Davis Strait (DS), and Baffin Bay (BB). The Archipelago Ecoregion (yellow) includes: Gulf of Boothia (GB), M'Clintock Channel (MC), Lancaster Sound (LS, orange), Viscount-Melville Sound (VM), Norwegian Bay (NW), and Kane Basin (KB).

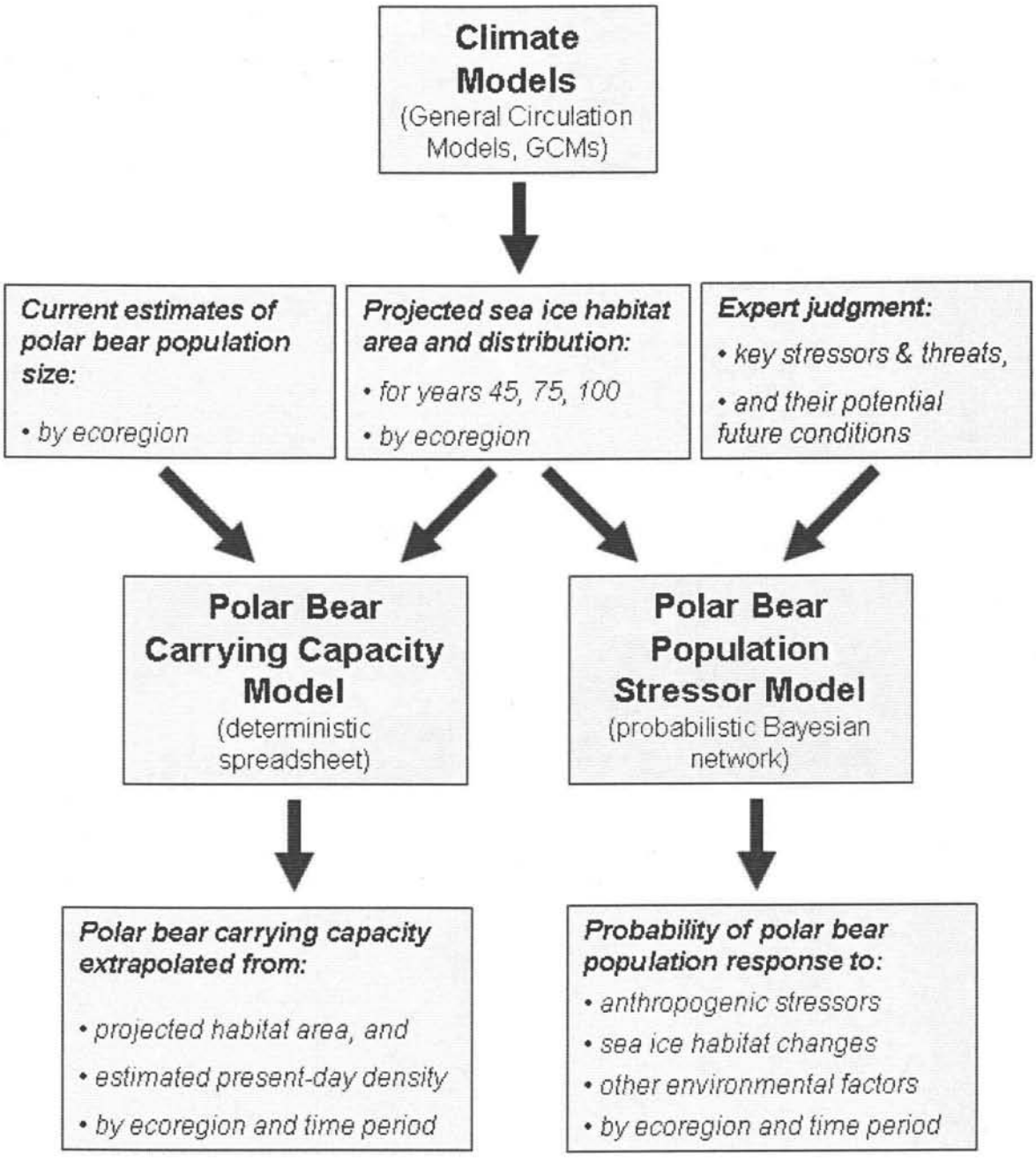


Figure 2. Linkages followed in this report, from available information on sea ice polar bears and other environmental correlates, and leading to projections of future polar bear carrying capacity and overall population outcome.

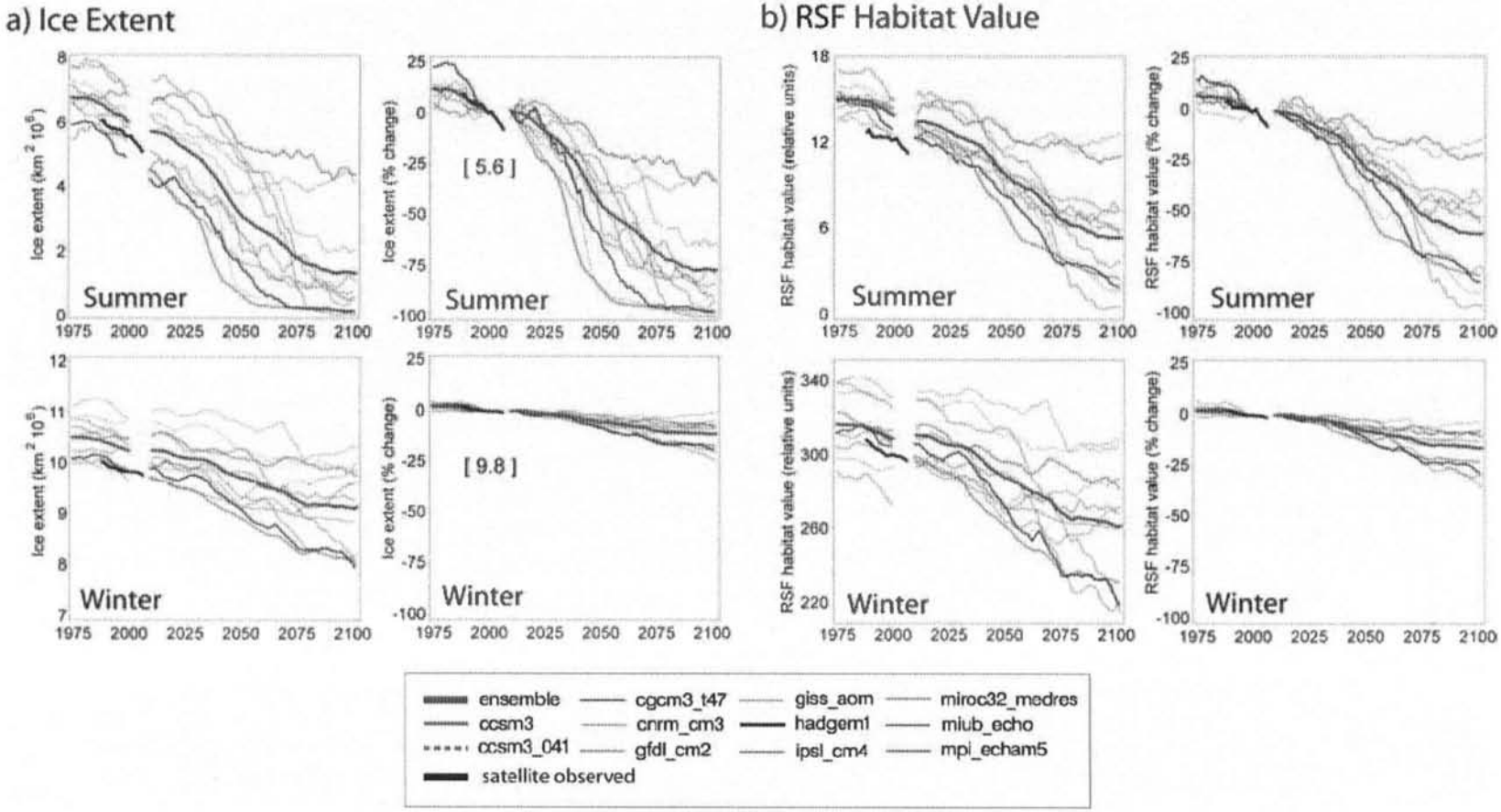


Figure 3. (a) Average summer and winter sea ice extent in the entire polar basin (divergent and convergent regions) expressed in square km (left) and as a percent change relative to each model's 1990-1999 mean for 20th century hindcasts (right). (b) Average RSF habitat values for summer and winter expressed in raw RSF units (left) and percent change to each model's 1990-1999 mean for the 20th century hindcasts (right).

Black line is the PMW satellite record of actual observations. Numbers in brackets are seasonal mean of values for 1990-1999. Note most hindcast model results overestimated the amount of habitat available during the observation period.

Figure 4. The basic influence diagram for the Bayesian network polar bear population stressor model showing the role of 4 listing factor categories used by U.S. Fish and Wildlife Service.

The final output node, overall population outcome, represents expected the joint polar bear population numerical and distribution responses to multiple stressors and environmental conditions.

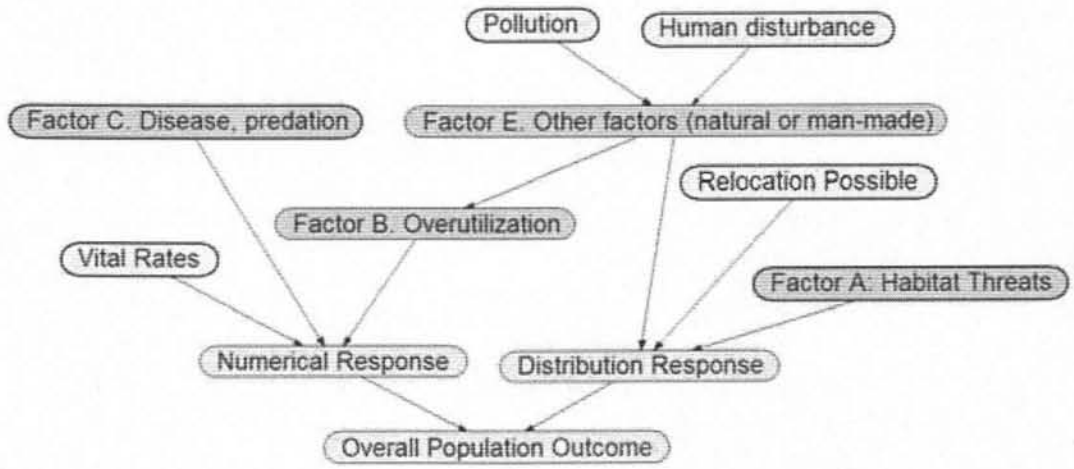


Figure 5. The full Bayesian network population stressor model developed to evaluate overall population outcome.

Input nodes are set to initial uniform probabilities. The model is solved by specifying input node values for each combination of 4 geographic regions, 5 time periods, and 4 global climate modeling scenarios or data sources (input data are specified in Table 3).

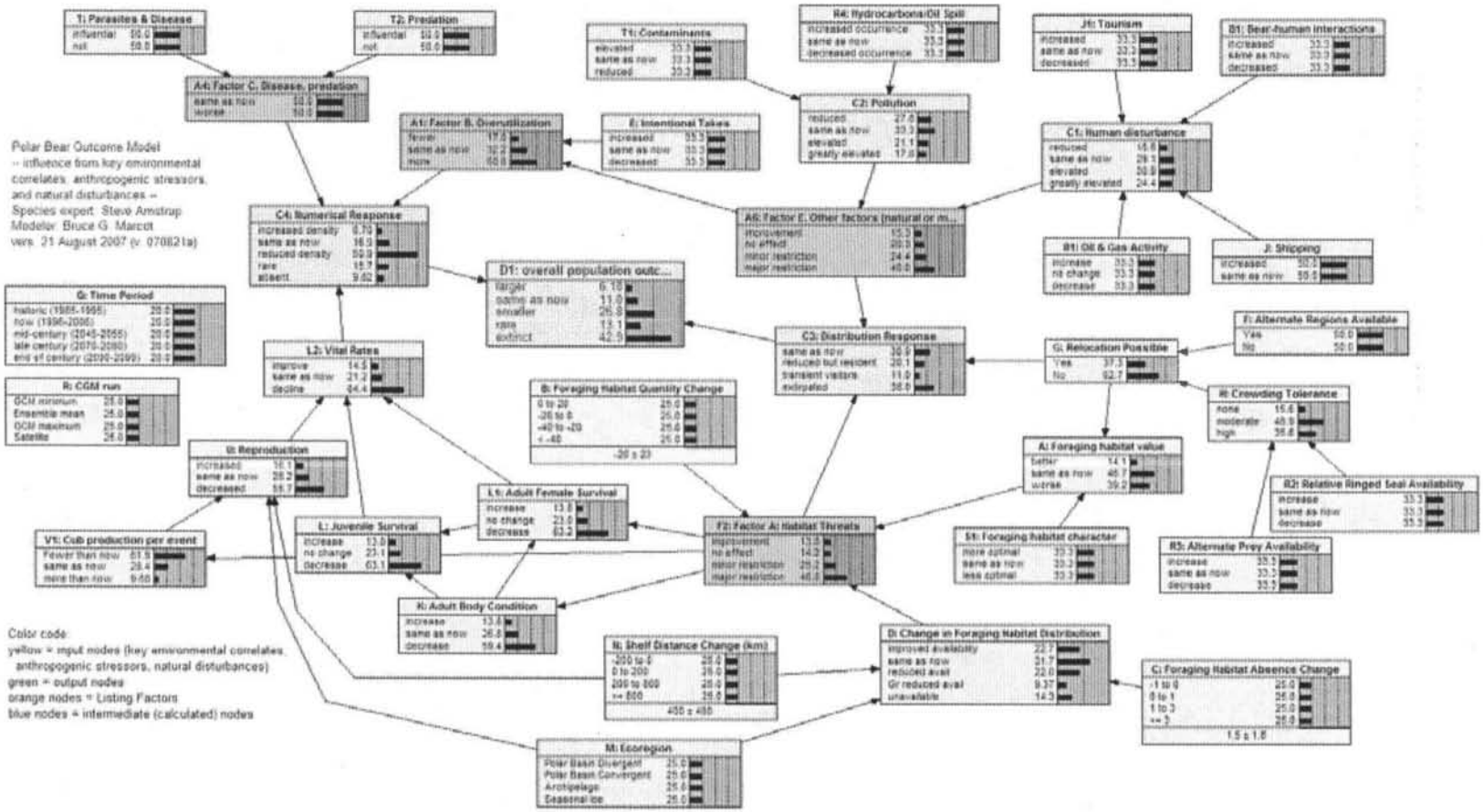


Figure 6. Annual (12-month sum) polar bear habitat area $H_{t,G}$ at t years -10 and 0 from satellite data and 0, 45, 75, and 100 from minimum, ensemble mean, and maximum global change model (GCM) runs, in four geographic regions G and all regions combined (see Table 4).

Optimal (selected) habitat areas (from resource selection function [RSF] models) are shown for the two Polar Basin regions.

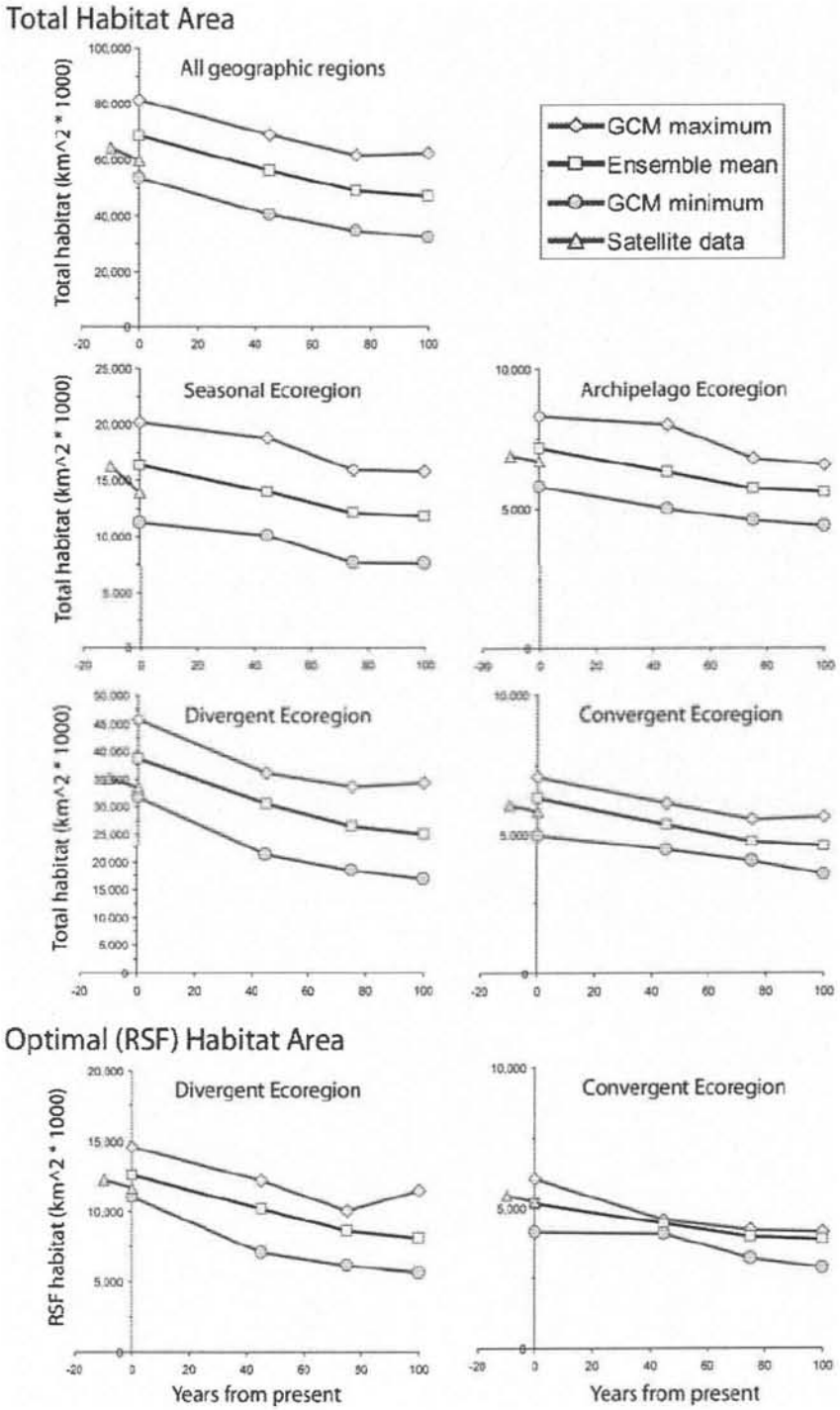


Figure 7. Percent change in polar bear habitat amounts CH_{tG} at t years -10 and 0 from satellite data and 0, 45, 75, and 100 from minimum, ensemble mean, and maximum global change model (GCM) runs, in four geographic regions G and all regions combined, normalized to 0% change at year 0 (see Table 4).

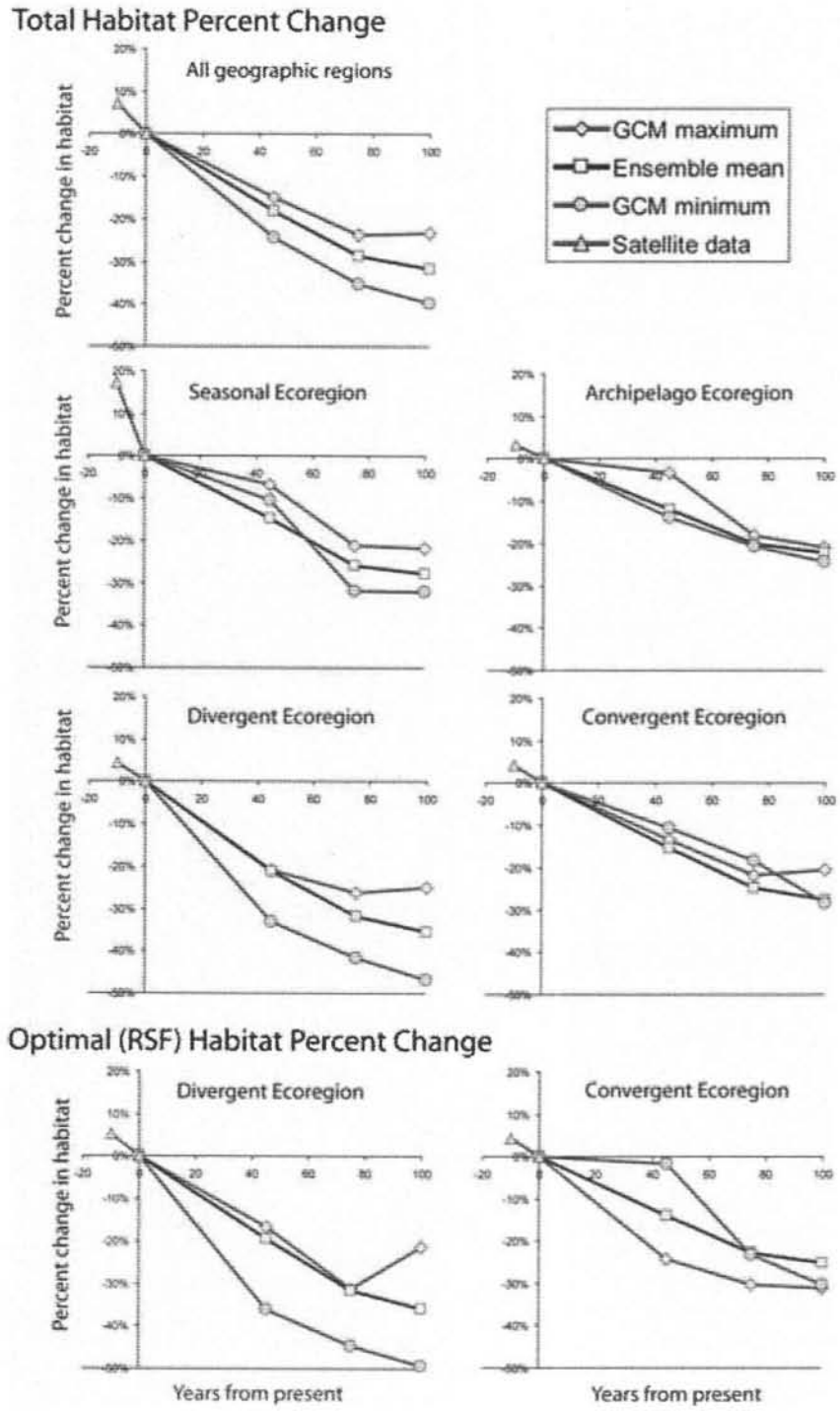


Figure 8. Normalized polar bear carrying capacity $K_{t,G}^{norm}$ at t years -10 and 0 based on habitat amount from satellite data at year -10, empirical bear counts at year 0, and habitat amounts at years 0, 45, 75, and 100 from minimum, ensemble mean, and maximum global change model (GCM) runs, in four geographic regions G and all regions combined (see Table 6).

GCM-based values are normalized to year 0 empirical counts. Note that all graphs are plotted on the same y-axis scale for comparison.

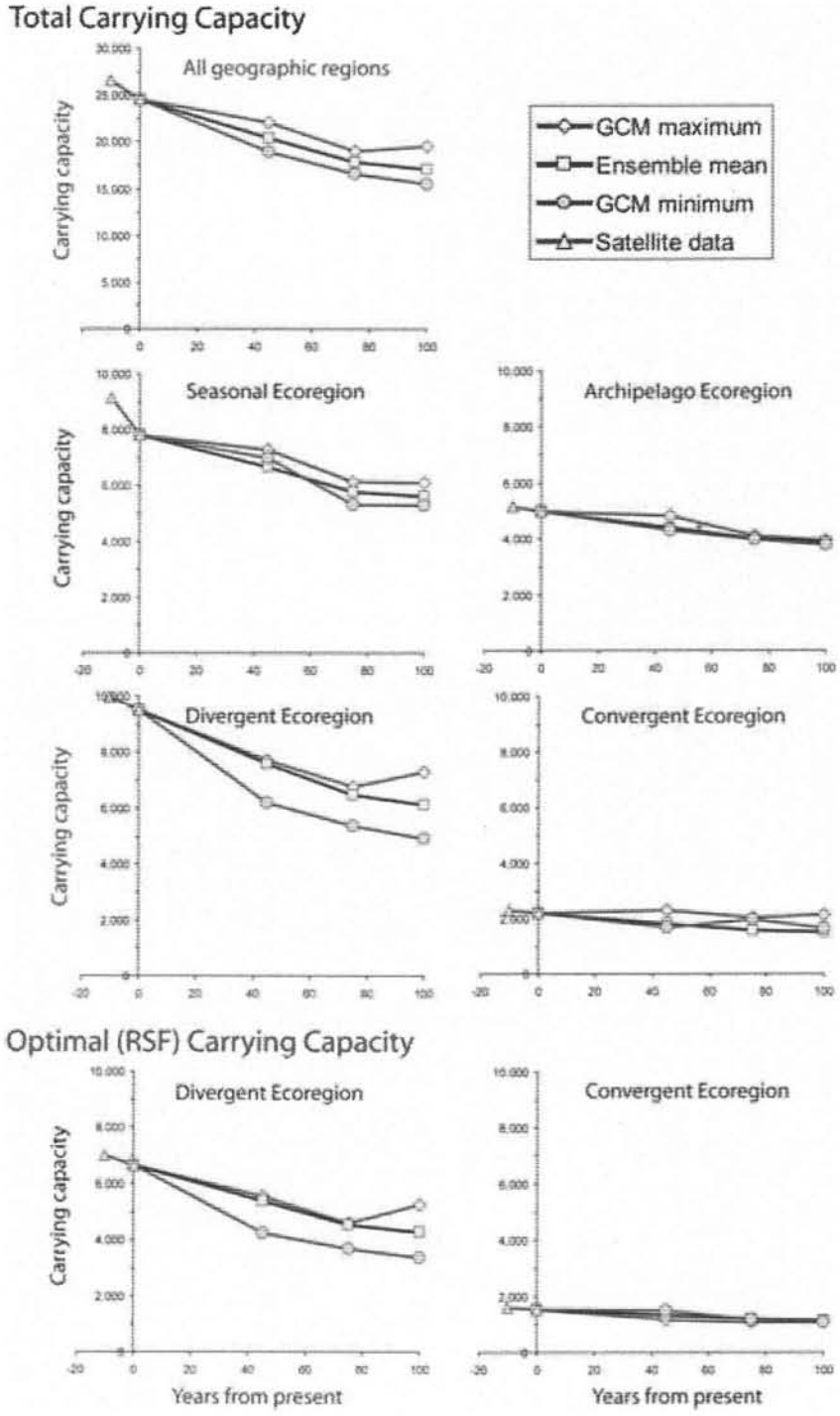
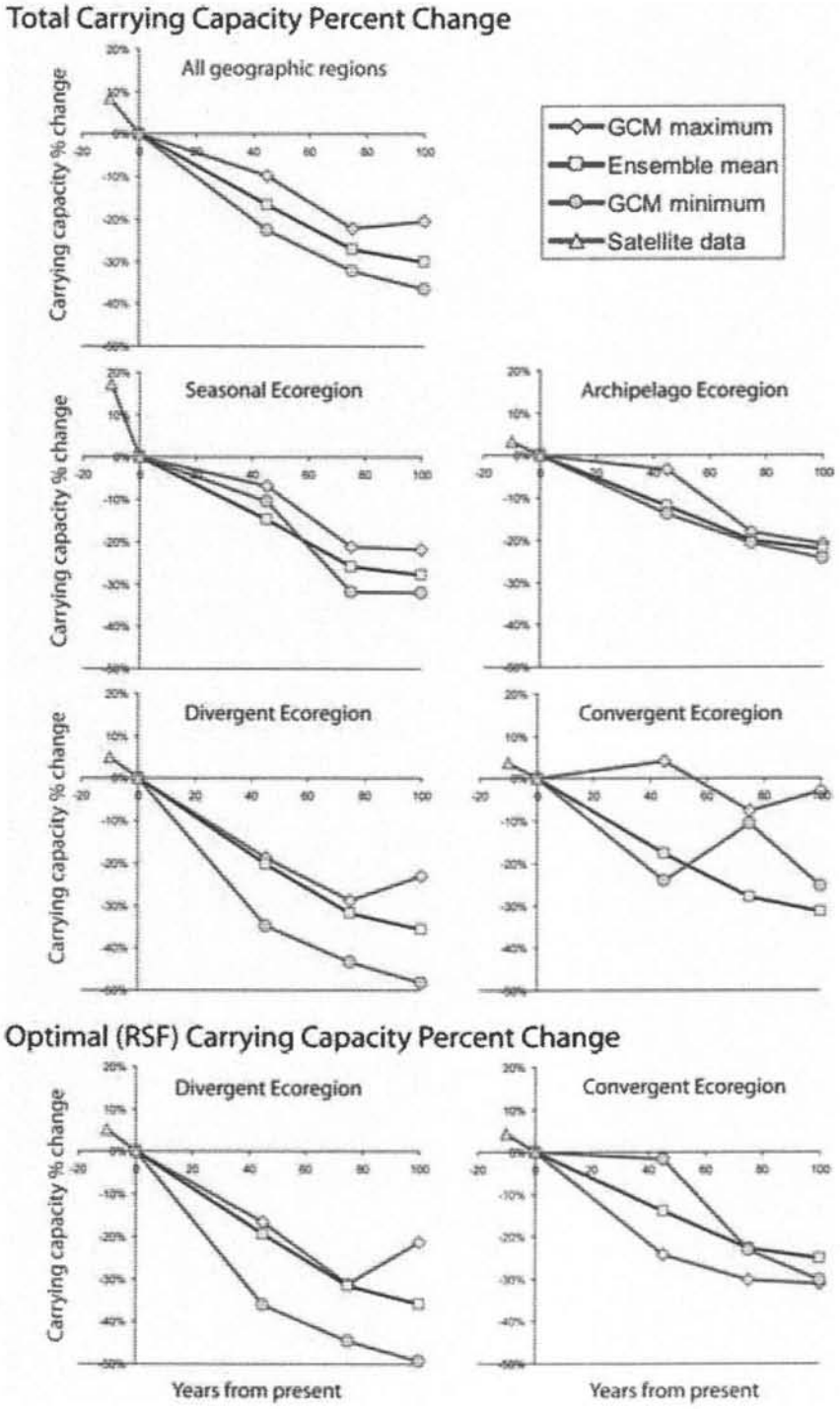


Figure 9. Polar bear carrying capacity trends $CK_{t,G}$ at t years -10 and 0 based on carrying capacity values from Figure 8, in four geographic regions G and all regions combined, normalized to 0% change at year 0 (see Table 6).



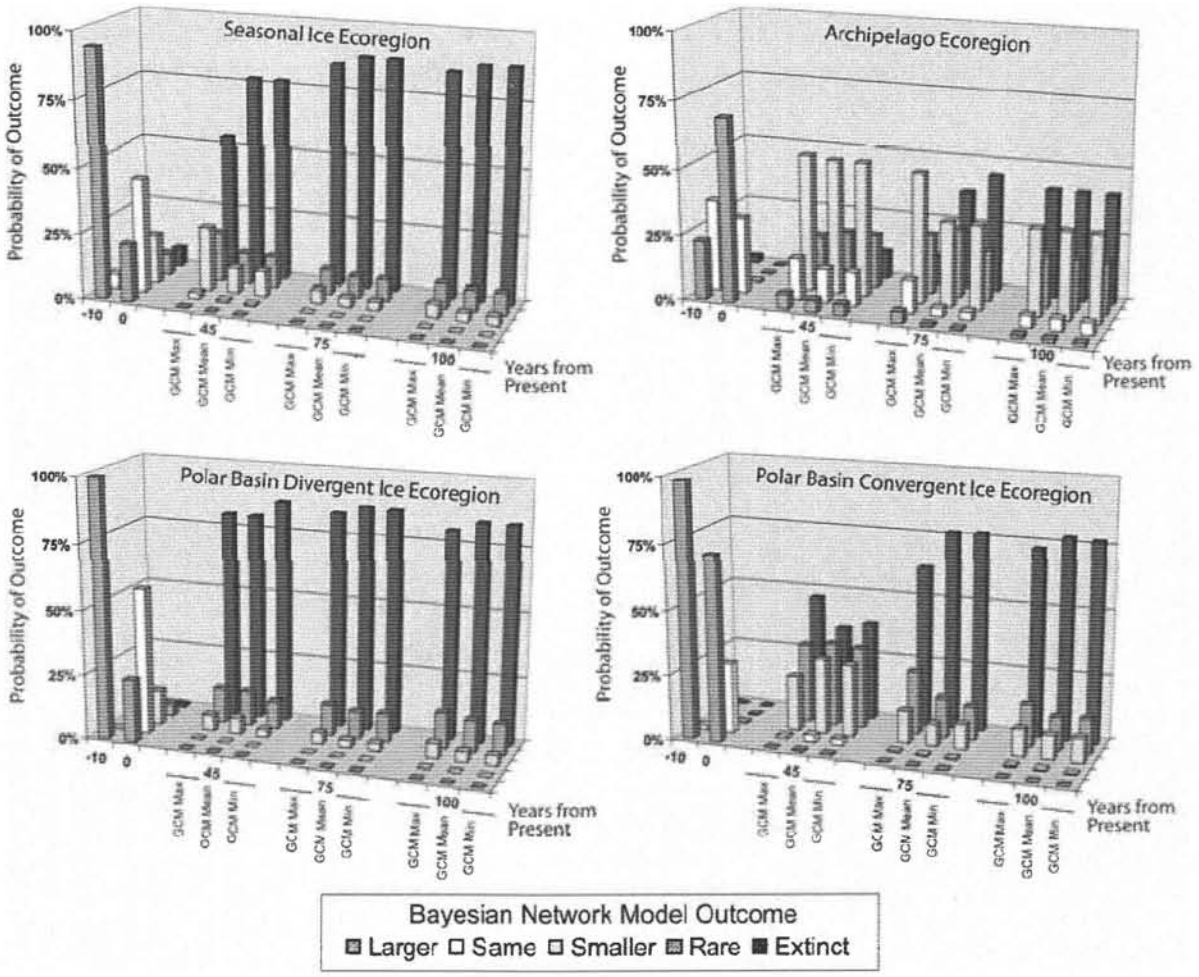


Figure 10. Projected polar bear population outcomes of Bayesian network model for 4 ecoregions at 5 time periods relative to present.

Present and prior decade (years 0 and -10) sea ice conditions were from observed record. Future ice conditions were based on the ensemble mean of 10 GCMs, and the 2 GCMs that forecasted maximum and minimum ice extent in each ecoregion at each time period. Note that strength of dominant outcomes (tallest bars) is inversely proportional to heights of competing outcomes. Outcome definitions: larger = more abundant than present (Year 0) plus distribution at least the same as at present; same = numerical and distribution responses similar to present; smaller = reduced in numbers and distribution; rare = numerically rare but occupying similar distribution, or reduced numerically but spatially represented as transient visitors, extinct =are numerically absent or distributionally extirpated.

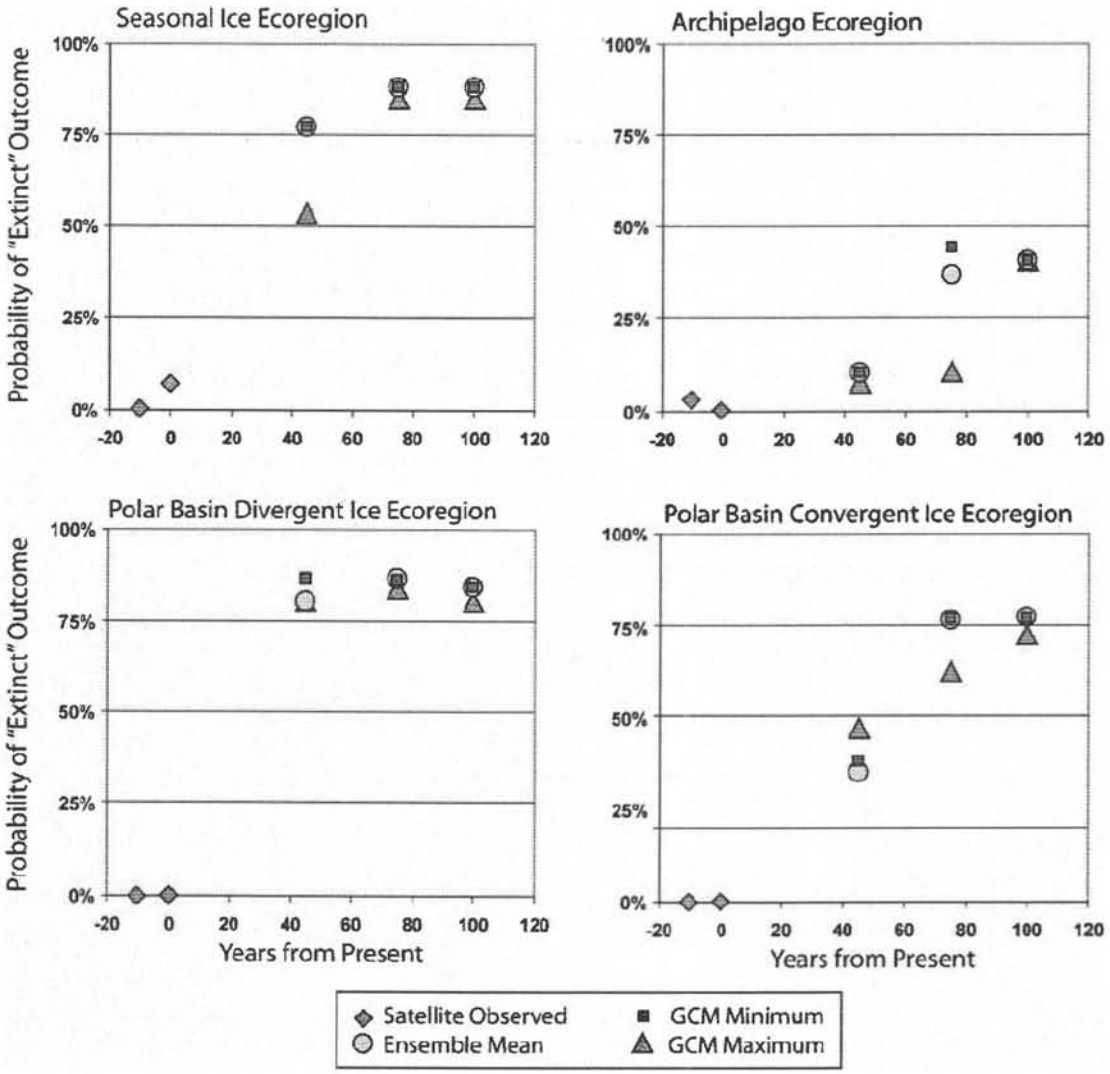


Figure 11. Projected probabilities of the "extinct" overall population outcome (node D1 in Fig. 5), from the Bayesian network population stressor model.

Projections include 4 ecoregions, and 5 time periods relative to present. Present and prior decade (years 0 and -10) sea ice conditions were from observed record. Future ice conditions were based on the ensemble mean of 10 GCMs, and the 2 GCMs that forecasted maximum and minimum ice extent in each ecoregion at each time period.

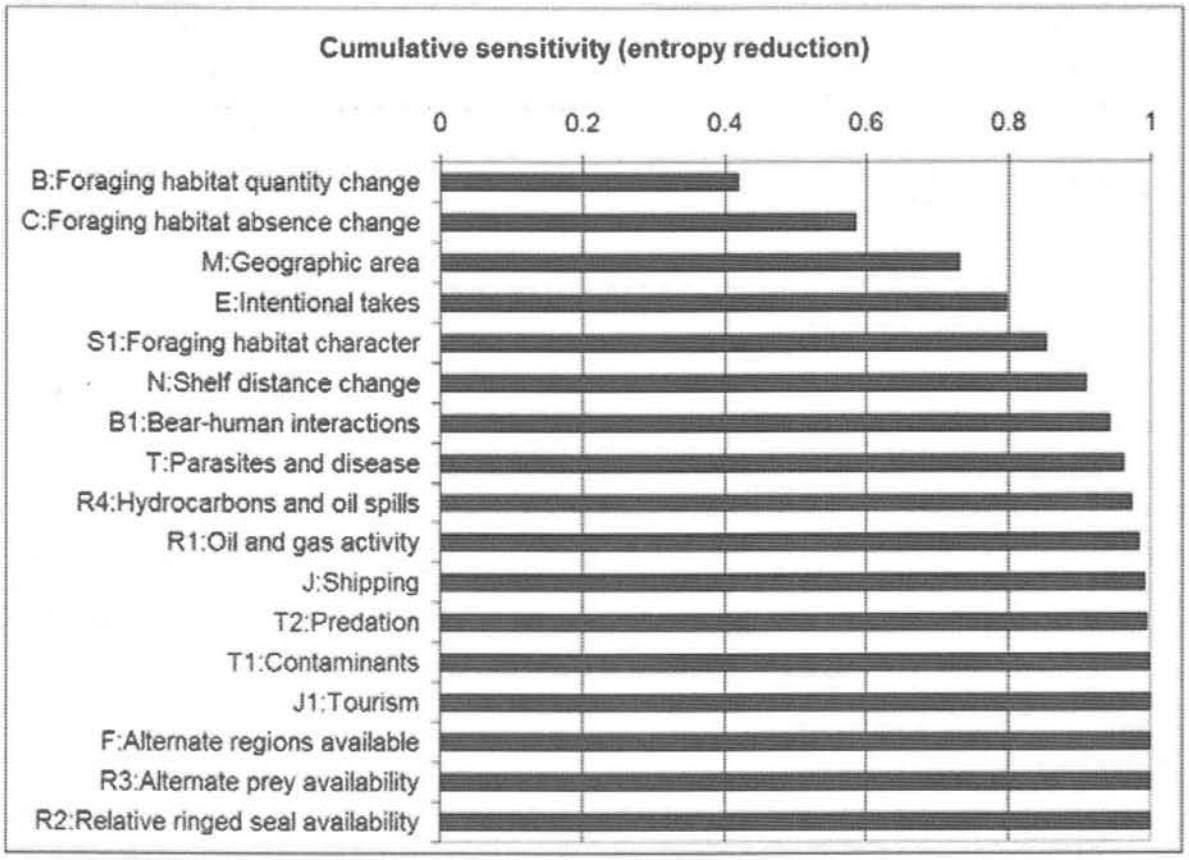


Figure 12. Cumulative sensitivity of overall population outcome (node D1, Fig. 5) to all input variables (yellow boxes, Fig. 5), in the Bayesian network population stressor model.

The 17 input variables on the vertical axis are listed, top to bottom, in decreasing order of their individual influence on overall population outcome (see Appendix 1, Sensitivity Test 1). The horizontal axis represents the cumulative proportion of total entropy reduction (mutual information) from the input variables. For example, the first two variables, foraging habitat quantity change and foraging habitat absence change, together account for 58% of all explainable entropy reduction.

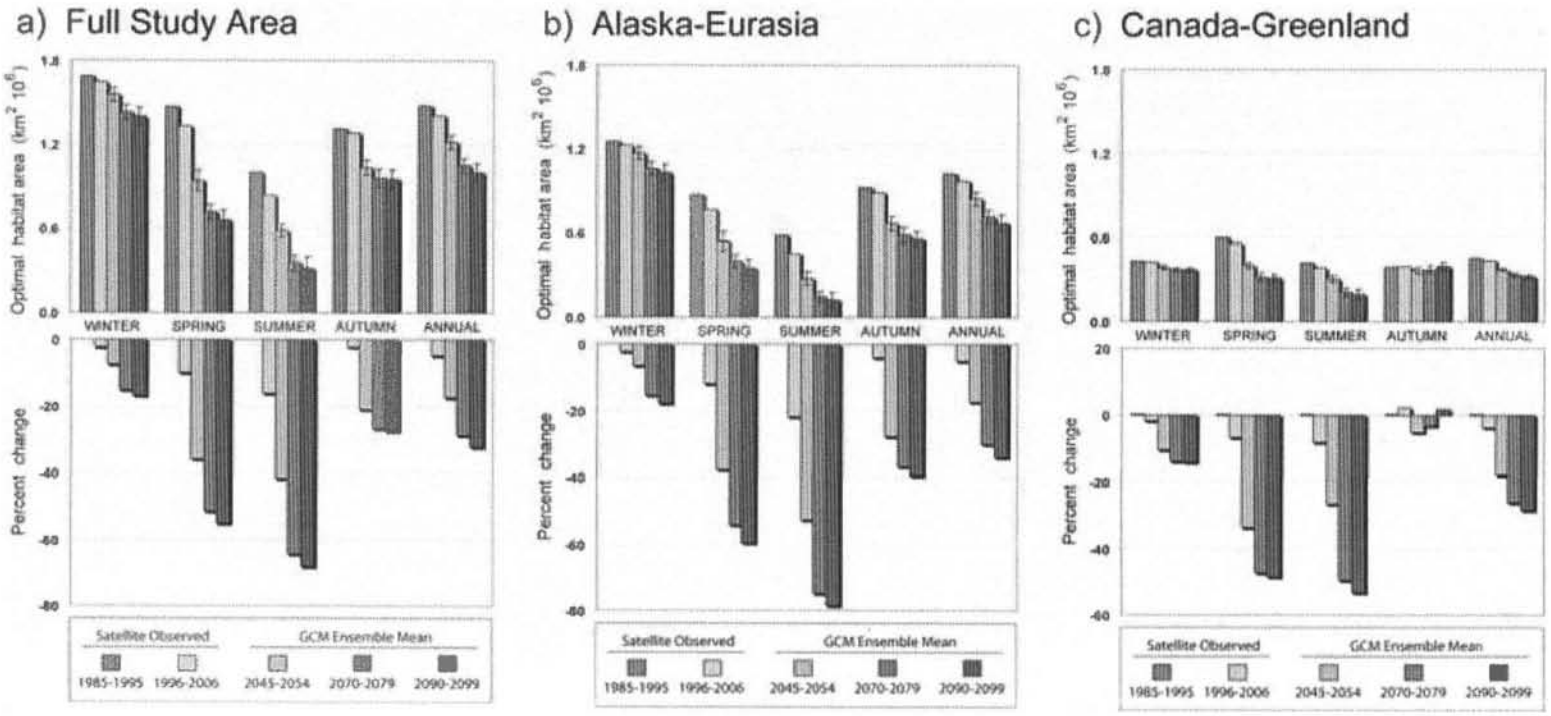


Figure 13. Mean (SE) area of optimal RSF polar bear habitat in the polar basin by season and decadal time period (top), and percentage change in the same values (bottom), from ensemble mean of 10 IPCC AR-4 general circulation models.

Note the modest changes in annual values which were used in our carrying capacity model in comparison to the spring and summer values.

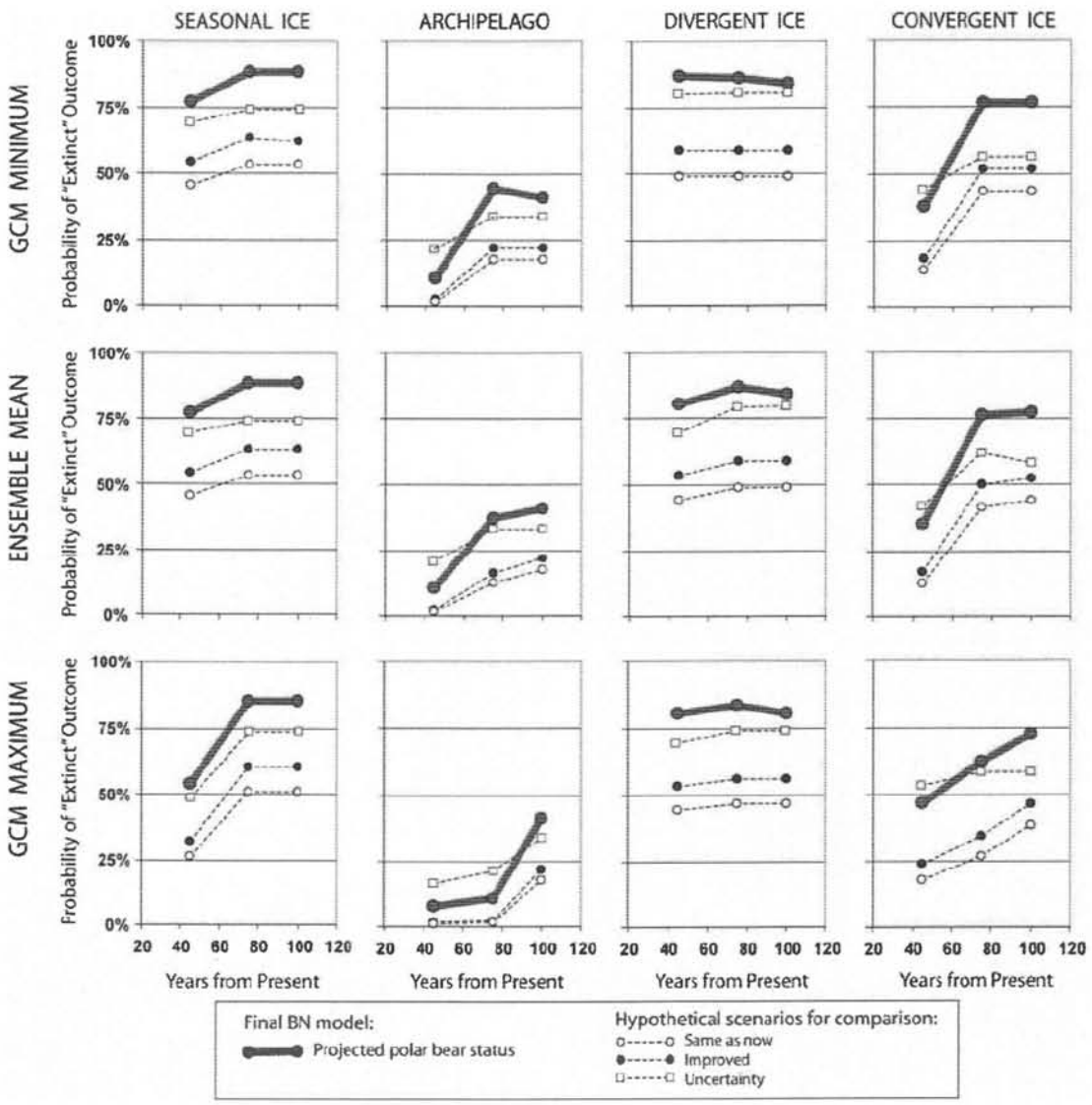


Figure 14. Probability of "extinct" outcomes projected by a Bayesian network (BN) polar bear population stressor model. Projections include 4 ecoregions, and 3 future time periods relative to present.

Future ice conditions were based on the ensemble mean of 10 GCMs, and the 2 GCMs that forecasted maximum and minimum ice extent in each ecoregion at each time period. General BN runs (thick red lines, Table 8, Figure 11) are compared to results obtained by 3 scenarios in which certain inputs were fixed: "Same" = direct mortalities (BN node A1, Figure 5) fixed at "same as now" and other human factors (node A6) at "no effect" (open circles); "Fewer" = node A1 fixed at "fewer" and node A6 at "improvement" (solid circles); and "Uncertain" = all input nodes other than those expressing quantitative sea ice conditions held at their uniform, prior probabilities (complete uncertainty) with the three ice-related nodes (N, B, and C) varying the same as the original runs (open squares).

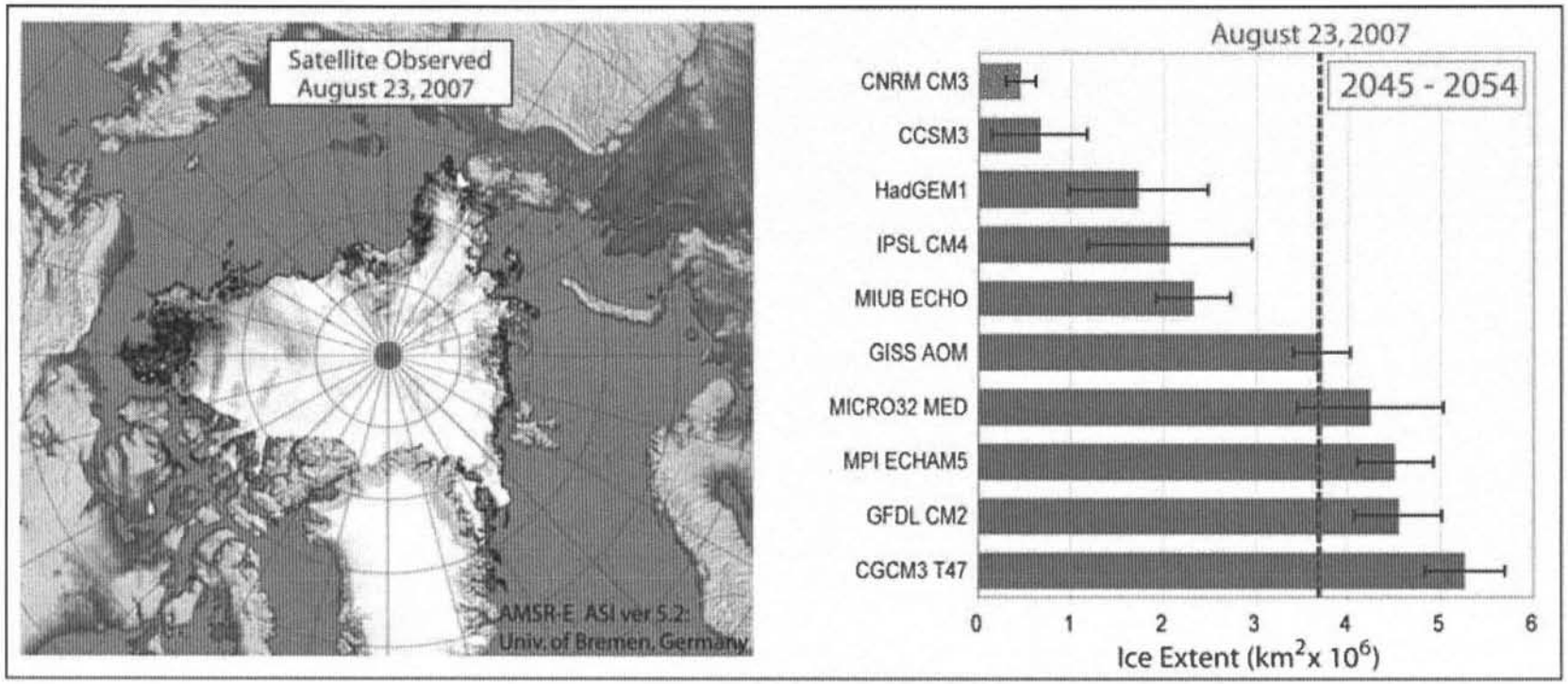


Figure 15. Area of sea ice extent (>50% ice concentration) on August 23, 2007, compared to 10 IPCC AR-4 GCM mid-century projections of ice extent for September 2045–2054 (mean ± 1 sd, n = 10 years).

Note that the 4 models which project the greatest remaining sea ice extent at mid century forecast more perennial sea ice than we have at present. Ice extent for August 23, 2007, was calculated using near-real-time ice concentration estimates derived with the NASA Team algorithm and distributed by the NSIDC (http://nsidc.org).

Appendix 1. Results of sensitivity analyses of the Bayesian network population stressor model

This appendix presents the results of conducting a series of sensitivity analyses of the Bayesian network population stressor model discussed in the text (also see Fig. 5). Sensitivity analysis reveals the degree to which selected input or summary variables influence the calculated values of a specified output variable. Presented here are results of 10 sensitivity tests on various summary and output nodes in the model (see text for explanation of calculations). Note that mutual information is also called entropy reduction. All tests were conducted using the Bayesian network modeling software package Netica (Norsys, Inc.).

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SENSITIVITY GROUP 1: SENSITIVITY OF OVERALL POPULATION OUTCOME
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Sensitivity Test 1. Sensitivity of node D1:Overall Population Outcome to all input nodes

Node	Mutual Info	Node title
B	0.11624	Foraging Habitat Quantity Change
C	0.04591	Foraging Habitat Absence Change
M	0.04003	Geographic Area
E	0.01837	Intentional Takes
S1	0.01569	Foraging habitat character
N	0.01325	Shelf Distance Change (km)
B1	0.00939	Bear-human interactions
T	0.00546	Parasites & Disease
R4	0.00308	Hydrocarbons/Oil Spill
R1	0.00289	Oil & Gas Activity
J	0.00224	Shipping
T2	0.00100	Predation
T1	0.00082	Contaminants
J1	0.00046	Tourism
F	0.00000	Alternate Regions Available
R3	0.00000	Alternate Prey Availability
R2	0.00000	Relative Ringed Seal Availability

Sensitivity Test 2. Sensitivity of node D1:Overall Population Outcome to Listing Factor nodes

Node	Mutual Info	Node title
F2	0.60174	Factor A: Habitat Threats
A1	0.06391	Factor B. Direct Mortalities
A6	0.03659	Factor E. Other factors (natural or man-made)
A4	0.01123	Factor C. Disease, predation

Sensitivity Test 3. Sensitivity of node D1:Overall Population Outcome to intermediate nodes

This does NOT includes the Listing Factor nodes included in Sensitivity Test 2, above.

Node	Mutual Info	Node title
L2	0.57024	Vital Rates
L1	0.53323	Adult Female Survival
L	0.53295	Juvenile Survival
K	0.51522	Adult Body Condition
V1	0.42691	Cub production per event
U	0.23368	Reproduction
D	0.18791	Change in Foraging Habitat Distribution
A	0.02592	Foraging habitat value
C1	0.02114	Human disturbance
G	0.00000	Relocation Possible
H	0.00000	Crowding Tolerance
C2	0.00000	Pollution

Sensitivity Test 4. Sensitivity of node D1:Overall Population Outcome to selected intermediate nodes

This includes all (6) nodes that are two links distant from the outcome node.

Node	Mutual Info	Node title
F2	0.60174	Factor A: Habitat Threats
L2	0.57024	Vital Rates
A1	0.06391	Factor B. Direct Mortalities
G	0.00000	Relocation Possible
A6	0.03659	Factor E. Other factors (natural or man-made)
A4	0.01123	Factor C. Disease, predation

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SENSITIVITY GROUP 2: SENSITIVITY OF SUBMODELS
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Sensitivity Test 5. Sensitivity of node A4:Factor C. Disease, predation

Node	Mutual Info	Node title
T	0.39016	Parasites & Disease
T2	0.06593	Predation

Sensitivity Test 6. Sensitivity of node C2: Pollution

Node	Mutual Info	Node title
R4	0.69005	Hydrocarbons/Oil Spill
T1	0.13542	Contaminants

Sensitivity Test 7. Sensitivity of node C1:Human disturbance

Node	Mutual Info	Node title
B1	0.45796	Bear-human interactions
R1	0.12450	Oil & Gas Activity
J	0.08941	Shipping
J1	0.01729	Tourism

Sensitivity Test 8. Sensitivity of node A:Foraging habitat value

Node	Mutual Info	Node title
S1	0.63429	Foraging habitat character
F	0.00000	Alternate Regions Available
R3	0.00000	Alternate Prey Availability
R2	0.00000	Relative Ringed Seal Availability

Sensitivity Test 9. Sensitivity of node D:Change in Foraging Habitat Distribution

Node	Mutual Info	Node title
M	0.33239	Geographic Area
C	0.32674	Foraging Habitat Absence Change
N	0.06131	Shelf Distance Change (km)

Sensitivity Test 10. Sensitivity of node L2:Vital Rates

Node	Mutual Info	Node title
L1	1.09792	Adult Female Survival
L	1.09537	Juvenile Survival
F2	0.99215	Factor A: Habitat Threats
K	0.97559	Adult Body Condition
V1	0.69213	Cub production per event
U	0.36497	Reproduction
M	0.04728	Geographic Area
N	0.01955	Shelf Distance Change (km)

Appendix 2. Documentation of the Bayesian network polar bear population stressor model

This appendix documents the structure of the Bayesian network (BN) population stressor model. We used the BN modeling shell Netica® (Norsys, Inc.) to create a model that represents potential influences on distribution response, numerical response, and overall population response of polar bears under multiple stressors, which include anthropogenic stressors, natural disturbances, and other key environmental correlates to polar bear population amount and distribution.

The BN population stressor model was created to represent the knowledge and judgment of one polar bear biologist (S. Amstrup) with guidance from an ecologist modeler (B. Marcot). See the text for a brief explanations of Bayesian modeling and statistics. The general underlying influence diagram for the BN model is shown in Figure 4, and the full model is in Figure 5. A BN model consists of a series of variables represented as "nodes" (boxes in Fig. 5) that interact through links (arrows in Fig. 5). Nodes that have no incoming arrows are "input nodes" (the yellow boxes in Fig. 5, e.g., node T Parasites & Disease). Nodes with both incoming and outgoing arrows are summary nodes (or latent variables, e.g., node L2 Vital Rates). In our model, we also specified four of the summary nodes as listing factors used by USDI Fish and Wildlife Service (S. Morey, pers. comm.). Nodes with incoming arrows but no outgoing arrows are outcome nodes (node D1 Overall Population Outcome).

Each node in this model consists of a short node name (e.g., node D1), a longer node title (e.g., Overall Population Outcome), a set of states (e.g, larger, same as now, smaller, rare, and extinct), and an underlying probability table. The probability tables consist of unconditional (or prior) probabilities in the input nodes, or conditional probabilities in all other nodes, the latter representing probabilities of each state as a function of (conditional upon) the states of all nodes that directly influence it.

The following table presents a complete list of all nodes in the model with their short code letter names, their fuller titles, a description, their states, and the group (Node Set, in Netica parlance) to which it belongs (input nodes, output node, summary node, or summary listing factor node).

Node name	Node title	Node description	States
		Input nodes	
T	Parasites & Disease	As the climate warms, regions of the arctic are hospitable to parasites and disease agents which formerly didn't survive there. Polar bears have always been free of most disease and parasite agents. *Trichinella* is one notable exception, but even rabies, common in the Arctic has had no significance to polar bears. Changes in other species disease vulnerability suggest that similar changes could occur in polar bears so that they could move from a position where parasites and disease are not influential on a population level to where they are influential.	influential not
T2	Predation	Predation on polar bears by other species is very uncommon partly because bears spend almost all of their time on the ice. With more time on land, polar bears, especially young will be subject to increased levels of predation from wolves, and perhaps grizzly bears. This will vary by region as some regions where polar bears occur have few other predators. Intraspecific predation is one behavior which is known to occur in bears. It has rarely been observed in polar bears and historically is not thought to have been influential. Recent observations of predation on other bears by large males, in regions where it has not been observed before, are consistent with the hypothesis that this sort of behavior may increase in frequency if polar bears are nutritionally stressed. At present, intraspecific predation is not thought to be influential at the population level anywhere in the polar bear range. It appears, however, that its frequency may be on the increase. At some point, it therefore could become influential. At very low population levels, even a miner increase in predation could be influential.	influential not
E	Intentional Takes	This node represents direct mortalities including hunting, and collection for zoos, and management actions. It also includes research deaths even though they are not intentional. These are mortality sources that are very much controllable by regulation.	increased same_as_now decreased
T1	Contaminants	Increased precipitation and glacial melt have recently resulted in greater influx of contaminants into the Arctic region from the interior of Eurasia via the larte. northward flowing rivers. Similarly, differing atmospheric circulation patterns have altered potential pathways for contaminants from lower latitudes. This node reflects the possible increase or decrease of contamination in the Arctic as a result of modified pathways. These contaminants can act to make habitat less suitable and directly affect things like survival and reproduction. The greatest likelihood seems to be that such contaminants will increase in Arctic regions (and indeed worldwide) as increasing numbers of chemicals are developed and as their persistence in the environment is belatedly determined. Some contaminants have been reduced and we have the ability to reduce others, but the record of reduction and the persistence of many of these chemicals in the environment suggests the greatest likelihood is for elevated levels in the short to medium term with some probability of stability or even declines far in the future.	elevated same_as_now reduced
R4	Hydrocarbons / Oil Spill	This refers to the release of oil or oil related products into polar bear habitat. Such action would result in direct mortality of bears direct mortality of prey, and could result in displacement of bears from areas they formerly occupied. Hence, it has ramifications for both habitat quality and population dynamics directly. Hydrocarbon exploration and development are expanding and proposed to expand further in the Arctic. Greater levels of such activity are most likely to increase the probability of oil spills. Also, increased shipping will result in higher levels of hydrocarbon release into Arctic waters.	increased_occurrence same_as_now decreased_occurrence
J1	Tourism	As sea ice extent declines spatially and temporally access and opportunities for Arctic Tourism also will increase. Increased tourism could lead to direct disturbances of polar bears as well as to increased levels of contamination. Here, we address only the physical presence of more tourism and the conveyances used by tourists (vessels, land vehicles, aircraft). The greatest likelihood seems to be that tourism will increase. It could decline, however, if governments take actions to reduce interactions with increasingly stressed polar bears. However, as tourism currently accounts for essentially no limitation to polar bears this effect only comes into play when it is noted to increase. I believe that tourism will increase in all areas of the Arctic until such time as fuel becomes too expensive for	increased same_as_now decreased

Node name	Node title	Node description	States
		people to venture to such remote areas or in the polar basin divergent unit, when it is essentially devoid of ice, it may not attract many tourists and such activity may surge and then decline in that region. The arctic areas with more interesting coastlines etc., however will probably see nothing but increases in tourism. Contamination that may accompany such activities, and biological effects from introduced organisms that may compete with residents of the food web or cause disease are covered under the nodes for contamination and parasites and disease.	
B1	Bear-human interactions	This includes non-lethal takes which may increase as a result of increased human-bear interactions due to food stressed bears more frequently entering Arctic communities. Such takes can displace bears from their preferred locations and reduce habitat quality. This is separate from the similar interactions that may occur around oil and gas or other industrial sites which also can displace bears and lower habitat quality. These interactions also, however, can result in deaths as when problem bears are shot in defense of life and property So, this node includes a component of both habitat quality and direct mortality. I believe that bear-human interactions will increase until such time areas are devoid of bears or climate cools again and ice returns.	increased same_as_now decreased
R1	Oil & Gas Activity	This refers to the spatial effects of oil and gas activity. It refers to activities and infrastructure which may physically displace bears from habitat that was formally available to them. It also, can result in direct killings of bears which become a persistent safety problem around industrial facilities. Oil companies etc. have great resources to prevent these events from leading to mortalities, but such mortalities cannot be totally avoided and are likely to increase as habitat base shrinks. I think oil and gas activity will increase in the polar basin region through mid century and then decline because resources will have been tapped. We may see some increase in exploration and development in the Archipelago however, as it becomes increasingly accessible.	increase no_change decrease
J	Shipping	As sea ice extent declines spatially and temporally it is predicted that shipping in Arctic regions will increase. Increased shipping could lead to direct disturbances of polar bears as well as to increased levels of contamination. Here, we address only the physical presence of more vessel traffic. Contamination (bilge oil etc.), and biological effects from introduced organisms that may compete with residents of the food web or cause disease are covered under the nodes for contamination and parasites and disease. We allow only two states here: increased and same as now, because we can think of no reason why shipping will decrease in the foreseeable future. Even if international shipping does not increase, local shipping will because barges and vessels are more efficient ways to move fuel and freight into remote Arctic locations than aircraft.	increased same_as_now
F	Alternate Regions Available	Are there geographic regions to which bears from the subject region may effectively be able to relocate. This ability is contingent on other regions with suitable habitats being contiguous with regions where habitat quantity or quality have degraded to the point they won't support polar bears on a seasonal or annual basis. For example, if the sea ice is deteriorating throughout the polar basin including the Beaufort Sea and the last vestiges of ice are along the Alaskan Coast, there may no where else to go if the ice deteriorates to an unsatisfactory state. If, however, the ice retreates to the northeast as its extent reduces, bears remaining on the ice may have access to suitable habitats in the archipelago or in NE Greenland. I believe that bears in the seasonal ice region and in the polar basin will be able to collapse into the archipelago. Ice patterns suggest that the remaining ice in the arctic is likely to converge on the archipelage rather than form disjunct chunks of ice (although some GCMs do predict the latter, this is contrary to the historical record and the paleo record). Yes = other suitable areas are contiguous No = other suitable regions are not contiguous	Yes No
R2	Relative	This node expresses changes in prey availability that are likely to occur as sea ice cover declines and its character	increase

Node name	Node title	Node description	States
	Ringed Seal Availability	changes. This node specifically includes only the possibility that ringed seals, the mainstay of polar bears over most of their range might change in abundance and availability. This is specific to the amount of remaining ice. That is, as sea ice declines in coverage (which is the only way it seems possible for it to go) will the remaining habitat be more productive. Availability here refers to the combined effects of abundance and accessibility recognizing that seals may occupy areas that make them less available to polar bears even if the seals are still relatively abundant. Examples of this are the recent observations of failed bear attempts to dig through solid ice (a result of the thinner ice that deforms and rafts more easily) that predominates now, and the fact that seals may simply stay in open water all summer and not be available to bears even if the seal numbers are stable. My opinion is that only in the northern part of the ice convergent zone of the polar basin and in portions of the archipelago are conditions to improve for ringed seal availability. And, there, such improvements are likely to be transient perhaps through mid century. increase = greater abundance or availability of ringed seals same as now decrease = less abundance or availability	same_as_now decrease
R3	Alternate Prey Availability	This node expresses changes in prey availability that are likely to occur as sea ice cover declines and its character changes. This is largely expert opinion because there is little to go on to suggest prey base change possibilities in the future. With very different ice and other ecological differences that may accompany global warming things could occur which are totally unforeseen. Today's experience, however, suggests that little in the way of significant alternate prey is likely to emerge to allow bears to replace traditional prey that may be greatly reduced in the future. Where alternate prey could become important is in the seasonal ice regions and the archipelago. Now, harp and hooded seals have become important to polar bears as they have moved farther north than historically. As the ice retreats into the archipelago it is reasonable to expect that these animals may penetrate deeper into the archipelago and provide at least a transient improvement in alternate prey. It is unclear, however, that such changes could persist as bears prey on these seals which are forced onto smaller an smaller areas of ice. So, I project only transient improvements followed by decline. This node specifically addresses the possibility that alternate prey either marine or terrestrial might change in a way that would allow polar bears to take advantage of it. increase = greater availability of alternate prey same as now decrease = less opportunity for access to prey items other than ringed seals	increase same_as_now decrease
S1	Foraging habitat character	This node expresses a subjective assessment of the quality of sea ice for foraging by polar bears. Recent observations of the changes in sea ice character in the southern Beaufort Sea suggest that the later freeze up warmer winters, and earlier ice retreat in summer have resulted in thinner ice that more easily deforms and more frequently rafts over itself. These changes have reduced the quality of ice as a denning substrate, and may have reduced its quality as a foraging substrate since the extensive ice deformation can result in ice covered refugia for ringed seals which are less likely for polar bears to get into. Also, it can result in very rough sharp pressure ridges that are hugely expansive compared to earlier years. This rough ice may also provide refuge for seals, and it also is surely difficult for polar bear coys to negotiate as they attempt to move out onto the ice after den emergence in spring. More optimal ice is somewhat heavier not as rough, with pressure ridges composed of larger ice blocks. However, it can go the other way now. Very heavy stable ice in the Beaufort Sea in the past may have been limiting polar bears. This is also probably currently true in portions of the Canadian Archipelago and in the northern part of the Ice convergent zone of the polar basin. So, in those areas, I expect that ice quality will at first improve with global warming and then decline. Because my only sense of this ice quality is in the polar basin, I am leaving all priors uniform for the other ice regions.	more_optimal same_as_now less_optimal

Node name	Node title	Node description	States
C	Foraging Habitat Absence Change	This node expresses the length in months of ice absence from the continental shelf regions currently preferred by polar bears. It correspondes to the value "proportional ice free months" from Dave Douglas' calculations based on GCMs. This is the number of months during which the continental shelf was ice free where ice free is defined as fewer than 50% of the pixels over the shelf having less than 50% ice cover. We express this as a change from now. so the figures in this node represent the difference in months between the forecasted number of ice free months for three future time periods and the number of ice free months for the present which is defined as the GCM model outputs for the period 2001-2010. The bears in some regions already experience protracted ice free periods. In other regions they don't. The impact of the length of the ice free period is dependent mainly upon the productivity of the environment, and has a different impact in the Beaufort Sea for example than it does in the currently seasonal ice environments which are, for the most part, very productive. For example, in the archipelago and PB convergence regions the mean time expressed in teh table must be interpreted with regard to the fact that in large parts of these areas even at a mean 1-3 months of increased absence, actual absence in some parts of these regions would still be 0. An absence difference of GT 3 months means a mean absence of 7 or 8 months in the PB divergent zone, and 8 9 or 10 months in the seasonal ice zone, but only 3 + months in portions of the archipelago or the PB convergence region.	-1 to 0 0 to 1 1 to 3 >=3
B	Foraging Habitat Quantity Change	This node expresses the proportional change in the area of polar bear habitat over time. Polar bear habitat is expressed as the number of square km months of optimal RSF habitat in the two polar basin geographic units, and as square km months of ice over continental shelf in the other regions. Because the other regions are almost entirely shallow water areas, the habitat in those areas boils down to essentially the ice extent months over each region. We further express this as the percent change in quantity of these ice habitats, from the baseline now which is defined as the period 1996-2006. Interpreting the percent difference must take into account that a given percent change in the archipelago or the PB convergent region is a very different thing than it might be in the other two units. The absolute change in the archipelago, for example may be very small, but because it is measured from essentially 0, it may look like a great %. These measurements are derived from the satellite record for the observational period and from the GCM outputs of sea ice for future periods.	0 to 20 -20 to 0 -40 to -20 < -40
N	Shelf Distance Change (km)	This node expresses the distance that the ice retreats from traditional autumn/winter foraging areas which are over the continental shelves and other shallow water areas within the polar basin. It is calculated by extracting the largest contiguous chunk of ice whose pixels have >50% concentration and determining the mean of the measured distances between all cells in the subpopulation unit and the nearest point within that chunk of ice. It is expressed as the difference between this mean distance calculated for the period 1996-2006 and the same mean distance calculated for the other time periods of interest. These distances are derived from the satellite record for the observational period and from the GCM outputs of sea ice for future periods. Expressing this value as a change from the current time allows the model to show that conditions improve in a hind cast back to the period of 1985-1995. This measurement is available only from the polar basin management units because all other management units occur in areas that are essentially all shelf. Hence, the measurement of distance to shelf means nothing. How far has the ice retreated from shore areas where polar bears traditionally have foraged in autumn and winter. Can/will bears make the trip from remaining summer refugia to these areas. This node also could be expressed simply as accessible or inaccessible as in denning areas above. This may not apply to regions other than the polar basin, because we don't have reliable assessments of where the sea ice will be at maximum retreat. Need to look at this question more closely.	-200 to 0 0 to 200 200 to 800 >= 800

Node name	Node title	Node description	States
		NOTE that we need to revisit how these values are calculated because the July values put in don't really seem to reflect real distances in for example the Archipelago where the ice is not expected to be away from the shelf for a long time to come. NOTE also that this difference change means a very different think in the divergent unit than it does in teh convergent unit. The mean distance to the shelf in the archipelago unit at future times will incorporate regions where there is no ice retreat at all and some regions where the change may be quite great (like the northern Beaufort). The overall change in the unit will actually be much more modest than the mean value suggests. In the divergent unit, however, a large mean distance means that the ice is uniformly a long way from the continental shelf.	
M	Geographic Area	Geographic region used for combining populations of polar bears.	Polar_Basin_Divergence Polar_Basin_Convergence Archipelago Seasonal_Ice
		Output Nodes \a	
D1	Overall Population Outcome	Composite influence of numerical response and distribution response.	larger same_as_now smaller rare extinct
C4	Numerical Response	This node represents the anticipated numerical response of polar bears based upon the sum total of the identified factors which are likely to have affected numbers of polar bears in any particular area.	increased_density same_as_now reduced_density rare absent
C3	Distribution Response	This is the sum total of ecological and human factors that predict the future distribution of polar bears. Reduced but Resident: habitat has changed in a way that would likely lead to a reduced spatial distribution (e.g. due to avoidance of a human development, or sea ice is still present in the area but in more limited quantity). Bears would still occur in the area, but their distribution would be more limited. Transient = habitat is seasonally limited or human activities have resulted in a situation where available ice is precluded from use on a seasonal basis.	same_as_now reduced_but_resident transient_visitors extirpated
		Summary Nodes	
C2	Pollution	This is the sum of pollution effects from hydrocarbon discharges directly into arctic waters and from other pollutants brought to the Arctic from other parts of the world. The FWS listing proposal included Pollution as one of the "other factors" along with direct human bear interactions that may displace bears or otherwise make habitats less satisfactory, I viewed the main effect of pollution as a potential effect on population dynamics. Clearly, severe pollution as in an oil spill for example, could make habitats unsatisfactory and result in direct displacement. The main effect, however, is likely to be how pollution affects immune systems, reproductive performance, and survival. Hence, I have included input from this node as well as from the human disturbance node into both the habitat and the abundance side of the network by including input from Factor E into both population effects and habitat effects.	reduced same_as_now elevated greatly_elevated
C1	Human disturbance	This node expresses the combination of the changes in "other" direct human disturbances to polar bears. This does not include changes in sea ice habitat. Nor does it include the contamination possibilities from hydrocarbon exploration. Those are covered elsewhere. It does cover the direct bear-human interactions that can occur in association with industrial development.	reduced same_as_now elevated greatly_elevated
H	Crowding Tolerance	The degree to which polar bears may tolerate increased densities that may result from migration of bears from presently occupied regions that become unsuitable to other regions already occupied by polar bears.	none moderate

Node name	Node title	Node description	States
		In essence, this is the tolerance of bears to live in more crowded conditions than those at which they presently live. And, it is a function of food availability I believe that bears have a reasonable tolerance of crowding if food is abundant or if they are in good condition while waiting for sea ice to return etc. Examples of these situations include 1) portions of the high arctic like near resolute, where bear densities on the sea ice in spring are apparently much higher than they are in most of the polar basin, and 2) the high densities at which polar bears occur on land in Hudson Bay in summer when they are loafing and waiting for the sea ice to return. I assumed that crowding tolerance has little or no effect on outcome likelihoods until habitat quantity was reduced substantially requiring bears from one area to either perish or find some place else to go on at least a seasonal basis. Thereafter, if relocations of members of some subpopulations meant invading the areas occupied by other bears crowding tolerance entered an assessment of whether or not relocation was a practical solution.	high
G	Relocation Possible	Is it likely that polar bears displaced from one region could either seasonally or permanently relocate to another region in order to persist. This is a function of foraging effects (e.g. prey availability) in the alternative area (here I am specifically focusing on prey availability in the alternative area rather than the area from which the bears may have been displaced) crowding tolerance, and contiguity of habitats.	Yes No
A	Foraging habitat value	This node expresses the sum total of things which may work to alter the quality of habitats available to polar bears in the future. The idea here is that sea ice is retreating spatially and temporally, but is the ice that remains of comparable, better or worse quality as polar bear habitat. Our RSF values are projected into the future with the assumption that a piece of ice in 2090 that looks the same as piece of ice in 1985 has the same value to a polar bear. Perhaps because of responses we cannot foresee, it may be better seal habitat, or it may be habitat for an alternate prey. Conversely, it may be worse because of atmospheric and oceanic processes (e.g. the epontic community is less vibrant due to thinner ice which is not around for as long each year). Or it may be worse habitat because of oil and gas development, tourism, shipping etc.	better same_as_now worse
D	Change in Foraging Habitat Distribution	This node expresses the combination of the quantitative ways the retreat of sea ice may affect use of continental shelf habitats. Our analyses indicate, in addition to reductions of total ice (and RSF Optimum ice) extent (expressed under habitat quantity), we will see seasonal retreats of the sea ice away from coastal areas now preferred by polar bears, and these retreats are projected to progressively become longer. These changes will affect polar bears by reducing the total availability of ice substrate for bears. They also will make ice unavailable for extended periods in many regions bears now occur year round. This will result in the opportunity for seasonal occupancy but not year-round occupancy as they have had in the past. Note that in the PB Convergent unit because it includes the NB and QE and EG each of which has different starting points, the values in the CPT express kind of an average. Similarly, in the Seasonal region, there is a huge difference between HBay and Foxe Basin or BB. so, again the CPT values are a sort of an average, trying to reflect these differences. Ultimately, we need to subdivide these regions a bit more to really reflect what is going on. Also note that the "same as now" category doesn't really work very well for the seasonal ice environment where now is seasonal. The only way to go from here is to better than now or to sporadic. Having a step between now and sporadic is not useful. In fact, all of these categories need to be changed.	improved_availability same_as_now reduced_avail Gr_reduced_avail Unavailable
L2	Vital Rates	This expresses the combined effect of changes in survival of adult females and of young and reproductive patterns. The probabilities assigned each of the states reflects the relative importance to polar bear population dynamics of each of these vital rates to the growth of the population. This node does not reflect human influences on population growth such as hunting, or mortalities resulting from bear-human interactions. Those things, along with effects of parasites, contaminants, etc. are brought in as modifiers at the level of the next node.	improve same_as_now decline

Node name	Node title	Node description	States
U	Reproduction	The sum of trends in numbers of cubs produced and the effect of retreating sea ice on the ability of females to reach traditional denning areas.	increased same_as_now decreased
V1	Cub production per event	This node describes the number of cubs produced per denning attempt.	Fewer_than_now same_as_now more_than_now
L	Juvenile Survival	Annual natural survival rate of cubs and yearlings. Note that this is conditional on survival of the mother. This is the survival rate for juveniles that would occur in absence of hunting or other anthropogenic factors. Those anthropogenic factors that would influence survival are included in node F.	increase no_change decrease
L1	Adult Female Survival	Annual natural survival rate of sexually mature females. This is the survival rate for adult females that would occur in absence of hunting or other anthropogenic factors. Those anthropogenic factors that would influence survival are included in node F.	increase no_change decrease
K	Adult Body Condition	Body mass index or other indicator of ability of bears to secure resources. Our analysis suggests body condition has been declining in the SBS and is inversely correlated with ice extent. Also recent analyses indicate that body condition is an important predictor of survival of polar bears in SHB.	increase same_as_now decrease
Summary Nodes – USFWS Listing Factors \b			
F2	Factor A: Habitat Threats	This node summarizes the combined information about changes in habitat quantity and quality. It approximately reflects factor A of the proposal to list polar bears as threatened.	improvement no_effect minor_restriction major_restriction
A1	Factor B. Overutilization	This node approximates the FWS listing Factor B. It includes the combination of hunting (harvest), take for scientific purposes, and take for zoos. It also includes mortalities from bear-human interactions etc. brought in from Factor E. These all are factors which serve to modify the population changes that would be brought about without the direct local interference of humans.	fewer same_as_now more
A4	Factor C. Disease, predation	This node expresses probability of changing vulnerability of polar bears to diseases and parasites, and to potential increases of intraspecific predation/cannibalism.	same_as_now worse
A6	Factor E. Other factors (natural or man-made)	This node approximately corresponds to Factor E of the listing proposal. It includes factors (other than the changes in sea ice quality and quantity) which may affect habitat suitability for polar bears. Also, its effects can be directly on population dynamics features. Hence, it applies directly to both the habitat and population sides of our network. Included here are effects of a variety of contaminants, including: petroleum hydrocarbons, persistent organic pollutants, and metals. Although we don't know much quantitatively about effects of these contaminants at the population level, we know qualitatively that effects on immune systems and steroid levels etc. will ultimately have such effects. We also know that oil spills will have immediate and dire effects. It also includes effects of human activities and developments which may directly affect habitat quality, including: shipping and transportation activities, habitat change, noise, spills, ballast discharge, and ecotourism. This includes disturbance but not direct killing of bears by humans as a result of DLP cases (direct killing is included under node A1). I viewed human disturbances as the most predictable in their negative effects until pollution levels reached their greatly elevated stage at which time, their import to future populations was judged to be great.	improvement no_effect minor_restriction major_restriction
Descriptive (Disconnected) Nodes \c			
Q	Time Period	The states for this node correspond to years -10 (historic), 0 (now), 45 (mid-century), 75 (late century), and 100 (end of century).	historic (1985-1995) now (1996-2006)

Node name	Node title	Node description	States
			mid-century (2045-2055) late century (2070-2080) end of century (2090-2099)
R	CGM run	The states for this node correspond to the data source (either "satellite" for year -10 and 0 runs) and GCN modeling scenario (minimum, ensemble mean, or maximum) basis for a given condition.	GCM_minimum Ensemble_mean GCM_maximum Satellite

\a Output nodes here include the Numerical Response and Distribution Response nodes that provide summary output conditions.

\b USDI Fish and Wildlife Service (USFWS) lists 5 Listing Factors. Listing factor D pertains to inadequacy of existing regulatory mechanisms, and was not included in the BN population stressor model because it does not correspond to any specific environmental stressor.

\c These two nodes are included in the model to help denote the basis for a given model run. They are not included as environmental stressors per se.

Appendix 3. Probability tables for each node in the Bayesian network model

Following are probability tables for each node in the BN model. (These were generated in the Netica software.) Not included here are all input nodes (yellow coded nodes in Fig. 5) because each of their prior probability tables was set to uniform distributions.

node H – "Crowding Tolerance"

Node R2 - Alternative prey availability	Node R3 - Relative ringed seal availability	Level of Crowding Tolerance		
		none	moderate	high
increase	increase	0.0	0.2	0.8
increase	same as now	0.0	0.4	0.6
increase	decrease	0.1	0.5	0.4
same as now	increase	0.0	0.4	0.6
same as now	same as now	0.1	0.8	0.1
same as now	decrease	0.3	0.6	0.1
decrease	increase	0.1	0.5	0.4
decrease	same as now	0.3	0.5	0.2
decrease	decrease	0.5	0.5	0.0

node G – "Relocation Possible"

Node F - Alternative regions available	Node H - Crowding tolerance	Possibilty of relocation	
		Yes	No
Yes	none	0.0	1.0
Yes	moderate	0.8	0.2
Yes	high	1.0	0.0
No	none	0.0	1.0
No	moderate	0.0	1.0
No	high	0.0	1.0

node A – "Foraging habitat value"

Node S1 - Foraging habitat character	Node G - Relocation possible	Value of foraging habitat		
		better	same as now	worse
more optimal	Yes	0.7	0.3	0.0
more optimal	No	0.2	0.6	0.2
same as now	Yes	0.1	0.8	0.1
same as now	No	0.0	0.8	0.2
less optimal	Yes	0.0	0.3	0.7
less optimal	No	0.0	0.0	1.0

node N – "Shelf Distance Change (km)"

Distance of shelf change			
-200 to 0	0 to 200	200 to 800	>= 800
0.25	0.25	0.25	0.25

node D – "Change in Foraging Habitat Distribution"

Node M - Geographic area	Node C - Foraging habitat absence change	Node N - Shelf distance change	Distribution of foraging habitat improved availab	same as now	reduced avail	Gr reduced avail	unavailable
Polar Basin Dive	-1 to 0	-200 to 0	1.0	0.0	0.0	0.0	0.0
Polar Basin Dive	-1 to 0	0 to 200	0.8	0.2	0.0	0.0	0.0
Polar Basin Dive	-1 to 0	200 to 800	0.2	0.6	0.2	0.0	0.0
Polar Basin Dive	-1 to 0	>= 800	0.0	0.4	0.6	0.0	0.0
Polar Basin Dive	0 to 1	-200 to 0	0.5	0.5	0.0	0.0	0.0
Polar Basin Dive	0 to 1	0 to 200	0.0	0.2	0.8	0.0	0.0
Polar Basin Dive	0 to 1	200 to 800	0.0	0.0	0.5	0.5	0.0
Polar Basin Dive	0 to 1	>= 800	0.0	0.0	0.25	0.5	0.25
Polar Basin Dive	1 to 3	-200 to 0	0.2	0.4	0.4	0.0	0.0
Polar Basin Dive	1 to 3	0 to 200	0.0	0.0	0.5	0.3	0.2
Polar Basin Dive	1 to 3	200 to 800	0.0	0.0	0.2	0.4	0.4
Polar Basin Dive	1 to 3	>= 800	0.0	0.0	0.0	0.2	0.8
Polar Basin Dive	>= 3	-200 to 0	0.0	0.3	0.5	0.2	0.0
Polar Basin Dive	>= 3	0 to 200	0.0	0.0	0.2	0.4	0.4
Polar Basin Dive	>= 3	200 to 800	0.0	0.0	0.0	0.1	0.9
Polar Basin Dive	>= 3	>= 800	0.0	0.0	0.0	0.0	1.0
Polar Basin Conv	-1 to 0	-200 to 0	1.0	0.0	0.0	0.0	0.0
Polar Basin Conv	-1 to 0	0 to 200	0.8	0.2	0.0	0.0	0.0
Polar Basin Conv	-1 to 0	200 to 800	0.6	0.4	0.0	0.0	0.0
Polar Basin Conv	-1 to 0	>= 800	0.4	0.6	0.0	0.0	0.0
Polar Basin Conv	0 to 1	-200 to 0	1.0	0.0	0.0	0.0	0.0
Polar Basin Conv	0 to 1	0 to 200	0.6	0.4	0.0	0.0	0.0
Polar Basin Conv	0 to 1	200 to 800	0.2	0.4	0.4	0.0	0.0
Polar Basin Conv	0 to 1	>= 800	0.0	0.2	0.8	0.0	0.0
Polar Basin Conv	1 to 3	-200 to 0	0.6	0.4	0.0	0.0	0.0
Polar Basin Conv	1 to 3	0 to 200	0.1	0.5	0.4	0.0	0.0
Polar Basin Conv	1 to 3	200 to 800	0.0	0.3	0.7	0.0	0.0
Polar Basin Conv	1 to 3	>= 800	0.0	0.0	1.0	0.0	0.0
Polar Basin Conv	>= 3	-200 to 0	0.4	0.6	0.0	0.0	0.0
Polar Basin Conv	>= 3	0 to 200	0.1	0.3	0.5	0.1	0.0
Polar Basin Conv	>= 3	200 to 800	0.0	0.2	0.6	0.2	0.0

Polar Basin Conv	>= 3	>= 800	0.0	0.0	0.7	0.3	0.0
Archipelago	-1 to 0	-200 to 0	0.0	1.0	0.0	0.0	0.0
Archipelago	-1 to 0	0 to 200	0.0	1.0	0.0	0.0	0.0
Archipelago	-1 to 0	200 to 800	0.0	1.0	0.0	0.0	0.0
Archipelago	-1 to 0	>= 800	0.0	1.0	0.0	0.0	0.0
Archipelago	0 to 1	-200 to 0	0.6	0.4	0.0	0.0	0.0
Archipelago	0 to 1	0 to 200	0.6	0.4	0.0	0.0	0.0
Archipelago	0 to 1	200 to 800	0.6	0.4	0.0	0.0	0.0
Archipelago	0 to 1	>= 800	0.6	0.4	0.0	0.0	0.0
Archipelago	1 to 3	-200 to 0	0.4	0.6	0.0	0.0	0.0
Archipelago	1 to 3	0 to 200	0.4	0.6	0.0	0.0	0.0
Archipelago	1 to 3	200 to 800	0.4	0.6	0.0	0.0	0.0
Archipelago	1 to 3	>= 800	0.4	0.6	0.0	0.0	0.0
Archipelago	>= 3	-200 to 0	0.0	0.6	0.4	0.0	0.0
Archipelago	>= 3	0 to 200	0.0	0.6	0.4	0.0	0.0
Archipelago	>= 3	200 to 800	0.0	0.6	0.4	0.0	0.0
Archipelago	>= 3	>= 800	0.0	0.6	0.4	0.0	0.0
Seasonal Ice	-1 to 0	-200 to 0	0.5	0.5	0.0	0.0	0.0
Seasonal Ice	-1 to 0	0 to 200	0.5	0.5	0.0	0.0	0.0
Seasonal Ice	-1 to 0	200 to 800	0.5	0.5	0.0	0.0	0.0
Seasonal Ice	-1 to 0	>= 800	0.5	0.5	0.0	0.0	0.0
Seasonal Ice	0 to 1	-200 to 0	0.0	0.2	0.6	0.2	0.0
Seasonal Ice	0 to 1	0 to 200	0.0	0.2	0.6	0.2	0.0
Seasonal Ice	0 to 1	200 to 800	0.0	0.2	0.6	0.2	0.0
Seasonal Ice	0 to 1	>= 800	0.0	0.2	0.6	0.2	0.0
Seasonal Ice	1 to 3	-200 to 0	0.0	0.0	0.2	0.4	0.4
Seasonal Ice	1 to 3	0 to 200	0.0	0.0	0.2	0.4	0.4
Seasonal Ice	1 to 3	200 to 800	0.0	0.0	0.2	0.4	0.4
Seasonal Ice	1 to 3	>= 800	0.0	0.0	0.2	0.4	0.4
Seasonal Ice	>= 3	-200 to 0	0.0	0.0	0.0	0.1	0.9
Seasonal Ice	>= 3	0 to 200	0.0	0.0	0.0	0.1	0.9
Seasonal Ice	>= 3	200 to 800	0.0	0.0	0.0	0.1	0.9
Seasonal Ice	>= 3	>= 800	0.0	0.0	0.0	0.1	0.9

node F2 – "Factor A: Habitat Threats"

Node B - Foraging habitat quantity change	Node D - Change in foraging habitat distribution	Node A - Foraging habitat value	Level of habitat threat			
			improvement	no effect	minor restriction	major restriction
0 to 20	improved availab	better	1.0	0.0	0.0	0.0
0 to 20	improved availab	same as now	1.0	0.0	0.0	0.0
0 to 20	improved availab	worse	0.8	0.2	0.0	0.0
0 to 20	same as now	better	1.0	0.0	0.0	0.0
0 to 20	same as now	same as now	0.8	0.2	0.0	0.0
0 to 20	same as now	worse	0.3	0.5	0.2	0.0
0 to 20	reduced avail	better	0.4	0.4	0.2	0.0
0 to 20	reduced avail	same as now	0.2	0.6	0.2	0.0
0 to 20	reduced avail	worse	0.0	0.2	0.6	0.2
0 to 20	Gr reduced avail	better	0.0	0.2	0.4	0.4
0 to 20	Gr reduced avail	same as now	0.0	0.0	0.4	0.6
0 to 20	Gr reduced avail	worse	0.0	0.0	0.2	0.8
0 to 20	unavailable	better	0.0	0.0	0.0	1.0
0 to 20	unavailable	same as now	0.0	0.0	0.0	1.0
0 to 20	unavailable	worse	0.0	0.0	0.0	1.0
-20 to 0	improved availab	better	0.8	0.2	0.0	0.0
-20 to 0	improved availab	same as now	0.2	0.6	0.2	0.0
-20 to 0	improved availab	worse	0.2	0.4	0.4	0.0
-20 to 0	same as now	better	0.2	0.6	0.2	0.0
-20 to 0	same as now	same as now	0.0	0.2	0.6	0.2
-20 to 0	same as now	worse	0.0	0.0	0.6	0.4
-20 to 0	reduced avail	better	0.1	0.5	0.2	0.2
-20 to 0	reduced avail	same as now	0.0	0.1	0.5	0.4
-20 to 0	reduced avail	worse	0.0	0.0	0.4	0.6
-20 to 0	Gr reduced avail	better	0.0	0.0	0.5	0.5
-20 to 0	Gr reduced avail	same as now	0.0	0.0	0.2	0.8
-20 to 0	Gr reduced avail	worse	0.0	0.0	0.0	1.0
-20 to 0	unavailable	better	0.0	0.0	0.0	1.0
-20 to 0	unavailable	same as now	0.0	0.0	0.0	1.0
-20 to 0	unavailable	worse	0.0	0.0	0.0	1.0

-40 to -20	improved availab	better	0.4	0.4	0.2	0.0
-40 to -20	improved availab	same as now	0.1	0.5	0.4	0.0
-40 to -20	improved availab	worse	0.0	0.3	0.5	0.2
-40 to -20	same as now	better	0.1	0.4	0.4	0.1
-40 to -20	same as now	same as now	0.0	0.1	0.4	0.5
-40 to -20	same as now	worse	0.0	0.0	0.4	0.6
-40 to -20	reduced avail	better	0.0	0.1	0.6	0.3
-40 to -20	reduced avail	same as now	0.0	0.0	0.5	0.5
-40 to -20	reduced avail	worse	0.0	0.0	0.2	0.8
-40 to -20	Gr reduced avail	better	0.0	0.0	0.3	0.7
-40 to -20	Gr reduced avail	same as now	0.0	0.0	0.0	1.0
-40 to -20	Gr reduced avail	worse	0.0	0.0	0.0	1.0
-40 to -20	unavailable	better	0.0	0.0	0.0	1.0
-40 to -20	unavailable	same as now	0.0	0.0	0.0	1.0
-40 to -20	unavailable	worse	0.0	0.0	0.0	1.0
< -40	improved availab	better	0.2	0.6	0.2	0.0
< -40	improved availab	same as now	0.0	0.2	0.6	0.2
< -40	improved availab	worse	0.0	0.0	0.5	0.5
< -40	same as now	better	0.0	0.1	0.6	0.3
< -40	same as now	same as now	0.0	0.0	0.3	0.7
< -40	same as now	worse	0.0	0.0	0.2	0.8
< -40	reduced avail	better	0.0	0.1	0.2	0.7
< -40	reduced avail	same as now	0.0	0.0	0.1	0.9
< -40	reduced avail	worse	0.0	0.0	0.0	1.0
< -40	Gr reduced avail	better	0.0	0.0	0.0	1.0
< -40	Gr reduced avail	same as now	0.0	0.0	0.0	1.0
< -40	Gr reduced avail	worse	0.0	0.0	0.0	1.0
< -40	unavailable	better	0.0	0.0	0.0	1.0
< -40	unavailable	same as now	0.0	0.0	0.0	1.0
< -40	unavailable	worse	0.0	0.0	0.0	1.0

node C1 – "Human disturbance"

Node B1 - Bear-human interactions	Node J - Shipping	Node R1 - Oil & gas activity	Node J1- Tourism	Level of human disturbance			
				reduced	same as now	elevated	greatly elevated
increased	increased	increase	increased	0.0	0.0	0.0	1.0
increased	increased	increase	same as now	0.0	0.0	0.0	1.0
increased	increased	increase	decreased	0.0	0.0	0.1	0.9
increased	increased	no change	increased	0.0	0.0	0.0	1.0
increased	increased	no change	same as now	0.0	0.0	0.1	0.9
increased	increased	no change	decreased	0.0	0.0	0.2	0.8
increased	increased	decrease	increased	0.0	0.0	0.3	0.7
increased	increased	decrease	same as now	0.0	0.0	0.6	0.4
increased	increased	decrease	decreased	0.0	0.0	0.5	0.5
increased	same as now	increase	increased	0.0	0.0	0.0	1.0
increased	same as now	increase	same as now	0.0	0.0	0.2	0.8
increased	same as now	increase	decreased	0.0	0.0	0.3	0.7
increased	same as now	no change	increased	0.0	0.0	0.5	0.5
increased	same as now	no change	same as now	0.0	0.0	0.7	0.3
increased	same as now	no change	decreased	0.0	0.2	0.6	0.2
increased	same as now	decrease	increased	0.0	0.0	0.7	0.3
increased	same as now	decrease	same as now	0.0	0.2	0.7	0.1
increased	same as now	decrease	decreased	0.0	0.4	0.6	0.0
same as now	increased	increase	increased	0.0	0.0	0.2	0.8
same as now	increased	increase	same as now	0.0	0.0	0.5	0.5
same as now	increased	increase	decreased	0.0	0.2	0.6	0.2
same as now	increased	no change	increased	0.0	0.2	0.8	0.0
same as now	increased	no change	same as now	0.0	0.3	0.7	0.0
same as now	increased	no change	decreased	0.0	0.5	0.5	0.0
same as now	increased	decrease	increased	0.0	0.3	0.7	0.0
same as now	increased	decrease	same as now	0.0	0.5	0.5	0.0
same as now	increased	decrease	decreased	0.0	0.6	0.4	0.0
same as now	same as now	increase	increased	0.0	0.2	0.8	0.0
same as now	same as now	increase	same as now	0.0	0.4	0.6	0.0
same as now	same as now	increase	decreased	0.0	0.5	0.5	0.0
same as now	same as now	no change	increased	0.0	0.8	0.2	0.0

same as now	same as now	no change	same as now	0.0	1.0	0.0	0.0
same as now	same as now	no change	decreased	0.1	0.9	0.0	0.0
same as now	same as now	decrease	increased	0.3	0.7	0.0	0.0
same as now	same as now	decrease	same as now	0.5	0.5	0.0	0.0
same as now	same as now	decrease	decreased	0.6	0.4	0.0	0.0
decreased	increased	increase	increased	0.0	0.0	0.6	0.4
decreased	increased	increase	same as now	0.0	0.2	0.6	0.2
decreased	increased	increase	decreased	0.0	0.3	0.7	0.0
decreased	increased	no change	increased	0.1	0.6	0.3	0.0
decreased	increased	no change	same as now	0.2	0.6	0.2	0.0
decreased	increased	no change	decreased	0.3	0.5	0.2	0.0
decreased	increased	decrease	increased	0.2	0.6	0.2	0.0
decreased	increased	decrease	same as now	0.3	0.7	0.0	0.0
decreased	increased	decrease	decreased	0.4	0.6	0.0	0.0
decreased	same as now	increase	increased	0.0	0.5	0.5	0.0
decreased	same as now	increase	same as now	0.2	0.6	0.2	0.0
decreased	same as now	increase	decreased	0.3	0.6	0.1	0.0
decreased	same as now	no change	increased	0.5	0.5	0.0	0.0
decreased	same as now	no change	same as now	0.7	0.3	0.0	0.0
decreased	same as now	no change	decreased	0.8	0.2	0.0	0.0
decreased	same as now	decrease	increased	0.9	0.1	0.0	0.0
decreased	same as now	decrease	same as now	1.0	0.0	0.0	0.0
decreased	same as now	decrease	decreased	1.0	0.0	0.0	0.0

node C2 – "Pollution"

Node R4 - Hydrocarbons / oil spill	Node T1 - Contaminants	Level of pollution reduced	same as now	elevated	greatly elevated
increased occurr	elevated	0.0	0.0	0.0	1.0
increased occurr	same as now	0.0	0.0	0.6	0.4
increased occurr	reduced	0.0	0.4	0.4	0.2
same as now	elevated	0.0	0.3	0.7	0.0
same as now	same as now	0.0	1.0	0.0	0.0
same as now	reduced	0.4	0.6	0.0	0.0
decreased occurr	elevated	0.3	0.5	0.2	0.0
decreased occurr	same as now	0.8	0.2	0.0	0.0
decreased occurr	reduced	1.0	0.0	0.0	0.0

node A6 – "Factor E. Other factors natural or man-made"

Node C1 - C1	Node C2 - C2	Level of other factors improvement	no effect	minor restrictio	major restrictio
reduced	reduced	1.0	0.0	0.0	0.0
reduced	same as now	1.0	0.0	0.0	0.0
reduced	elevated	0.3	0.4	0.3	0.0
reduced	greatly elevated	0.0	0.3	0.3	0.4
same as now	reduced	0.6	0.4	0.0	0.0
same as now	same as now	0.0	1.0	0.0	0.0
same as now	elevated	0.0	0.4	0.6	0.0
same as now	greatly elevated	0.0	0.2	0.2	0.6
elevated	reduced	0.0	0.2	0.5	0.3
elevated	same as now	0.0	0.0	0.5	0.5
elevated	elevated	0.0	0.0	0.4	0.6
elevated	greatly elevated	0.0	0.0	0.3	0.7
greatly elevated	reduced	0.0	0.0	0.3	0.7
greatly elevated	same as now	0.0	0.0	0.2	0.8
greatly elevated	elevated	0.0	0.0	0.1	0.9
greatly elevated	greatly elevated	0.0	0.0	0.0	1.0

node C3 – "Distribution Response"

Node F2 - Factor A. Habitat Threats	Node A6 - Factor E. Other factors (natural or man-made)	Node G - Relocation possible	Distribution response same as now	reduced but resi	transient visito	extirpated
improvement	improvement	Yes	1.0	0.0	0.0	0.0
improvement	improvement	No	1.0	0.0	0.0	0.0
improvement	no effect	Yes	1.0	0.0	0.0	0.0
improvement	no effect	No	1.0	0.0	0.0	0.0
improvement	minor restrictio	Yes	0.9	0.1	0.0	0.0
improvement	minor restrictio	No	0.9	0.1	0.0	0.0
improvement	major restrictio	Yes	0.8	0.1	0.1	0.0
improvement	major restrictio	No	0.8	0.2	0.0	0.0
no effect	improvement	Yes	1.0	0.0	0.0	0.0
no effect	improvement	No	1.0	0.0	0.0	0.0
no effect	no effect	Yes	1.0	0.0	0.0	0.0
no effect	no effect	No	1.0	0.0	0.0	0.0
no effect	minor restrictio	Yes	0.8	0.1	0.1	0.0
no effect	minor restrictio	No	0.8	0.2	0.0	0.0
no effect	major restrictio	Yes	0.5	0.2	0.3	0.0
no effect	major restrictio	No	0.5	0.5	0.0	0.0
minor restrictio	improvement	Yes	0.5	0.25	0.25	0.0
minor restrictio	improvement	No	0.5	0.5	0.0	0.0
minor restrictio	no effect	Yes	0.4	0.3	0.3	0.0
minor restrictio	no effect	No	0.4	0.6	0.0	0.0
minor restrictio	minor restrictio	Yes	0.3	0.3	0.4	0.0
minor restrictio	minor restrictio	No	0.3	0.6	0.0	0.1
minor restrictio	major restrictio	Yes	0.2	0.2	0.6	0.0
minor restrictio	major restrictio	No	0.2	0.5	0.0	0.3
major restrictio	improvement	Yes	0.0	0.3	0.35	0.35
major restrictio	improvement	No	0.0	0.3	0.0	0.7
major restrictio	no effect	Yes	0.0	0.2	0.4	0.4
major restrictio	no effect	No	0.0	0.2	0.0	0.8
major restrictio	minor restrictio	Yes	0.0	0.1	0.45	0.45
major restrictio	minor restrictio	No	0.0	0.1	0.0	0.9
major restrictio	major restrictio	Yes	0.0	0.0	0.3	0.7
major restrictio	major restrictio	No	0.0	0.0	0.0	1.0

node K – "Adult Body Condition"

Node F2 -	Quality of adult body condition		
Factor A. Habitat Threats	increase	same as now	decrease
improvement	1.0	0.0	0.0
no effect	0.0	1.0	0.0
minor restrictio	0.0	0.5	0.5
major restrictio	0.0	0.0	1.0

node L1 – "Adult Female Survival"

Node K -	Node F2 -	Adult Female Survival		
Adult Body	Factor A.		no	
Condition	Habitat Threats	increase	change	decrease
increase	improvement	1.0	0.0	0.0
increase	no effect	0.8	0.2	0.0
increase	minor restrictio	0.1	0.6	0.3
increase	major restrictio	0.0	0.5	0.5
same as now	no effect	0.5	0.5	0.0
same as now	minor restrictio	0.0	0.6	0.4
same as now	major restrictio	0.0	0.3	0.7
decrease	improvement	0.0	0.4	0.6
decrease	no effect	0.0	0.2	0.8
decrease	minor restrictio	0.0	0.1	0.9
decrease	major restrictio	0.0	0.0	1.0

node L – "Juvenile Survival"

Node K - Adult Body Condition	Node L1 - Adult Female Survival	Juvenile Survival		
		increase	no change	decrease
increase	increase	1.0	0.0	0.0
increase	no change	0.7	0.3	0.0
increase	decrease	0.0	0.4	0.6
same as now	increase	0.8	0.2	0.0
same as now	no change	0.0	1.0	0.0
same as now	decrease	0.0	0.2	0.8
decrease	increase	0.0	0.6	0.4
decrease	no change	0.0	0.3	0.7
decrease	decrease	0.0	0.0	1.0

node V1 – "Cub production per event"

Node F2 -	Cub Production per event		
Factor A. Habitat Threats	Fewer than now	same as now	more than now
improvement	0.0	0.3	0.7
no effect	0.0	1.0	0.0
minor restrictio	0.6	0.4	0.0
major restrictio	1.0	0.0	0.0

node U – "Reproduction"

Node M - Geographic Area	Node V1 - Cub production per event	Node N - Shelf Distance Change (km)	Rate of reproduction increased	same as now	decreased
Polar Basin Dive	Fewer than now	-200 to 0	0.0	0.3	0.7
Polar Basin Dive	Fewer than now	0 to 200	0.0	0.2	0.8
Polar Basin Dive	Fewer than now	200 to 800	0.0	0.0	1.0
Polar Basin Dive	Fewer than now	>= 800	0.0	0.0	1.0
Polar Basin Dive	same as now	-200 to 0	0.7	0.3	0.0
Polar Basin Dive	same as now	0 to 200	0.0	1.0	0.0
Polar Basin Dive	same as now	200 to 800	0.0	0.3	0.7
Polar Basin Dive	same as now	>= 800	0.0	0.0	1.0
Polar Basin Dive	more than now	-200 to 0	1.0	0.0	0.0
Polar Basin Dive	more than now	0 to 200	0.5	0.5	0.0
Polar Basin Dive	more than now	200 to 800	0.0	0.5	0.5
Polar Basin Dive	more than now	>= 800	0.0	0.0	1.0
Polar Basin Conv	Fewer than now	-200 to 0	0.0	0.5	0.5
Polar Basin Conv	Fewer than now	0 to 200	0.0	0.4	0.6
Polar Basin Conv	Fewer than now	200 to 800	0.0	0.3	0.7
Polar Basin Conv	Fewer than now	>= 800	0.0	0.2	0.8
Polar Basin Conv	same as now	-200 to 0	1.0	0.0	0.0
Polar Basin Conv	same as now	0 to 200	0.5	0.5	0.0
Polar Basin Conv	same as now	200 to 800	0.2	0.6	0.2
Polar Basin Conv	same as now	>= 800	0.0	0.5	0.5
Polar Basin Conv	more than now	-200 to 0	1.0	0.0	0.0
Polar Basin Conv	more than now	0 to 200	0.8	0.2	0.0
Polar Basin Conv	more than now	200 to 800	0.4	0.4	0.2
Polar Basin Conv	more than now	>= 800	0.2	0.4	0.4
Archipelago	Fewer than now	-200 to 0	0.0	0.2	0.8
Archipelago	Fewer than now	0 to 200	0.0	0.2	0.8
Archipelago	Fewer than now	200 to 800	0.0	0.2	0.8
Archipelago	Fewer than now	>= 800	0.0	0.2	0.8
Archipelago	same as now	-200 to 0	0.2	0.6	0.2
Archipelago	same as now	0 to 200	0.2	0.6	0.2
Archipelago	same as now	200 to 800	0.2	0.6	0.2

Archipelago	same as now	>= 800	0.2	0.6	0.2
Archipelago	more than now	-200 to 0	0.8	0.2	0.0
Archipelago	more than now	0 to 200	0.8	0.2	0.0
Archipelago	more than now	200 to 800	0.8	0.2	0.0
Archipelago	more than now	>= 800	0.8	0.2	0.0
Seasonal Ice	Fewer than now	-200 to 0	0.0	0.2	0.8
Seasonal Ice	Fewer than now	0 to 200	0.0	0.2	0.8
Seasonal Ice	Fewer than now	200 to 800	0.0	0.2	0.8
Seasonal Ice	Fewer than now	>= 800	0.0	0.2	0.8
Seasonal Ice	same as now	-200 to 0	0.2	0.6	0.2
Seasonal Ice	same as now	0 to 200	0.2	0.6	0.2
Seasonal Ice	same as now	200 to 800	0.2	0.6	0.2
Seasonal Ice	same as now	>= 800	0.2	0.6	0.2
Seasonal Ice	more than now	-200 to 0	0.8	0.2	0.0
Seasonal Ice	more than now	0 to 200	0.8	0.2	0.0
Seasonal Ice	more than now	200 to 800	0.8	0.2	0.0
Seasonal Ice	more than now	>= 800	0.8	0.2	0.0

node L2 – "Vital Rates"

Node L1 - Adult Female Surival	Node L - Juvenile Survival	Node U - Reproduction	Vital Rates improve	same as now	decline
increase	increase	increased	1.0	0.0	0.0
increase	increase	same as now	1.0	0.0	0.0
increase	increase	decreased	0.6	0.4	0.0
increase	no change	increased	0.9	0.1	0.0
increase	no change	same as now	0.8	0.2	0.0
increase	no change	decreased	0.7	0.2	0.1
increase	decrease	increased	0.3	0.5	0.2
increase	decrease	same as now	0.2	0.5	0.3
increase	decrease	decreased	0.0	0.4	0.6
no change	increase	increased	0.7	0.3	0.0
no change	increase	same as now	0.6	0.4	0.0
no change	increase	decreased	0.2	0.5	0.3
no change	no change	increased	0.2	0.8	0.0
no change	no change	same as now	0.0	1.0	0.0
no change	no change	decreased	0.0	0.8	0.2
no change	decrease	increased	0.0	0.6	0.4
no change	decrease	same as now	0.0	0.5	0.5
no change	decrease	decreased	0.0	0.3	0.7
decrease	increase	increased	0.2	0.4	0.4
decrease	increase	same as now	0.0	0.6	0.4
decrease	increase	decreased	0.0	0.5	0.5
decrease	no change	increased	0.1	0.5	0.4
decrease	no change	same as now	0.0	0.4	0.6
decrease	no change	decreased	0.0	0.3	0.7
decrease	decrease	increased	0.0	0.2	0.8
decrease	decrease	same as now	0.0	0.0	1.0
decrease	decrease	decreased	0.0	0.0	1.0

node A1 – "Factor B. Overutilization"

Node E - Intentional Takes	Node A6 - Factor E. Other factors (natural or man-made)	Level of Overutilization		
		fewer	same as now	more
increased	improvement	0.0	0.4	0.6
increased	no effect	0.0	0.0	1.0
increased	minor restrictio	0.0	0.0	1.0
increased	major restrictio	0.0	0.0	1.0
same as now	improvement	1.0	0.0	0.0
same as now	no effect	0.0	1.0	0.0
same as now	minor restrictio	0.0	0.6	0.4
same as now	major restrictio	0.0	0.3	0.7
decreased	improvement	1.0	0.0	0.0
decreased	no effect	1.0	0.0	0.0
decreased	minor restrictio	0.0	0.8	0.2
decreased	major restrictio	0.0	0.6	0.4

node A4 – "Factor C. Disease, predation"

Node T - Parasites & Disease	Node T2 - Predation	Level of disease, predation	
		same as now	worse
influential	influential	0.0	1.0
influential	not	0.3	0.7
not	influential	0.7	0.3
not	not	1.0	0.0

node C4 – "Numerical Response"

Node L2 - Vital Rates	Node A1 - Factor B. Overutilization	Node A4 - Factor C. Disease, Predation	Numerical Response increased densit	same as now	reduced density	rare	absent
improve	fewer	same as now	1.0	0.0	0.0	0.0	0.0
improve	fewer	worse	0.5	0.25	0.25	0.0	0.0
improve	same as now	same as now	0.8	0.2	0.0	0.0	0.0
improve	same as now	worse	0.5	0.25	0.25	0.0	0.0
improve	more	same as now	0.3	0.35	0.35	0.0	0.0
improve	more	worse	0.1	0.4	0.5	0.0	0.0
same as now	fewer	same as now	0.2	0.8	0.0	0.0	0.0
same as now	fewer	worse	0.0	0.8	0.2	0.0	0.0
same as now	same as now	same as now	0.0	1.0	0.0	0.0	0.0
same as now	same as now	worse	0.0	0.3	0.7	0.0	0.0
same as now	more	same as now	0.0	0.2	0.8	0.0	0.0
same as now	more	worse	0.0	0.0	1.0	0.0	0.0
decline	fewer	same as now	0.0	0.5	0.5	0.0	0.0
decline	fewer	worse	0.0	0.3	0.7	0.0	0.0
decline	same as now	same as now	0.0	0.0	1.0	0.0	0.0
decline	same as now	worse	0.0	0.0	0.75	0.25	0.0
decline	more	same as now	0.0	0.0	0.4	0.4	0.2
decline	more	worse	0.0	0.0	0.2	0.4	0.4

node D1 – "overall population outcome"

Node C4 -	Node C3 -	Overall population outcome				
Numerical response	Distribution response	larger	same as now	smaller	rare	extinct
increased densit	same as now	1.0	0.0	0.0	0.0	0.0
increased densit	reduced but resi	0.3	0.5	0.2	0.0	0.0
increased densit	transient visito	0.1	0.3	0.3	0.3	0.0
increased densit	extirpated	0.0	0.0	0.0	0.0	1.0
same as now	same as now	0.0	1.0	0.0	0.0	0.0
same as now	reduced but resi	0.0	0.3	0.7	0.0	0.0
same as now	transient visito	0.0	0.0	0.6	0.4	0.0
same as now	extirpated	0.0	0.0	0.0	0.0	1.0
reduced density	same as now	0.0	0.0	1.0	0.0	0.0
reduced density	reduced but resi	0.0	0.0	0.7	0.3	0.0
reduced density	transient visito	0.0	0.0	0.3	0.7	0.0
reduced density	extirpated	0.0	0.0	0.0	0.0	1.0
rare	same as now	0.0	0.0	0.0	1.0	0.0
rare	reduced but resi	0.0	0.0	0.0	0.8	0.2
rare	transient visito	0.0	0.0	0.0	0.7	0.3
rare	extirpated	0.0	0.0	0.0	0.0	1.0
absent	same as now	0.0	0.0	0.0	0.0	1.0
absent	reduced but resi	0.0	0.0	0.0	0.0	1.0
absent	transient visito	0.0	0.0	0.0	0.0	1.0
absent	extirpated	0.0	0.0	0.0	0.0	1.0