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Rebuttal of "Polar Bear Population Forecasts: A Public-Policy Forecasting Audit"

Steven C. Amstrup
US Geological Survey, Alaska Science Center, Anchorage, Alaska 99508, samstrup@usgs.gov

Hal Caswell
Biology Department, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, hcaswell@whoi.edu

Eric DeWeaver
Atmospheric and Oceanic Science Department, University of Maryland, College Park, Maryland 20742, eric@atmos.umd.edu

Ian Stirling
Wildlife Research Division, Science and Technology Branch, Environment Canada, Edmonton, Alberta T6H 3S5, Canada, ian.stirling@ec.gc.ca

David C. Douglas
US Geological Survey, Alaska Science Center, Juneau, Alaska 99801, ddouglas@usgs.gov

Bruce G. Marcot
USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon 97205, bmarcot@fs.fed.us

Christine M. Hunter
Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, Alaska 99775, ffcmh1@uaf.edu

Observed declines in the Arctic sea ice have resulted in a variety of negative effects on polar bears (*Ursus maritimus*). Projections for additional future declines in sea ice resulted in a proposal to list polar bears as a threatened species under the United States Endangered Species Act. To provide information for the Department of the Interior's listing-decision process, the US Geological Survey (USGS) produced a series of nine research reports evaluating the present and future status of polar bears throughout their range. In response, Armstrong et al. [Armstrong, J. S., K. C. Green, W. Soon. 2008. Polar bear population forecasts: A public-policy forecasting audit. *Interfaces* **38**(5) 382–405], which we will refer to as AGS, performed an audit of two of these nine reports. AGS claimed that the general circulation models upon which the USGS reports relied were not valid forecasting tools, that USGS researchers were not objective or lacked independence from policy decisions, that they did not utilize all available information in constructing their forecasts, and that they violated numerous principles of forecasting espoused by AGS. AGS (p. 382) concluded that the two USGS reports were "unscientific and inconsequential to decision makers." We evaluate the AGS audit and show how AGS are mistaken or misleading on every claim. We provide evidence that general circulation models are useful in forecasting future climate conditions and that corporate and government leaders are relying on these models to do so. We clarify the strict independence of the USGS from the listing decision. We show that the allegations of failure to follow the principles of forecasting espoused by AGS are either incorrect or are based on misconceptions about the Arctic environment, polar bear biology, or statistical and mathematical methods. We conclude by showing that the AGS principles of forecasting are too ambiguous and subjective to be used as a reliable basis for auditing scientific investigations. In summary, we show that the AGS audit offers no valid criticism of the USGS conclusion that global warming poses a serious threat to the future welfare of polar bears and that it only serves to distract from reasoned public-policy debate.

Key words: polar bear; *Ursus maritimus*; global warming; climate models; forecasting principles; forecasts; projections; audit; Endangered Species Act.
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Polar bears (*Ursus maritimus*) are highly dependent on Arctic sea ice, and recent 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. 2007a). Observed sea ice declines (Maslanik et al. 1996, Overpeck et al. 2005, Stroeve et al. 2005, Comiso 2006, Serreze et al. 2007) and projected declines (Holland et al. 2006, Zhang and Walsh 2006, Stroeve et al. 2007) suggest that the future welfare of polar bears rangewide might be diminished. In January 2007, the US Secretary of the Interior proposed listing the polar bear as a threatened species under the Endangered Species Act (ESA) (US Fish and Wildlife Service 2007). Classification as a "threatened species" under the ESA requires a determination that the species in question will become "endangered" 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.

By law, a decision on a proposed ESA listing must be made within one year of the proposal. During that year, public comments and additional scientific analyses are considered in the decision-making process. To inform the polar bear listing "decision," the Secretary of the Interior requested that the US Geological Survey (USGS) conduct additional analyses of polar bears and their sea ice habitats. USGS scientists and collaborators analyzed data from a variety of sources; in September 2007, they produced nine reports targeting specific questions identified as pertinent to the final decision by the US Fish and Wildlife Service (FWS). A defining feature of several of the USGS reports was the use of sea ice projections from global climate or general circulation models (GCMs), which had been incorporated into the reports of the Intergovernmental Panel on Climate Change (IPCC), to forecast changes in polar bear habitat.

In response to the proposal to list the polar bear and to the release of the USGS reports, Armstrong et al. (2008; AGS) performed an audit of two of the USGS reports. This audit claimed that (1) GCMs are not valid for forecasting climate and therefore are of no value in projecting the future of polar bears, (2) the USGS researchers were biased, and (3) the USGS violated numerous forecasting principles espoused by AGS.

In this paper, we respond to the AGS audit. We explain why and how GCMs are valid tools for forecasting future climate, we show that the USGS researchers were unbiased, and we show that AGS failed to understand both the simulation modeling based on empirical data and the interpretation of the results of this modeling. Finally, we examine the principles of forecasting espoused by AGS and show that they are ambiguous and subjective, and therefore cannot be used to evaluate scientific processes.

The Claims of the AGS Audit

AGS focused on two USGS reports: Amstrup et al. (2007) and Hunter et al. (2007). Amstrup et al. (2007) presented an analytic carrying-capacity model and a Bayesian network (BN) model that used the wide range of information available on polar bears worldwide and sea ice projections (based on GCMs) to forecast future polar bear population trends throughout the Arctic. Hunter et al. (2007) used empirical data from an intensive sampling program from 2001–2006 to develop a demographic model of the polar bear population in the southern Beaufort Sea, and then linked that model to projections of future sea ice conditions obtained from GCMs.

The AGS audit made three major claims:

(1) AGS claimed that the GCMs that the IPCC used are not valid for forecasting future climate, and that because the USGS reports were based on outcomes of GCMs, the USGS projections of polar bear populations are invalid.

(2) AGS claimed that the USGS researchers were not objective and lacked independence from "organizational bias or pressure" during the preparation of their reports.

(3) AGS claimed the USGS researchers failed to follow certain principles of forecasting. AGS provided examples of some of these alleged failures, including, but not limited to, improper use of data, improper analysis and interpretation, and incorrect policy decisions.

Below, we respond to each AGS allegation.

Alleged Failure of General Circulation Models to Forecast Future Climate

AGS claimed that the GCMs developed for the IPCC and used by the USGS do not provide forecasts of future climate. They stated this claim, which preceded all other AGS arguments, as a fact that therefore negated any uses to which the USGS might have put the GCM results. After claiming that GCMs do not provide valid forecasts, AGS (p. 382) stated, "Nevertheless, we audited their conditional forecasts of what would happen to the polar bear population *assuming*, as the authors did, that the extent of summer sea ice would decrease substantially during the coming decades." This argument, that GCMs are not valid forecasting tools, expressed as unqualified fact, could a priori bias AGS readers against the information in the USGS reports. Therefore, we provide some detail regarding why GCMs are valid for climate forecasting, and we provide examples of how these forecasts are already being used in important policy decisions.

AGS (p. 384) supported their claim that GCMs are not valid for forecasting future climate with an out-of-context quotation, taken from a blog (Trenberth 2007) by the climate scientist Kevin Trenberth. In that quote, however, Trenberth was saying that GCMs do not make unconditional predictions. Rather, GCMs allow projection of future climate when they include a persistent directional climate forcing, such as increasing concentrations of greenhouse gases (GHGs).

The earth maintains an energy balance with space in which incoming shortwave radiation from the sun ultimately must be balanced by the outgoing long-wave radiation emitted from the earth and its atmosphere (Lutgens and Tarbuck 2004). A climate forcing is any factor that perturbs that balance (Hansen and Sato 2004). GHGs provide a forcing by increasing the degree to which the sun's energy is retained and heats the earth before being reradiated into space. Increases in solar radiation can also provide a positive climate forcing. The shading effects of aerosols released into the atmosphere by volcanoes can provide a negative climate forcing—cooling the earth by reflecting the sun's energy back into space before it can warm the earth. In contrast to weather forecasts, which are predictions based upon a set of initial conditions, climate-model forecasts are conditional on these forcing scenarios (e.g., a set of GHG concentration values for each year). Such conditional predictions are commonly referred to as projections of future climate change. The projected climate change (the climate forecast) depends on the forcing scenario (e.g., the rate of GHG increase, or the atmospheric prevalence of aerosols) assumed. Without a persistent climate forcing, the climate in a GCM merely fluctuates because of the natural variability in the simulated climate system. In that case, climate models would indeed provide poor projections of future climate.

The important point, from a forecasting perspective, is that the application of a persistent climate forcing requires a directional response in the earth's climate. It is by virtue of this requirement that GCMs make predictions of future climate. The basic physics of the earth's climate system, which Charney (1979), Hartmann (1994), Philander (1998), Weart (2003), Held and Soden (2000), Le Treut et al. (2007), and others describe, guarantees that the earth's temperature will warm as GHG concentrations rise. There will still be natural fluctuations in the climate system because of shifting oceanic and atmospheric circulation patterns and other forcings (e.g., volcanic eruptions). These fluctuations, however, will occur over a higher baseline than otherwise would have been the case. Hence, the general trajectories of rising temperatures and less sea ice than otherwise would have been the case are assured.

Another important implication of GHG-forced global warming is that the likelihood of exceeding particular climate thresholds becomes greater over time. Depending on the natural chaotic behavior of the climate system and the amplifying effects of positive climate feedbacks, the year in which the increase in global mean temperature exceeds, say, 2°C might occur before or after the end of the 21st century. However, a continuing buildup of GHGs makes exceeding this temperature threshold virtually certain. The same premise holds for ice-free conditions in the Arctic. Natural variability and uncertainty in climate feedbacks prevent GCMs from predicting the year in which ice-free summers will first occur. However, we can be confident that, given continued GHG increases, ice-free Arctic summers ultimately will become the norm. The farther into the future we look, the more likely it is that this threshold will have been crossed. The farther into the future GCMs project, the more consistently they project ice-free Arctic summers.

Therefore, climate forecasts are fundamentally different from weather forecasts. Whereas skillful weather forecasting depends critically on accurate representation of the initial state, the skill of GCM projections depends primarily on the accurate representation of the sensitivity of global climate to GHGs and other climate forcings (Randall et al. 2007). Successful simulations of past climates, volcanically induced climate perturbations, and recent temperature trends suggest that GCMs largely have incorporated the physics of climate forcings correctly (Hansen et al. 1996, 2006; Soden et al. 2002; Jansen et al. 2007; Rahmstorf et al. 2007) and can thus provide credible projections of future climate change (Randall et al. 2007).

This difference between dependence on climate sensitivity and dependence on initial conditions explains the apparent paradox between confidently predicting aspects of the general climate 50 years from now, but not being able to predict the weather a few weeks from now (Le Treut et al. 2007). A weather forecast substantially bases the prediction of tomorrow's or next week's weather on today's weather; thus, the error of the prediction necessarily grows with time. Conversely, GCM-based predictions of ice-free Arctic summers become more certain as time progresses. This is because global warming causes ice-free conditions, and the world will continue to warm as GHG levels increase. Therefore, assuming that current trends in GHG emissions persist, the forecast of ice-free Arctic summers by 2100 is more accurate than the forecast of ice-free conditions by, for example, 2020.

The USGS used GCM outputs to project polar bear habitat and populations for the middle and latter part of the century, and hence benefited from the increased certainty of reduced summer sea ice for the more distant time frames. In addition, the USGS researchers used forecasts from an ensemble of climate models; therefore, they could assess the uncertainties in climate-model projections and in polar bears' reactions and incorporate them into their projections of the decline of polar bear habitat and populations.

The GCM projections used by the USGS were based on the assumption that levels of GHG buildup during the 21st century would follow the anticipated business-as-usual trajectory, i.e., the A1B scenario (Nakicenovic et al. 2000). Sea ice decline might be less severe if GHG increases are lower than the USGS assumed, and reliance on the A1B scenario could be criticized in that regard. Atmospheric CO_2, however, has been increasing faster than the A1B scenario projected because of increases in emissions and a decline in the efficiency of CO_2 uptake by carbon sinks on land and in the ocean (Canadell et al. 2007). Therefore, there seems little reason for optimism that the GHG buildup will be less than the A1B scenario projection that the USGS used.

The foundation of GCMs in accepted physical principles and the ability of GCMs to reproduce observed features of current climate and past climate changes have resulted in "considerable confidence that GCMs provide credible quantitative estimates of future climate change, particularly at continental scales and above" (Randall et al. 2007, p. 600). This confidence recently has been reflected in a variety of private- and public-policy actions, as the following examples illustrate.

- Former US Senator Ted Stevens (R-Alaska) initiated an effort in Congress to implement new fisheries-management policies for the Arctic in response to forecasted reductions in sea ice (*SitNews* 2008).
- The US Coast Guard has begun considering new base locations to follow forecasted sea ice retreats (Wald and Revkin 2007).
- The US Climate Change Science Program (USCCSP) has concluded that forecasts of increasingly severe storms, floods, and droughts, which GCM outputs have suggested for years (Weart 2003), are now a reality and will increase in frequency and intensity in the future (US Climate Change Science Program 2008).
- Major insurance companies are implementing corporate programs to address the forecasts for climate change (Atkins 2004, Britt 2005, Scherer 2006). The US Government Accountability Office corroborated the increased risks that government and private insurers face because of global warming forecasts (US Government Accountability Office 2007).

In view of the compelling evidence that GCMs provide valid estimates of the climate response to GHG increases, and because policy decisions have been made based upon these estimates, the AGS claim that GCMs are not valid for forecasting the future climate is puzzling. AGS appear to have simply chosen to believe, despite the laws of physics, that human contributions of GHGs to the atmosphere do not warm the world. Two of them expressed this view in their audit of the scientific reports of the IPCC 4th Assessment when they came to this remarkable conclusion: "Claims that the Earth will get warmer have no more credence than saying that it will get colder" (Green and Armstrong 2007, p. 997). The average temperatures over which climate variations (natural and those that might be forced by other human factors) occur must continue to rise as long as GHG concentrations continue to increase. Therefore, this conclusion represents faithful adherence to opinion despite contravening facts. Green and Armstrong (2007, p. 997) also concluded that the thousands of refereed scientific publications that comprise the basis of the IPCC reports and represent the state of scientific knowledge on past, present, and future climates "were not the outcome of scientific procedures." Such cavalier statements appear to reflect an overt attempt by the authors of those reports to cast doubt about the reality of human-caused global warming and our understanding of it.

Readers must be aware that AGS's strong bias against the reality of global warming could have adversely affected their examination of the USGS reports. As we show in subsequent sections, AGS audited the USGS reports based on a series of subjective forecasting principles. In performing their audit, each author graded the reports on conformity to these subjective criteria. Given this procedure, a bias shared by all AGS authors is likely to have influenced the grading and skewed the results toward an unfavorable assessment. Because AGS and Green and Armstrong (2007) incorrectly portrayed the known relationship between GHGs and global warming and the use of GCMs as tools for estimating the climate response to GHG forcing, the problem of bias in the application of subjective auditing criteria by AGS cannot be overlooked.

Alleged Political Influence on USGS Research

AGS (p. 384) claimed that the USGS research was subject to "organizational bias or pressure," and thus violated the principle of keeping forecasts "independent of politics." The authors appeared to believe that USGS researchers lacked independence from politics because they were part of a "USGS Science Strategy to support the US Fish and Wildlife Service Polar Bear Listing Decision." The USGS reports were developed to support the decision-making process. Contrary to AGS assertions, however, none of the reports makes recommendations on the decision. In a separate review, Cochran (2008, pp. 397–398) also emphasized the absence of any policy recommendations in the USGS reports.

The USGS reports provided scientific results and interpretations to help FWS and the Secretary of the Interior decide whether or not to list polar bears as a threatened species. There were no expressed or implied management or policy recommendations in any of the nine reports (Cochran 2008, p. 397). As the ESA provides, a proposal to list a species triggers a process that involves further research and consideration of public comments. The USGS research was part of this information-gathering process. The USGS reports made data-based forecasts of polar bear population dynamics; they incorporated those population demographic forecasts with other information into broader forecasts of the future worldwide status of polar bears. These forecasts, along with other inputs, informed the decision-making process mandated by the ESA (US Fish and Wildlife Service 2008). No recommendations regarding the decision, however, were asked or offered. The AGS (p. 383) claim that the USGS reports made "recommendations with respect to the polar bear listing decision" is totally unfounded (Cochran 2008).

The AGS claims that the USGS reports were somehow biased reveal that the authors do not understand the difference between forecasts of ecological outcomes and policy recommendations that address the possible ranges of outcomes. AGS (pp. 383–384) claim that to go from the USGS forecasts to policy recommendations, one must assume the following: Global warming will continue to reduce sea ice extent, polar bears will be unable to adapt, listing will be a successful solution to the threats facing the polar bear, and other policies would be inferior to an ESA listing. The USGS reports considered the first two of these four claims (we already have established the fact of global warming, and we discuss adaptation in detail below). The last two were irrelevant to the USGS work (Cochran 2008, p. 397). The USGS role was to provide scientific input into the decision-making process. Consideration of other management mechanisms or strategies was wholly in the realm of the decision makers. Although ESA provides for policy makers to consider the adequacy of existing regulatory mechanisms, it does not expressly provide for incorporating "what-if" considerations regarding other possible actions that might be invoked to protect a species. These last two points, therefore, were not appropriate for the USGS to consider and did not enter into the research described in its reports.

AGS claims of bias also suggest they are unaware that different branches of the US Department of the Interior have different responsibilities regarding research and policy. The USGS is its research arm; the USGS role is to provide science that can be used in management or policy decisions that the other agencies within the department (e.g., FWS) or departmental-level personnel (e.g., the Secretary of the Interior) make. Science and policy functions are insulated from each other precisely to prevent bias from entering into scientific results. In the case of the nine USGS reports, there was a strict separation of research and policy staff throughout the period between the proposal to list polar bears and the final decision. Results of the USGS research were withheld from FWS decision makers until the reports were publicly released in September 2007, and the FWS decision-related activities were conducted independently from USGS personnel.

Alleged Failures of Amstrup et al. (2007) to Follow Principles of Forecasting

AGS claimed to audit the USGS reports by comparing the methods used in those reports to a set of self-described principles of forecasting. In many cases, however, AGS incorrectly stated what the USGS actually did, thereby making any evaluation relative to forecasting principles problematic. In this section, we review the alleged failures of the USGS to follow the forecasting principles. We illustrate how AGS appeared not to understand the USGS reports and the research on which they were based, and we show how their audit could mislead the reader. This next section focuses on Amstrup et al. (2007), which we will refer to as AMD, and the following section focuses on Hunter et al. (2007). In our last section, we examine the principles themselves.

Alleged Failure to Match Methods to the Situation

AGS (p. 385) accused AMD of failing to "match the forecasting methods to the situation (Principle 6.7)." In fact, the research in AMD was carefully matched to the situation. The first aspect of "the situation" is that the analysis was to inform a listing decision under the ESA. Therefore, it had to address the factors that the ESA identified (e.g., habitat destruction, overutilization, disease). These considerations were included explicitly as summary nodes in the BN model that AMD presented. Incorporating the ESA listing factors directly into the model assured that policy makers could see the relevance of model outcomes to the legal requirements for listing as specified in the ESA.

Using the BN model was itself a way to assure that the work of AMD matched the situation. AMD needed to consider the possible effects of numerous inputs on the posterior probability of various outcome states. Indeed, the final BN model described in AMD included 38 nodes, 44 links, and 1,667 conditional probability values. Because the input variables in BN models are linked to probable outcome states with Bayesian learning (Jensen 2001), the logic of the links is established by Bayes' theorem rather than being dependent upon the judgment of the individuals performing the analysis. Biological syntheses are typically mental exercises in which domain experts attempt to derive likely outcome states from the available information inputs. Clearly, the collection of inputs that AMD wanted to consider would have been difficult to synthesize as a mental exercise alone. The BN model, however, provided a logical structure by which such large numbers of variables could be linked logically to provide probabilities of various outcome states without relying solely on the judgments of AMD. This process assured that the analytical process in AMD was, as well as possible, matched to the situation.

AMD also assured that their work matched the situation by making the methods as transparent as possible. Because the USGS findings were to inform an important management decision, it was necessary to make the steps from data to conclusions, and the uncertainty in those conclusions, as transparent as possible. Thus, AMD specified each input value, assumption, and conditional probability assignment used in the BN model. The program that was used to calculate the Bayesian links among all the variables was carefully described in AMD and is available to anyone. Contrary to transforming "opinions into a complex set of formulae" as AGS (p. 385) described it, AMD carefully explained the biological and geophysical bases of all inputs and documented all inputs within the text and tables of the report. Every component of the model represented a matching of the forecasting methods to the situation; any reader of AMD could exactly replicate the BN model results. This transparency was an essential part of the situation.

Alleged Failure to be Conservative Under Uncertainty

AGS (p. 386) accused AMD of violating the principle "Be conservative in situations of high uncertainty or instability (Principle 7.3)," where "being conservative means moving forecasts towards 'no change' ... ."

Actually, AGS overlooked the fact that AMD did invoke this definition of "conservative" as it applies to trends. Given an unequivocal trend of nearly four decades of sea ice decline as Figure 3 in Meier et al. (2007) and Figure 1 in Stroeve et al. (2007) illustrate, and given the documented impact of that decline on preferred polar bear habitats (Durner et al. 2009), the conservative action was to apply the principle of "no change" and conclude that the negative trend in polar bear habitat will continue. Similarly, the climate models used by AMD assumed "no change" in the physical processes operating in the ocean-atmosphere system, and they assumed a business-as-usual (i.e., no change) GHG-forcing scenario (Nakicenovic et al. 2000). These "no-change" parameterizations led to forecasts that the observed declining trends in sea ice will continue. It was doubly apparent that this aspect of the AMD approach was conservative. First, AMD used the business-as-usual GHG emissions scenario, although GHG emissions of recent years have substantially outpaced the business-as-usual rates (Canadell et al. 2007). GHG emissions that are higher than projected can only result in greater warming of the earth. The AMD conservatism also was reflected in the fact that half of the GCMs that AMD used in their analyses projected more sea ice at mid-century than existed in summer 2007.

As examples of uncertainty, AGS (p. 386) cited the negative impact on polar bears of especially cold winters and heavy ice, reported by Amstrup et al. (1986) and Stirling (2002). How observations of the negative impact of cold winters on polar bears contribute to uncertainty regarding projections of the future of polar bears is not clear. It is a well-known principle of ecology that all organisms have a range of conditions in which they can survive and a somewhat narrower range of conditions that are most suitable. On either side of that preferred range, abundance declines (Pianka 1981). Hence, as AMD discussed, it is well known that for polar bears, excessively cold conditions with too heavy ice could be negative—just as excessively warm conditions with too little ice could be negative. The reality that both too-heavy and too-light sea ice conditions are known to limit their populations only serves to emphasize the sensitivity of polar bears to changes in the sea ice.

AGS (p. 386) erroneously cited three papers to support their claim that there is too much uncertainty to conclude anything about the future of sea ice. Each of these papers, however, only provides more evidence that warming is occurring at a global level and sea ice is responding. First, AGS cited Zhang (2007) for the claim that "Antarctic ice mass has been increasing." AGS ignored the fact that the Antarctic (a continent surrounded by oceans) is different from the Arctic (an ocean surrounded by continents); therefore, it is responding to the present level of warming in different ways than the Arctic is. Most importantly, AGS ignored the purpose of Zhang's (2007) paper, which was to emphasize that the observed growth in Antarctic sea ice extent between 1979 and 2004 is consistent with warming in both the ocean and the atmosphere. Rather than a paper describing uncertainty, Zhang (2007) provided an elegant explanation of how the observed increase in sea ice in the Antarctic is consistent with global warming. It is also clear from Zhang (2007) that continued warming will eventually result in sea ice decreases in the Antarctic.

AGS (p. 386) cited a finding by Richter-Menge et al. (2007) that the Bering Sea "has been cooling since 2006." Richter-Menge et al. (2007) actually reported only that the Bering Sea was cooler in 2006 and early 2007 relative to recent previous years, not that it has been cooling since 2006. AGS cited Richter-Menge et al. (2007) as if to suggest that because one small part of the ocean showed a cooling trend, global warming must not be occurring. AGS failed to point out that Richter-Menge et al. (2007, p. S63) prefaced their comments about the Bering sea by saying, "In 2006 there continues to be consistent signs of a general warming in the Arctic region ... ."

Richter-Menge et al. (2007, pp. S65–S66) also emphasized that because of warmer contributions from both the Atlantic and Pacific water layers, the heat content of the Beaufort Gyre has increased. Because the Beaufort Gyre is critical to the maintenance of Arctic sea ice (Rigor and Wallace 2004), warmer waters in the Gyre pose an important threat to the maintenance of sea ice in the polar basin. The point of Richter-Menge et al. (2007) was that despite continued heat buildup in the Arctic, altered circulation patterns had in 2006 interrupted the pattern of continuous warming that had dominated this region in the previous several years. It is well known that there might be transient cooling in portions of the ocean because of changing circulation patterns, even as the heat content of the world's oceans continues to grow (Levitus et al. 2005). Hence, pointing out that one region cooled in any particular year is of no consequence to the well-documented trend of ocean warming.

Finally, AGS (p. 386) claimed that Melling et al. (2005) reported, "Despite the warming of local air temperatures by 1.6 ± 0.6°C, there was no consistent mid-September (the period of minimal ice extent) ice decline in the Canadian Beaufort Sea over the continental shelf, which had been ice-covered for the 36 years between 1968 and 2003." What Melling et al. (2005) actually said is, "The ice-covered area of zone A has decreased at an average 0.06 per decade and that of old ice by 0.08 per decade. These trends reflect the unprecedented northward retreat of the old pack from the Alaskan shelf edge since 1997 (Maslanik et al. 1999). Over the continental shelf (zone B), which is typically almost free of ice in September, there has been no trend in ice-covered area and only a small decrease in old ice." Therefore, the major points of Melling et al. (2005) were that in the farther offshore regions that are normally covered by ice in summer, there has been a major ice-area decline and that in the near shore area, which is normally ice free, there has been no change. The Melling et al. (2005) study in no way discounts the retreat of perennial sea ice in the Arctic as a whole (Meier et al. 2007) or the recorded declines in preferred polar bear habitats in the Beaufort Sea (Durner et al. 2009).

When the statements of Zhang (2007), Richter-Menge et al. (2007), and Melling et al. (2005) are placed in their proper context, it is obvious that none suggests that there is too much uncertainty to conclude arctic ice or polar bear habitats are presently declining. These papers are three among many that document global warming and its effects on sea ice. It appears that AGS was attempting to use incomplete and inaccurate selections from the literature to instill doubt in the reader about global warming and the declines it is causing in Arctic sea ice.

AMD concluded that polar bears might be extirpated, by mid-century, from regions where two-thirds of them currently reside. AGS (p. 386) stated, "We believe that the authors derived their 2/3 figure informally from the outputs of their Bayesian network modeling exercise." They further stated that "there is, however, no clear link between the sets of probabilities for each population state and for each of the author's four Arctic eco-regions and the dramatic 2/3 population reduction figure." In fact, AMD explicitly described how the estimate was derived from sea ice projections and the anticipation ("conservative" under AGS's own definition) that major declines in sea ice will continue to have negative effects on polar bears in the future. AMD described all the steps in detail, and showed all the data.

AGS (p. 386) also raised a concern that this two-thirds figure was at odds with the AMD deterministic model. As AMD explained, conclusions of the BN model differed from the findings of the deterministic model because the deterministic model did not incorporate seasonal changes. The major changes that have occurred in polar bear habitat and those that are projected (Durner et al. 2009) occur in summer and fall. Therefore, the deterministic model could not resolve the full impact of the changes as effectively as the BN model could. Furthermore, the BN model incorporated numerous other potential stressors not included in the deterministic model.

Contrary to the claims of AGS, the AMD forecasts for polar bears at mid-century followed from conservative sea ice projections and conservative use of all available knowledge about the ecology of polar bears. AMD incorporated the range of projections available from the considered GCMs into their models, and all showed dire effects for polar bears across large portions of their current range. Suggesting that AMD violated a "conservative" principle or derived their conclusions informally is clearly wrong.

Alleged Failure to Use Heterogeneous Experts

AGS (pp. 385–387) focused at length on the fact that only one polar bear expert participated in the AMD synthesis effort, thus violating Principle 8.5. AMD acknowledged this in their report and provided detailed guidance on how a next version of the synthesis will be improved. We must point out, however, that the AMD report was peer reviewed by other polar bear experts and by others familiar with the BN modeling approach. We must also point out that the AMD report was not an expression of the opinion of one expert, nor was it an opinion poll to be decided by a majority vote of some larger number of experts. It was a scientific analysis; as with any such analysis, the coauthors (three in this case) did not express interpretations in a vacuum. Rather, they synthesized the scientific knowledge of their subject. The interpretations expressed in the report rest not only on the three authors but on the shoulders of the authors of the 152 scientific publications cited in the report. There is great agreement among the world's polar bear scientists on the impact of declining sea ice on polar bear welfare (Aars et al. 2006). The BN model in AMD reflected not only Amstrup's understandings but also the judgments expressed in the voluminous published scientific literature on polar bears. The AMD report has indeed taken advantage of a large pool of heterogeneous experts.

Alleged Failure to Use All Important Variables

AGS (p. 387) alleged that AMD did not "use all important variables (Principle 10.2)" in building their model. AGS (p. 387) cited Dyck et al. (2007) as evidence that focusing on changing sea ice habitat alone grossly oversimplifies "the complex ecological relationships of the situation." They suggested that AMD overlooked the adaptability of polar bears. They also suggested that polar bears have experienced "much warmer conditions in the Arctic."

During their report preparation, AMD were aware of Dyck et al. (2007) and were aware of the persuasive rebuttal of Dyck et al. (2007) by Stirling et al. (2008). That rebuttal revealed that Dyck et al. (2007) were wrong on all their major points. Hence, AMD did not cite Dyck et al. (2007) or incorporate content of Dyck et al. (2007) into their effort.

Similarly, there is no evidence to support the speculation by AGS that adaptation to terrestrial habitats will rescue polar bears, and very good reasons to believe that it will not. The low productivity of most Arctic terrestrial habitats would prevent current polar bear populations from succeeding on land. Polar bears are, on average, the largest of bears because seals and other marine mammals on which they prey provide an incredibly rich food source. In some coastal areas where brown bears (*Ursus arctos*)—which are closely related to polar bears (Amstrup 2003)—have access to Pacific salmon (another very rich and abundant food source), they are comparable in size to polar bears. However, salmon are not available in the Arctic, and large-bodied bears appear unable to gather and process enough low-quality terrestrial foods of the kinds that are available in Arctic terrestrial areas fast enough to maintain body condition (Welch et al. 1997, Rode et al. 2001, Robbins et al. 2004). The findings of these nutritional studies are corroborated by observations of brown bears that reside in the terrestrial habitats adjacent to the sea ice where polar bears now live. These are the smallest of all brown bears, and they occur at lower densities than brown bears anywhere else (Miller et al. 1997). We do not expect that large populations of large-bodied polar bears could survive and flourish in Arctic terrestrial habitats that currently support only small populations of small-bodied brown bears. If the environment could support large bears, the brown bears already occupying those areas would be larger.

One of the strongest pieces of evidence that polar bears are unlikely to adapt successfully to a terrestrial food base is that they do not do so today. Like all bears, polar bears are opportunistic and will take a broad variety of foods when available (Stempniewicz 1993, 2006; Derocher et al. 2000; Brook and Richardson 2002). Although polar bears do eat things other than marine mammals when they are available, they have not been shown to derive much energetic benefit from these sources (Ramsay and Hobson 1991). In western Hudson Bay, Canada, where polar bears are forced onto land for extended periods every summer and where they have access to a variety of terrestrial foods, including human refuse, they lose an average of nearly 1 kg per day while they wait for the sea ice to refreeze in autumn (Derocher et al. 2004). In this region, many polar bears have been observed feeding on berries during the summer sea ice absence. However, polar bears that were known to have recently fed on berries appeared to show little metabolic benefit over bears that were simply fasting (Hobson et al. 2009). Between 1980 and 2004, while sea ice breakup in western Hudson Bay occurred 0.75 day earlier each year, the mean weight of solitary adult females decreased 2.7 kg per year (Stirling and Parkinson 2006). The lengthening periods during which polar bears have been required to stay on land in western Hudson Bay clearly have not placed them in favorable foraging situations. It seems unlikely, therefore, that during the more protracted ice absences that are projected, polar bears will suddenly begin to benefit from being on land.

Finally, available evidence suggests that polar bears have never experienced temperatures as warm as they will face during the time frame of the AMD projections. Polar bears apparently branched off of brown bear stocks less than 300,000 years ago (Cronin et al. 1991, Talbot and Shields 1996). If that is true, then polar bears have persisted through two periods that were warmer than the present. During the warmest of these, the last interglacial period, global mean temperatures were approximately 1°C warmer than present (Hansen et al. 2006). Corresponding with modern Arctic amplification (Serreze and Francis 2006), summer warmth in the Arctic was much greater than 1°C (CAPE Last Interglacial Project Members 2006). If GHG emissions continue along the trajectory of recent years, global mean temperature could be 2°C warmer by the middle or latter part of this century (Meehl et al. 2007). The Arctic warming associated with such an increase in global mean temperature will greatly exceed anything that has occurred during the evolutionary history of the polar bear.

In summary, there are no other "important variables" supporting a conclusion that the future of polar bears is too uncertain to forecast; nor is there any reliable information that would suggest an alternative to the projection of continuing declines in polar bear habitats and parallel declines in numbers and distribution of polar bears.

Alleged Failures of Hunter et al. (2007) to Follow Principles of Forecasting

AGS provided 11 examples of forecasting principles supposedly violated by Hunter et al. (2007), which we will refer to as H6. These alleged violations fell into one of three groups: violations related to decision making, data, or models. We consider each in turn.

Alleged Failures Related to Decision Making

AGS (pp. 387, 389) claimed that H6 failed to "describe alternative decisions that might be taken..." (Principle 1.1), failed to "provide relationships between forecasts and alternative decisions" (Principle 1.2), failed to incorporate policy variables, and failed to "forecast the effects of different policies" (Principle 10.7).

These claims were plainly irrelevant to H6 because the request for additional analyses by the Secretary of the Interior and the intent of the analyses were to project the future of the population in the absence of policy considerations. Under the law, such information must be objective to be considered in the final policy determination. As we discussed previously, objective science inputs are part of the information that the Department of the Interior requires to decide whether or not an ESA designation is appropriate. The inclusion of policy considerations in research reports is beyond the USGS purview and therefore would have been inappropriate.

Alleged Failures Related to Data

AGS (pp. 387–388) made several claims about the data H6 used to develop its analyses. The AGS claims that relate to both the quality and the quantity of the data are either simply wrong or reflect a misunderstanding of contemporary statistical practice.

AGS (p. 387) alleged that H6 failed to ensure that "information is reliable and sampling error is low" (Principle 4.2). In fact, the data were collected using state-of-the-art field techniques, in a carefully designed mark-recapture study that for the first time included simultaneous sampling across the population range. H6 estimated sampling error as part of the maximum-likelihood parameter-estimation procedure and incorporated the uncertainty that the sampling error implied into the population projections. Clearly, presenting sampling error and uncertainties ensures that the reader can assess the reliability of the data and analyses.

AGS (p. 388) thought that H6 did not use the 2006 (the last year of the study) data, thus violating the principle to "update frequently" (Principle 9.5).

However, as Regehr et al. (2007b) describe, H6 fully utilized the 2006 data.

AGS (pp. 387–388) also alleged that H6 failed to "obtain all important data" (Principle 4.4), suggesting that they could have obtained estimates of polar bear populations during much warmer and colder periods in the past. Unfortunately, comparable data for estimating vital rates (rates of survival, breeding, maturation, etc.) from the whole range of the population do not exist for periods when the climate was significantly different than it is presently.

AGS (p. 389) faulted H6 for failing to use "different types of data to measure a relationship" (Principle 10.5), although they did not suggest which different data types H6 should have used. H6 used mark-recapture data, radio telemetry data, data from the United States and Canada, satellite data, and oceanographic data. H6 also included analyses based on a parametric dependence on sea ice and an analysis that relied simply on the observed rates, without imposing any functional relationship between sea ice and the vital rates. In addition, H6 used six different data types to measure these relationships; this calls into question which "different" types of data H6 should have used.

Alleged Failures Related to the Models

According to AGS (p. 388), H6 failed to "match the model to the phenomena" (Principle 9.2). In fact, the models in H6 reflected a sequence of scientific choices that were explicitly aimed at matching model and phenomenon. The demographic model was carefully matched to well-established biological properties of the polar bear life cycle, breeding behavior, and dependence on the environment. The demographic analysis included not one, but a sequence of models (deterministic, stochastic, and environment-dependent), each of which matched additional "phenomena" of the environment.

The linkage of the demographic models in H6 to the sea ice projections was also carefully matched to the phenomena. AGS (p. 388) seemed particularly concerned about the application to the southern Beaufort Sea of ice projections for the larger polar-basin divergent ecoregion of which it is a part (Amstrup et al. 2007, Durner et al. 2009). However, the major patterns of ice dynamics are similar throughout this ecoregion (Rigor and Wallace 2004, Richter-Menge et al. 2006, Meier et al. 2007). In addition, the mobility of polar bears (Amstrup et al. 2000, 2004) means the relevant environmental area for them extends well beyond the southern Beaufort Sea study-area boundaries.

AGS (p. 388) also criticized H6 for failing to be "conservative in situations of high uncertainty" (Principle 7.3). They repeated their ill-founded idea, which we have already addressed, that a negative effect of too little ice is incompatible with a negative effect of too much ice. More to the point, AGS (p. 388) seemed to think that H6 *assumed* the direction of environmental changes and their effects on the population. H6 did not *assume* the negative effect of reduced sea ice—they *measured it as a statistical estimate from the data*. Contrary to AGS (p. 388), the H6 results were not based on "*extrapolation*" of trends. Dramatic declines in the summer sea ice extent have been observed (Meier et al. 2007, Stroeve et al. 2007), and the effects of those declining trends on polar bear habitat have been determined to be strongly negative (Durner et al. 2009). Those negative trends in habitat have been associated with negative trends in body size and survival of certain sex and age groups (Regehr et al. 2006, 2007a; Rode et al. 2007). The judgment of polar bear experts worldwide is that the overall effect of negative habitat trends will be negative for polar bears (Aars et al. 2006). However, H6 did not use knowledge of these established trends as the basis of their analyses. Rather, they estimated the effects of sea ice on polar bear vital rates from data and combined these measured effects with the projected reductions in sea ice extent to forecast future trends in polar bear numbers and growth rates. H6 never extrapolated forward the observed negative effects of sea ice declines and did not simply assume that the observed trends in polar bear habitat, vital rates, or condition would continue.

AGS (pp. 382, 388) suggested that because polar bear numbers might have increased in the last three or four decades, we should discount the evidence that they are now declining in some areas and might soon decline in others. AGS attribute past gains in numbers to reductions in human harvests of polar bears (Prestrud and Stirling 1994), but ignore the biological realities of recent polar bear population dynamics.

Indeed, increases were reported after harvest levels were tightened in 4 of the 19 recognized subpopulations of polar bears (Prestrud and Stirling 1994). Prevett and Kolenosky (1982) concluded that polar bear numbers in southern Hudson Bay increased after 1975. Derocher and Stirling (1995) estimated that the population in western Hudson Bay was relatively stable after 1978; however, they suggested it had been smaller before restrictions on harvests came into effect in the late 1960s and early 1970s. Similarly, reduced harvest levels in Svalbard and Alaska led to increased numbers during the 1970s and 1980s (Larsen 1984, 1986; Amstrup et al. 1986).

It is important to emphasize here that despite an absence of scientific information regarding worldwide population trends over the past several decades, many in the general press have, as did AGS, claimed that polar bear populations worldwide have grown. Dykstra (2008) thoroughly examined these media accounts, and verified that they have no scientifically established basis. However, population recoveries, where they have occurred, are irrelevant in light of the recent changes in the availability of sea ice for polar bears. Because polar bears are entirely dependent upon the sea ice for their survival (Stirling and Oritsland 1995, Amstrup 2003, AMD), any observed and projected reductions in preferred sea ice habitats (Durner et al. 2009) can only result in declines. In summary, polar bear numbers probably increased in some areas during the 1970s and 1980s, and perhaps even into the 1990s, because of greater protection from direct human mortalities. They now are declining, or soon will be declining (Stirling and Parkinson 2006), because of loss of habitat. To suggest that increases in polar bear numbers because of harvest controls has some relationship to projected decreases in response to losses of habitat only serves to distract the reader from the issue at hand.

Finally, AGS (p. 389) criticized H6 for failing to "list possible outcomes and assess their likelihoods" (Principle 14.7). H6, however, included no fewer than 11 figures showing possible outcomes and their probability distributions (or confidence intervals obtained from those probability distributions). As part of this criticism, AGS repeated their ill-founded speculations on the possible adaptation of polar bears to terrestrial existence.

The Principles of Forecasting and Their Use in Science

We have shown that all the specific allegations that AGS leveled against the USGS reports are without foundation. Next, we consider the basis of the AGS allegations. AGS based their audit on the idea that comparison to their self-described principles of forecasting could produce a valid critique of scientific results. AGS (p. 383) claimed their principles "summarize all useful knowledge about forecasting." Anyone can claim to have a set of principles, and then criticize others for violating their principles. However, it takes more than a claim to create principles that are meaningful or useful. In concluding our rejoinder, we point out that the principles espoused by AGS are so deeply flawed that they provide no reliable basis for a rational critique or audit.

Failures of the Principles

Armstrong (2001) described 139 principles and the support for them. AGS (pp. 382–383) claimed that these principles are *evidence based* and *scientific*. They fail, however, to be *evidence based* or *scientific* on three main grounds: They use relative terms as if they were absolute, they lack theoretical and empirical support, and they do not follow the logical structure that scientific criticisms require.

Using Relative Terms as Absolute

Many of the 139 principles describe properties that models, methods, and (or) data should include. For example, the principles state that data sources should be *diverse*, methods should be *simple*, approaches should be *complex*, representations should be *realistic*, data should be *reliable*, measurement error should be *low*, explanations should be *clear*, etc. AGS faulted the USGS reports for violations of many of these principles. However, it is impossible to look at a model, a method, or a datum and decide whether its properties meet or violate the principles because the properties of these principles are inherently relative.

Consider *diverse*. AGS faulted H6 for allegedly failing to use diverse sources of data. However, H6 used at least six different sources of data (mark-recapture data, radio telemetry data, data from the United States and Canada, satellite data, and oceanographic data).

Is this a diverse set of data? It is more diverse than it would have been if some of the data had not been used. It is less diverse than it would have been if some (hypothetical) additional source of data had been included. To criticize it as not being diverse, however, without providing some measure of comparison, is meaningless.

Consider *simple*. What is simple? Although it might be possible to decide which of two models is simpler (although even this might not be easy), it is impossible—in principle—to say whether any model considered in isolation is simple or not. For example, H6 included a deterministic time-invariant population model. Is this model simple? It is certainly simpler than the stationary, stochastic model, or the nonstationary stochastic model also included in H6. However, without a measure of comparison, it is impossible to say which, if any, are "simple." For AGS to criticize the report as failing to use simple models is meaningless.

We could go on at length with such examples. Suffice it to say that using relative terms as if they were absolute makes any principles based on them worthless.

A Lack of Theoretical and Empirical Support

If the principles of forecasting are to serve as a basis for auditing the conclusions of scientific studies, they must have strong theoretical and (or) empirical support. Otherwise, how do we *know* that these principles are necessary for successful forecasts? Closer examination shows that although Armstrong (2001, p. 680) refers to evidence and AGS (pp. 382–383) call the principles *evidence based*, almost half (63 of 139) are supported *only* by *received wisdo*m or *common sense*, with *no* additional empirical or theoretical support. Many others are supported by combinations of factors, such as *received wisdom and weak empirical support*, but we do not count those here.

Armstrong (2001, p. 680) defines *received wisdom* as when "the vast majority of experts agree," and *common sense* as when "it is difficult to imagine that things could be otherwise." In other words, nearly half of the principles are supported only by opinions, beliefs, and imagination about the way that forecasting should be done. This is not *evidence based*; therefore, it is inadequate as a basis for auditing scientific studies. Commonly held opinions might be correct. They might also be partially correct and capture only some aspects of a situation; they might also be wholly incorrect. Indeed, the history of science includes many cases demonstrating that received wisdom and common sense are wrong. Even Armstrong's (2001) own list includes at least three cases of principles that are supported by what he calls strong empirical evidence that "refutes received wisdom"—that is, at least three of the principles contradict received wisdom. How much confidence can we have in an audit in which 45 percent of the principles invoked are supported *only* by *received wisdom or common sense*—especially given that AGS are not experts in either climate science or ecology?

Forecasting Audits Are Not Scientific Criticism

The AGS audit failed to distinguish between scientific forecasts and nonscientific forecasts. Scientific forecasts, because of their theoretical basis and logical structure based upon the concept of hypothesis testing, are almost always projections. That is, they have the logical form of "if X happens, then Y will follow." The analyses in AMD and H6 take exactly this form. A scientific criticism of such a forecast must show that even if X holds, Y does not, or need not, follow.

In contrast, the AGS audit simply scored violations of self-defined principles without showing how the identified violation might affect the projected result. For example, the accusation that H6 violated the commandment to use *simple* models is not a scientific criticism, because it says nothing about the relative simplicity of the model with respect to other possible choices. It also says nothing about whether the supposedly nonsimple model in question is in error. A *scientific* critique on the grounds of simplicity would have to identify a complexity in the model, and show that the complexity cannot be defended scientifically, that the complexity undermines the credibility of the model, and that a simpler model can resolve the issue. AGS did none of these.

Scientific Standards and Citations of the Principles of Forecasting

Given the weaknesses of the forecasting principles, as we described above, it should come as no surprise that they have not become a part of scientific methodology. A search on the Web of Science (http://www.thomsonreuters.com/products_services/scientific/Web_of_Science) revealed only 38 citations of Armstrong (2001) between its publication and the preparation of the USGS reports in 2007. None of these citations appeared in a journal of ecology, conservation biology, wildlife management, zoology, or any other discipline relevant to polar bear populations. Instead, they came from studies of grain prices, apparel items, textile distribution, ship repair, software engineering, and minor league baseball franchises. Everyone involved in the polar bear studies took seriously the ethical obligation to rely on the best available practices and objective scientific information. To have relied solely, throughout those efforts, on subjective forecasting principles would have been ethically and scientifically inappropriate.

Conclusion

The warming of the earth's atmosphere by increased concentrations of GHGs is required by the fundamental laws of physics (Hartmann 1994, Philander 1998, Lutgens and Tarbuck 2004, Held and Soden 2006, Le Treut et al. 2007). That is, regardless of the natural, chaotic fluctuations in the climate system, a world with higher concentrations of GHGs in the atmosphere will be warmer than one in which the GHG concentrations are lower. The effects of global warming on polar bears, if it continues as projected, will be severe; by mid-century, polar bears will most likely be limited to a small portion of their current range. The nine USGS reports, and other available information on the species and its habitat, established that the future security of polar bears is ecologically threatened. The Secretary of the Interior determined that those ecological threats required policy action and, on May 15, 2008, listed polar bears as threatened under the ESA.

Creating doubt about well-supported scientific results to influence policy actions is a well-documented phenomenon in health-related research (Michaels 2008). Whatever the goals of AGS, their audit of the USGS reports similarly serves to create doubt—in this case, about global warming and its effects on polar bears. AGS continue previous efforts to create doubt about global warming and its probable consequences (Lee 2003). The two USGS reports that AGS audited clearly defined the scientific approaches, the threats, and the scientific uncertainties regarding the likely future status of polar bears. In this rejoinder, we have shown AGS to be scientifically wrong or misleading on every major point in their attempt to establish doubt about those reports.

Scientific discussion is necessary to advance knowledge and inform public-policy decisions. Expressions of ideology masked as scientific discussion, however, do neither. In this rebuttal, we have shown that the AGS audit of two USGS research reports did not offer accurate or appropriate critiques of the reports; it only served as a distraction from informed public-policy discussions of the consequences of global warming and its effects on the future status of polar bears.

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References

Aars, J., N. J. Lunn, A. E. Derocher. 2006. *Polar Bears: Proc. 14th Working Meeting of the IUCN/SSC Polar Bear Specialists Group*, World Conservation Union, Gland, Switzerland.

Amstrup, S. C. 2003. Polar bear. G. A. Feldhammer, B. C. Thompson, J. A. Chapman, eds. *Wild Mammals of North America: Biology, Management, and Conservation*, 2nd ed. Johns Hopkins University Press, Baltimore.

Amstrup, S. C., B. G. Marcot, D. C. Douglas. 2007. Forecasting the rangewide status of polar bears at selected times in the 21st century. Administrative report, US Geological Survey, Alaska Science Center, Anchorage, AK.

Amstrup, S. C., T. L. McDonald, G. M. Durner. 2004. Using satellite radiotelemetry data to delineate and manage wildlife populations. *Wildlife Soc. Bull.* **32**(3) 661–679.

Amstrup, S. C., I. Stirling, J. W. Lentfer. 1986. Past and present status of polar bears in Alaska. *Wildlife Soc. Bull.* **14**(3) 241–254.

Amstrup, S. C., G. M. Durner, I. Stirling, N. J. Lunn, F. Messier. 2000. Movements and distribution of polar bears in the Beaufort Sea. *Canadian J. Zoology* **78**(6) 948–966.

Armstrong, J. S. 2001. *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Kluwer Academic Publishers, Norwell, MA.

Armstrong, J. S., K. C. Green, W. Soon. 2008. Polar bear population forecasts: A public-policy forecasting audit. *Interfaces* **38**(5) 382–405.

Atkins, T. 2004. Insurer warns of global warming catastrophe. *Common Dreams* (March 3). Retrieved March 12, 2009, http://www.commondreams.org/cgi-bin/print.cgi?file=/headlines04/0303-07.htm.

Britt, R. R. 2005. Insurance company warns of global warming's costs. *Live Science* (November 1). Retrieved March 12, 2009, http://www.livescience.com/environment/051101_insurance_warming.html.

Brook, R. K., E. S. Richardson. 2002. Observations of polar bear predatory behaviour toward caribou. *Arctic* **55**(2) 193–196.

Canadell, J. G., C. Le Quéré, M. R. Raupach, C. B. Field, E. T. Buitenhuis, P. Ciais , T. J. Conway, N. P. Gillett, R. A. Houghton, G. Marland. 2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proc. National Acad. Sci. USA* **104**(47) 18866–18870.

CAPE Last Interglacial Project Members. 2006. Last interglacial arctic warmth confirms polar amplification of climate change. *Quaternary Sci. Rev.* **25**(13–14) 1383–1400.

Charney, J. G., ed. 1979. Carbon dioxide and climate: A scientific assessment. Report of the ad hoc study group on carbon dioxide and climate, National Academy of Sciences, Washington, DC.

Cochran, J. J. 2008. A commentary on polar bear population forecasts: A public-policy forecasting audit. *Interfaces* **38**(5) 395–400.

Comiso, J. C. 2006. Abrupt decline in the Arctic winter sea ice cover. *Geophysical Res. Lett.* **33**(18) L18504. doi:10.1029/2006GL027341.

Cronin, M. A., S. C. Amstrup, G. W. Garner, E. R. Vyse. 1991. Interspecific and intraspecific mitochondrial DNA variation in North American bears (*Ursus*). *Canadian J. Zoology* **69**(12) 2985–2992.

Derocher, A. E., I. Stirling. 1995. Estimation of polar bear population size and survival in western Hudson Bay. *J. Wildlife Management* **59**(2) 215–221.

Derocher, A. E., N. J. Lunn, I. Stirling. 2004. Polar bears in a warming climate. *Integrative Comparative Biol.* **44**(2) 163–176.

Derocher, A. E., Ø. Wiig, G. Bangjord. 2000. Predation of Svalbard reindeer by polar bears. *Polar Biol.* **23**(10) 675–678.

Durner, G. M., D. C. Douglas, R. M. Nielson, S. C. Amstrup, T. L. McDonald, I. Stirling, M. Mauritzen et al. 2009. Predicting 21st-century polar bear habitat distribution from global climate models. *Ecological Monographs* **79**(1) 25–58.

Dyck, M. G., W. Soon, R. K. Baydack, D. R. Legates, S. Baliunas, T. F. Ball, L. O. Hancock. 2007. Polar bears of western Hudson Bay and climate change: Are warming spring air temperatures the "ultimate" survival control factor? *Ecological Complexity* **4** 73–84.

Dykstra, P. 2008. Magic number: A sketchy "fact" about polar bears keeps going . . . and going . . . and going. *Society of Environmental Journalists* (July 23). Retrieved March 12, 2009, http://www.sej.org/pub/SEJournal_Excerpts_Su08.htm.

Green, K. C., J. S. Armstrong. 2007. Global warming: Forecasts by scientists versus scientific forecasts. *Energy Environ.* **18**(7–8) 997–1021.

Hansen, J., M. Sato. 2004. Greenhouse gas growth rates. *Proc. National Acad. Sci. USA* **101**(46) 16109–16114.

Hansen, J., M. Sato, R. Ruedy, K. Lo, D. W. Lea, M. Medina-Elizade. 2006. Global temperature change. *Proc. National Acad. Sci. USA* **103**(39) 14288–14293.

Hansen, J., M. Sato, R. Ruedy, A. Lacis, K. Asamoah, S. Borenstein, E. Brown et al. 1996. A Pinatubo climate modeling investigation. G. Fiocco, D. Fua, G. Visconti, eds. *The Mount Pinatubo Eruption: Effects on the Atmosphere and Climate*, NATO ASI Series, Vol. I42. Springer-Verlag, Heidelberg, Germany, 233–272.

Hartmann, D. L. 1994. *Global Physical Climatology. International Geophysics Series*, Vol. 56. Academic Press, San Diego.

Held, I. M., B. J. Soden. 2000. Water vapor feedback and global warming. *Annual Rev. Energy Environ.* **25**(1) 441–475.

Held, I. M., B. J. Soden. 2006. Robust responses of the hydrological cycle to global warming. *J. Climate* **19**(21) 5686–5699.

Hobson, K. A., I. Stirling, D. S. Andriashek. 2009. Isotopic homogeneity of breath CO_2 from fasting and berry-eating polar bears: Implications for tracing reliance on terrestrial foods in a changing Arctic. *Canadian J. Zoology* **87**(1) 50–55.

Holland, M. M., C. M. Bitz, B. Tremblay. 2006. Future abrupt reductions in the summer Arctic sea ice. *Geophysical Res. Lett.* **33**(23) L23503. doi:10.1029/2006GL028024.

Hunter, C. M., H. Caswell, M. C. Runge, E. V. Regehr, S. C. Amstrup, I. Stirling. 2007. Polar bear demography in the southern Beaufort Sea in relation to sea ice. Administrative report, US Geological Survey, Alaska Science Center, Anchorage, AK.

Jansen, E., J. Overpeck, K. R. Briffa, J. C. Duplessy, F. Joos, V. Masson-Delmotte, D. Olago et al. 2007. Paleoclimate. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, eds. *Climate Change 2007: The Physical Science Basis*. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, 433–497.

Jensen, F. V. 2001. *Bayesian Networks and Decision Graphs*. Springer-Verlag, New York.

Larsen, T. 1984. We've saved the ice bear. *Internat. Wildlife* **14**(4) 4–11.

Larsen, T. 1986. *Population Biology of the Polar Bear* (*Ursus maritimus*) *in the Svalbard Area*. Norsk Polarinstitutt Skrifter 184, Oslo, Norway.

Lee, J. S. 2003. A call for a softer, greener language. *New York Times* (March 2). Retrieved March 12, 2009, http://query.nytimes.com/gst/fullpage.html?res=9C0CEFD6113CF931A35750C0A9659C8B63.

Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson, M. Prather. 2007. Historical overview of climate change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, eds. *Climate Change 2007: The Physical Science Basis*. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, 93–127.

Levitus, S., J. Antonov, T. Boyer. 2005. Warming of the world ocean, 1955–2003. *Geophysical Res. Lett.* **32**(2) L02604. doi:10.1029/2004GL021592.

Lutgens, F. K., E. J. Tarbuck. 2004. *The Atmosphere*. Pearson Prentice Hall, Upper Saddle River, NJ.

Maslanik, J. A., M. C. Serreze, T. Agnew. 1999. On the record reduction in 1998 western Arctic sea-ice cover. *Geophysical Res. Lett.* **26**(13) 1905–1908.

Maslanik, J. A., M. C. Serreze, R. G. Barry. 1996. Recent decreases in Arctic summer ice cover and linkages to atmospheric circulation anomalies. *Geophysical Res. Lett.* **23**(13) 1677–1680.

Meehl, G. A., T. F. Stocker, W. D. Collins, P. Friedlingstein, A. T. Gaye, J. M. Gregory, A. Kitoh et al. 2007. Global climate projections. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, eds. *Climate Change 2007: The Physical Science Basis*. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, 747–845.

Meier, W. N., J. Stroeve, F. Fetterer. 2007. Whither Arctic sea ice? A clear signal of decline regionally, seasonally and extending beyond the satellite record. *Ann. Glaciology* **46**(1) 428–434.

Melling, H., D. A. Riedel, Z. Gedalof. 2005. Trends in the draft and extent of seasonal pack ice, Canadian Beaufort Sea. *Geophysical Res. Lett.* L24501. doi:10.1029/2005GL024483.

Michaels, D. 2008. *Doubt Is Their Product: How Industry's Assault on Science Threatens Your Health*. Oxford University Press, New York.

Miller, S. D., G. C. White, R. A. Sellers, H. V. Reynolds, J. W. Schoen, K. Titus, V. G. Barnes, Jr. et al. 1997. Brown and black bear density estimation in Alaska using radiotelemetry and replicated mark-resight techniques. *Wildlife Monographs* **133** 1–55.

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory et al. 2000. *Emissions Scenarios: A Special Report of Working Group III of the Intergovermental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

Obbard, M. E., M. R. L. Cattet, T. Moody, L. R. Walton, D. Potter, J. Inglis, C. Chenier. 2006. Temporal trends in the body condition of southern Hudson Bay polar bears. Research Information Note 3, Ontario Ministry of Natural Resources. Retrieved March 12, 2009, http://assets.panda.org/downloads/obbard_et_al_ccrn__3.pdf.

Overpeck, J. T., M. Sturm, J. A. Francis, D. K. Perovich, M. C. Serreze, R. Benner, E. C. Carmack et al. 2005. Arctic system on trajectory to new, seasonally ice-free state. *Eos Trans. Amer. Geophysical Union* **86**(34) 309, 312–313.

Philander, S. G. 1998. *Is the Temperature Rising? The Uncertain Science of Global Warming*. Princeton University Press, Princeton, NJ.

Pianka, E. R. 1981. Competition and niche theory. R. M. May, ed. *Theoretical Ecology*, 2nd ed. Blackwell Publishers Ltd., Sinauer Associates, Sunderland, MA, 167–196.

Prestrud, P., I. Stirling. 1994. International polar bear agreement and the current status of polar bear conservation. *Aquatic Mammals* **20**(3) 113–124.

Prevett, J. P., G. B. Kolenosky. 1982. The status of polar bears in Ontario. *Naturaliste Canadien* **109** 933–939.

Rahmstorf, S., A. Cazenave, J. A. Church, J. E. Hansen, R. F. Keeling, D. E. Parker, R. C. J. Somerville. 2007. Recent climate observations compared to projections. *Science* **316** 709.

Ramsay, M. A., K. A. Hobson. 1991. Polar bears make little use of terrestrial food webs: Evidence from stable-carbon isotope analysis. *Oecologia* **86** 598–600.

Randall, D. A., R. A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov et al. 2007. Climate models and their evaluation. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, eds. *Climate Change 2007: The Physical Science Basis*. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, 589–662.

Regehr, E. V., S. C. Amstrup, I. Stirling. 2006. Polar bear population status in the southern Beaufort Sea. US Geological Survey Open-File Report 2006–1337. Retrieved March 12, 2009, http://pubs.usgs.gov/of/2006/1337/pdf/ofr20061337.pdf.

Regehr, E. V., N. J. Lunn, S. C. Amstrup, I. Stirling. 2007a. Effects of earlier sea ice breakup on survival and population size of polar bears in western Hudson Bay. *J. Wildlife Management* **71**(8) 2673–2683.

Regehr, E. V., C. M. Hunter, H. Caswell, S. C. Amstrup, I. Stirling. 2007b. Survival and reproduction of polar bears in the southern Beaufort Sea in relation to declining sea ice. Administrative report, US Geological Survey, Alaska Science Center, Anchorage, AK.

Richter-Menge, J., J. Overland, A. Proshutinsky, V. Romanovsky, R. Armstrong, J. Morison, S. Nghiem et al. 2007. The poles: Arctic. *Bull. Amer. Meteorological Soc.* **88**(6) S62–S71. http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/bams/bams.pdf. [A. Arguez, ed. *State of the Climate in 2006*.]

Richter-Menge, J., J. Overland, A. Proshutinsky, V. Romanovsky, L. Bengtsson, L. Brigham, M. Dyurgerov et al. 2006. State of the Arctic. Special Report, Contribution 2952 from Pacific Marine Environmental Laboratory. National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research, Seattle. Retrieved March 12, 2009, http://www.pmel.noaa.gov/pubs/PDF/rich2952/rich2952.pdf.

Rigor, I. G., J. M. Wallace. 2004. Variations in the age of Arctic sea-ice and summer sea-ice extent. *Geophysical Res. Lett.* **31** L09401. doi:10.1029/2004GL019492.

Robbins, C. T., C. C. Schwartz, L. A. Felicetti. 2004. Nutritional ecology of ursids: A review of newer methods and management implications. *Ursus* **15**(2) 161–171.

Rode, K. D., S. C. Amstrup, E. V. Regehr. 2007. Polar bears in the southern Beaufort Sea III: Stature, mass, and cub recruitment in relationship to time and sea ice extent between 1982 and 2006. Administrative report, US Geological Survey, Alaska Science Center, Anchorage, AK.

Rode, K. D., C. T. Robbins, L. A. Shipley. 2001. Constraints on herbivory by grizzly bears. *Oecologia* **128** 62–71.

Scherer, R. 2006. New combatant against global warming: Insurance industry. *Christian Science Monitor* (October 13). Retrieved March 12, 2009, http://www.csmonitor.com/2006/1013/p01s01-usec.htm.

Serreze, M. C., J. A. Francis. 2006. The Arctic amplification debate. *Climatic Change* **76**(3–4) 241–264.

Serreze, M. C., M. M. Holland, J. Stroeve. 2007. Perspectives on the Arctic's shrinking sea-ice cover. *Science* **315**(5818) 1533–1536.

SitNews. 2008. Congress passes resolution protecting Arctic fisheries. (May 22). Retrieved March 12, 2009, http://www.sitnews.us/0508news/052208/052208_fisheries.html.

Soden, B. J., R. T. Wetherald, G. L. Stenchikov, A. Robock. 2002. Global cooling after the eruption of Mount Pinatubo: A test of climate feedback by water vapor. *Science* **296**(5568) 727–730.

Stempniewicz, L. 1993. The polar bear *Ursus maritimus* feeding in a seabird colony in Frans Josef Land. *Polar Res.* **12**(1) 33–36.

Stempniewicz, L. 2006. Polar bear predatory behaviour toward molting barnacle geese and nesting glaucous gulls on Spitsbergen. *Arctic* **59**(3) 247–251.

Stirling, I. 2002. Polar bears and seals in the eastern Beaufort Sea and Amundsen Gulf: A synthesis of population trends and ecological relationships over three decades. *Arctic* **55**(S1) 59–76.

Stirling, I., N. A. Oritsland. 1995. Relationships between estimates of ringed seal (*Phoca hispida*) and polar bear (*Ursus maritimus*) populations in the Canadian Arctic. *Canadian J. Fisheries Aquatic Sci.* **52**(12) 2594–2612.

Stirling, I., C. L. Parkinson. 2006. Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. *Arctic* **59**(3) 261–275.

Stirling, I., N. J. Lunn, J. Iacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. *Arctic* **52**(3) 294–306.

Stirling, I., A. E. Derocher, W. A. Gough, K. Rode. 2008. Response to Dyck et al. (2007) on polar bears and climate change in western Hudson Bay. *Ecological Complexity* **5** 193–201.

Stroeve, J., M. M. Holland, W. Meier, T. Scambos, M. Serreze. 2007. Arctic sea ice decline: Faster than forecast. *Geophysical Res. Lett.* **34**(9) L09501. doi:10.1029/2004GL021810.

Stroeve, J. C., M. C. Serreze, F. Fetterer, T. Arbetter, W. Meier, J. Maslanik, K. Knowles. 2005. Tracking the Arctic's shrinking ice cover: Another extreme September minimum. *Geophysical Res. Lett.* **32** L04501. doi:10.1029/2007GL029703.

Talbot, S. L., G. F. Shields. 1996. Phylogeography of brown bears (*Ursus arctos*) of Alaska and paraphyly within the Ursidae. *Molecular Phylogenetics Evolution* **5**(3) 477–494.

Trenberth, K. 2007. Predictions of climate. *Nature.com* (June 4). Retrieved March 12, 2009, http://blogs.nature.com/climatefeedback/2007/06/predictions_of_climate.html.

US Climate Change Science Program. 2008. Scientific assessment of the effects of global change on the United States. National Science and Technology Council, Committee on Environmental and Natural Resources. Retrieved March 12, 2009, http://www.climatescience.gov/Library/scientific-assessment/Scientific-AssessmentFINAL.pdf.

US Fish and Wildlife Service. 2007. Endangered and threatened wildlife and plants: Twelve-month petition finding and proposed rule to list the polar bear (*Ursus maritimus*) as threatened throughout its range. *Federal Register* **72**(5) 1064–1099.

US Fish and Wildlife Service. 2008. Endangered and threatened wildlife and plants: Determination of threatened status for the polar bear (*Ursus maritimus*) throughout its range. *Federal Register* **73**(95) 28211–28303.

US Government Accountability Office. 2007. Climate change: Financial risks to federal and private insurers in coming decades are potentially significant. Report GAO-07-285, Washington, DC.

Wald, M. L., A. C. Revkin. 2007. New Coast Guard task in Arctic's warming seas. *NY Times* (October 19). Retrieved April 8, 2009, http://www.nytimes.com/2007/10/19/us/19arctic.html?_r=2&oref=slogin&pagewanted=print.

Weart, S. R. 2003. *The Discovery of Global Warming*. Harvard University Press, Cambridge, MA.

Welch, C. A., J. Keay, K. C. Kendall, C. T. Robbins. 1997. Constraints on frugivory by bears. *Ecology* **78**(4) 1105–1119.

Zhang, J. 2007. Increasing Antarctic sea ice under warming atmospheric and oceanic conditions. *J. Climate* **20**(11) 2515–2529.

Zhang, X. D., J. E. Walsh. 2006. Toward a seasonally ice-covered Arctic ocean: Scenarios from the IPCC AR4 model simulations. *J. Climate* **19**(9) 1730–1747.