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CONSERVATION OF ARCTIC MARINE MAMMALS FACED WITH CLIMATE CHANGE

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Abstract. On a daily basis, societies are making decisions that will influence the effects of climate change for decades or even centuries to come. To promote informed management of the associated risks, we review available conservation measures for Arctic marine mammals, a group that includes some of the most charismatic species on earth. The majority of available conservation measures (e.g., restrictions on hunting, protection of essential habitat areas from development, reduction of incidental take) are intended to address the effects of increasing human activity in the Arctic that are likely to follow decreasing sea ice and rising temperatures. As important as those measures will be in the effort to conserve Arctic marine mammals and ecosystems, they will not address the primary physical manifestations of climate change, such as loss of sea ice. Short of actions to prevent climate change, there are no known conservation measures that can be used to ensure the long-term persistence of these species and ecosystems as we know them today.

Key words: Arctic; climate change; conservation; marine mammals; risk analysis.

Introduction

Anthropogenic climate change, perhaps more than any other consequence of human civilization, has the potential to change Arctic ecosystems profoundly. Temperatures and sea levels are rising and will lead to coastal and insular inundation (McCarthy et al. 2001). Important Arctic habitat, most notably sea ice (Parkinson et al. 1999), will be altered or destroyed, causing extensive redistribution of mobile species, the disappearance of nonmobile species throughout portions of their range, and possible species extinction (Thomas et al. 2004). Climate change will involve alteration of water and nutrient cycles and energy pathways in the world's oceans (Macdonald et al. 2005). It may alter oceanic and atmospheric circulation patterns (Schmittner 2005), with potentially severe biological and ecological consequences for many, if not all, ecosystems, marine and terrestrial. Through physical, chemical, and biological linkages, these changes will cascade through ecosystems. The unexpectedly rapid disintegration of the Larsen B ice shelf in the Antarctic (Shepherd et al. 2003), the surprisingly rapid pace of glacial decline on Greenland (Rignot and Kanagaratnam 2006), and other recent, unanticipated observations suggest we are in for a great many surprises with respect to the regional and global effects of climate change. The end result may be beyond our ability to predict or imagine.

The papers in this Special Issue examine the ongoing and potential physical effects of climate change in the coming century and their likely impacts on Arctic marine mammals. In this paper, we consider a range of conservation measures to address those impacts. By "conservation measures" we mean actions that can be taken to prevent, minimize, or mitigate human impacts on Arctic ecosystem components and processes, thereby perpetuating the natural ecology and evolution of these ecosystems. The term "prevention" may not be strictly accurate, inasmuch as climate change is underway and can no longer be prevented fully. Although "minimization" might be a more accurate term, we use "prevention" because it connotes a stronger, more effective, and, to the extent possible, more proactive management approach.

Whether mindful of it or not, societies already are conducting a de facto risk analysis on climate change and its potential consequences. In this paper we use a risk analysis framework (Maguire 1991, Harwood 2000) to consider potential conservation measures to address those risks. By taking this approach, we hope to make the analysis clearer and more useful for managing the human activities that contribute to climate change or exacerbate climate change effects.

The first steps in such an analysis are identification of the physical causes and manifestations of climate change and description of the hazards to which marine mammals may be exposed. Preceding papers in this volume provide such information, and we review them only briefly here. A range of natural factors contribute to climate change, including variations in energy output from the sun, variations in the geometric relationship

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between the sun and the earth, volcanic eruptions, and continental drift. Human activities contribute to climate change primarily through their influence on the earth's atmosphere. Emissions of carbon dioxide, methane, and other greenhouse gases appear to be the most important anthropogenic drivers of climate change, and much of the discussion regarding prevention measures has focused on controlling such emissions.

The major physical manifestations of climate change in the Arctic marine environment (ACIA 2004, Walsh 2008) include changes in temperature, sea ice, terrestrial ice (including permafrost), precipitation, freshwater flow, sea level, sea surface and water column temperatures, and oceanic and atmospheric circulation.

The biological and ecological consequences of climate change will vary depending on the species involved. As in other papers in this volume, we focus our discussion of "Arctic" marine mammals (i.e., those occurring in the Arctic year-round) on polar bear (*Ursus maritimus*), walrus (*Odobenus rosmarus*), ringed seal (*Phoca hispida*), bearded seal (*Erignathus barbatus*), beluga whale (*Dephinapterus leucas*), narwhal (*Monodon monoceros*), and bowhead whale (*Balaena mysticetus*) species. Other species that inhabit the Arctic at least seasonally include ribbon seals (*Histrio phoca fasciata*), spotted seals (*Phoca largha*), harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), gray whales (*Eschrichtius robustus*), killer whales (*Orcinus orca*), minke whales (*Balaenoptera acutorostrata*), fin whales (*Balaenoptera physalus*), and humpback whales (*Megaptera novaeangliae*).

The physical manifestations of climate change will affect Arctic marine mammals both directly and indirectly by changing their habitat and encouraging increased human presence and activities in Arctic regions. The possible effects of these changes are discussed in detail in other papers in this volume (Bluhm and Gradinger 2008, Burek et al. 2008, Laidre et al. 2008) and in other scientific publications (Stirling and Derocher 1993, Tynan and DeMaster 1997, Lowry 2000, Stirling 2002, ACIA 2004, Derocher et al. 2004). The cumulative impact of independent (additive) and interacting (synergistic) risk factors will determine the overall significance of climate change for marine mammals and that impact is considered in detail in Moore and Huntington (2008).

The remaining steps in a risk analysis focus on determination of the tolerable level of climate change effects, evaluation of the probability that those effects will be realized, and identification and evaluation of existing and potential conservation measures.

The Tolerable Effects of Climate Change

We, the human species, are changing the face of the earth in profound ways. How much change is tolerable is a question yet to be answered. We often cast our aspirations in terms such as "sustainable" and "healthy ecosystems," but we have not effectively defined those terms and come to grips with the discipline and constraints they require. Thus, they can easily become more a facade than a true standard against which we measure our impacts. Before considering the potential risks from climate change and deciding how best to respond to them, it is important to determine both the tolerance of Arctic ecosystems for climate change effects (i.e., inherent ability to withstand perturbation), as well as our (society's) tolerance for Arctic degradation (i.e., subjective human sensitivity to environmental loss). Although science can estimate the risk and resilience of species and ecosystem processes to changes in climatic conditions, society's perception of the risks and its willingness to accept a given level of environmental disturbance are more difficult to quantify. Determining those limits is vital because they will shape the standards and measures used to guide and influence Arctic conservation in the face of climate change.

Determining "safe" thresholds for human activities and impacts in the Arctic and elsewhere is made difficult by the considerable uncertainty about what constitutes a healthy ecosystem and how much disturbance different ecosystems can withstand before basic functions are lost or unacceptably diminished. The uncertainty stems in part from the complexity of ecosystems and the difficulty in understanding their physical, chemical, and biological elements and natural dynamics. The uncertainty is further confounded by the addition of human activities that may alter ecosystem composition and dynamics before sufficient baseline information has been collected to provide a basis for distinguishing natural dynamics from anthropogenic disturbance. For the purpose of conserving relatively natural ecosystems, the undesirable consequence of such uncertainty is that we may mistakenly attribute changes we see to natural causes, effectively rationalizing perpetual ecosystem decline from a healthy condition (e.g., the shifting baseline syndrome; Pauly 1995). Furthermore, uncertainty increases the subjectivity of threat assessment, allowing proponents of potentially damaging actions to justify their positions by claiming uncertainty as to whether damage will occur and with what severity.

The U.S. Marine Mammal Protection Act (MMPA) provides a national example of an effort to set tolerable limits for ecosystem disturbance. The MMPA has as its primary objective the maintenance of marine ecosystem health and stability. In support of that objective, the Act establishes a specific tolerance for change in the status of marine mammal populations. Marine mammal populations that fall below their "optimum sustainable population," which ranges from their maximum net productivity level (lower limit) to their environmental carrying capacity (upper limit), are deemed to be depleted, unable to fulfill their natural ecological role within marine ecosystems, and in need of special management protection (Gehringer 1976).

The implementation of the MMPA illustrates the difficulties inherent in setting and abiding by such limits and assessing progress in adhering to them. These difficulties can be placed in three categories: obtaining data on species, determining ecosystem parameters, and turning societal aspiration into action. With regard to data, the maximum net productivity level and the environmental carrying capacity have not been assessed for the majority of marine mammal stocks, including most of those in the U.S. Arctic (e.g., ringed seal, bearded seal, walrus, polar bear, beluga whale). Even reasonably precise estimates of abundance (e.g., with coefficients of variation ≤ 0.3) are available only for four of the 10 stocks of Arctic marine mammals in U.S. waters. The lack of information occurs in part because of the scientific and logistical difficulties in assessing these stocks and in part because funding support (i.e., social commitment) needed to conduct such assessments has so far been lacking.

Ecosystem parameters are even more complex. The maximum net productivity level and environmental carrying capacity are themselves subject to human influence, that is, they can be altered by the very human activities they are supposed to constrain. If they are not assessed for a population when it is in a relatively natural state, these levels may be underestimated, allowing more change than intended by the MMPA. In the Arctic, for example, if the environmental carrying capacity for ringed seals is determined by the amount of land-fast ice available for reproduction and the amount of land-fast ice available during the reproductive season has already declined due to climate change, then estimates of the environmental carrying capacity based on current conditions would be biased low relative to the natural conditions they were intended to reflect. In effect, standards lose their utility if they decline along with ecosystem health.

Finally, even well-intentioned standards for preventing environmental degradation have little meaning or utility if they are not acted upon. The complexity inherent in Arctic conservation is illustrated by the fact that the United States, which has some of the most progressive conservation laws in the world (e.g., the MMPA, the Endangered Species Act, etc.) is also a large contributor to climate change and has declined to ratify the Kyoto Protocol of the United Nations Framework Convention on Climate Change because doing so may affect its economy. The inconsistency reflects the fundamental conflict between socioeconomic systems based on resource consumption and human population growth on the one hand and environmental conservation on the other. Although laudable conservation goals have been established on both national and international levels, those goals have little meaning if we do not set corresponding limits on our activities and take the actions necessary to ensure that we are abiding by them. Whether we will do so, now or in the future, is a matter of choice, and that choice will influence whether the adverse ecological effects that have been projected will, in fact, be realized.

The conflict between socioeconomic expansion and ecosystem conservation is perhaps nowhere more evident than in the question of how we, as individuals, communities, nations, and a world community, will respond to human-driven climate change. The Kyoto Protocol (*available online*)[5] characterizes the international response and has as its objective

> *the stabilization of atmospheric concentrations of greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

Although general, this statement reflects important progress inasmuch as it recognizes human influence on the earth's climate system and acknowledges the potentially dangerous effects of climate change on the earth's ecosystems. It also recognizes the relationship between climate change and economic development.

Importantly, the Kyoto Protocol establishes a specific target for global greenhouse gas emissions at 5% below 1990 levels, to be achieved by 2012. Although a 5% reduction in emissions below 1990 levels may not be sufficient to contain climate change within tolerable limits, this standard provides an initial, measurable reference point and constitutes a partial basis for evaluation of efforts to combat the anthropogenic component of climate change. The question that remains is whether we, collectively, are willing to modify our socioeconomic behavior to meet such standards and conserve the Arctic and other ecosystems as we know them.

The Probability of Climate Change Effects

Although the long-term risks cannot be reliably quantified at present, the direction of probable effects is evident for the majority of Arctic marine mammals. The long-term impacts may range from positive or mixed for a few species (e.g., the gray whale) to negative but minor for species with plastic or variable natural history patterns and limited dependence on specific habitats. For others, those with relatively fixed or inflexible life history patterns and strongly dependent on specific habitat types at risk, the effects may be seriously negative (Tynan and DeMaster 1997, Lowry 2000, Derocher et al. 2004, Laidre et al. 2008). Severe impacts could range from population reduction to extirpation throughout much of a species' natural range and eventual extinction. With respect to the latter point, the Center for Biological Diversity recently petitioned the U.S. Fish and Wildlife Service to list polar bears as endangered under the U.S. Endangered Species Act, arguing that the species faces a real possibility of extinction in the foreseeable future (information *available online*).[6] The Fish and Wildlife Service, in turn, found that the evidence in the petition was sufficient to warrant full review. A precedent has already been established, albeit in another type of ecosystem, for listing species as threatened under the Endangered Species Act due to the risks posed by climate change (see NOAA [2006] for listing determinations for elkhorn [*Acropora palmata*] and staghorn [*A. cervicornis*] corals).

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[5] ⟨http://www.un.org/millennium/law/xxvii-23.htm⟩

Arctic marine mammals may experience multiple negative impacts, the majority of which involve profound changes in habitat. Habitat loss has been "the primary factor responsible for the rapid rate of species extinctions and the global decline in biodiversity in the past one hundred years" (Dayton et al. 2002:24). Habitat degradation resulting from climate change has the potential to exceed that caused by any other anthropogenic factor (Thomas et al. 2004). The full extent of climate-related habitat degradation is, however, difficult to predict because relationships between climate and habitat features are not well understood, anthropogenic contributions to climate change have yet to be brought under control, and a variety of other factors contribute to habitat degradation. Thus, the relative effect of climate change may be difficult to distinguish from the effects of other ongoing risk factors. Current climate models predict progression of the physical manifestations of climate change (ACIA 2004), yet it is difficult to determine how far-reaching the direct and indirect biological and ecological consequences of these changes might be. Nonetheless, evidence of effects is mounting (Stirling and Smith 2004, Stirling et al. 2004), and new and intensified human activities are being planned based on anticipated changes that will render the Arctic increasingly accessible in the coming decades. Experience from areas outside the Arctic (e.g., Northridge and Hofman 1999, Laist et al. 2001, Reynolds et al. 2005, Bejder et al. 2006) suggests that these activities will pose new risks to marine mammals.

Conservation Efforts to Address Climate Change

Hypothetically, conservation measures could be aimed at the causes of climate change, the physical manifestations of that change, or their biological and ecological consequences. With regard to the causes of climate change, virtually all effort is currently focused on controlling emissions of greenhouse gases to prevent or minimize the extent of change, and we know of no other method for addressing those causes. We also know of no measures that society can use to modify or alleviate the physical manifestations of climate change (e.g., melting sea ice, melting permafrost, increasing rainfall). Thus, beyond prevention, all known conservation measures are limited either to the biological and ecological consequences of climate change or to changes in human activities secondary to climate change (e.g., shipping, tourism, development). Such measures may be essential in the short term to prevent losses from factors other than climate change and also as interim measures to retain species or distributions until longer-term measures take effect.

In Table 1 we list and consider the potential utility of various conservation measures to address the threats to marine mammals and ecosystems as discussed in this Special Issue. A review of potential effects of climate change and corresponding conservation measures for Arctic marine mammals and marine ecosystems indicates the following:

1) The persistence of marine mammals in the Arctic will be determined by the cumulative influence of natural phenomena and anthropogenic factors, including climate change and the rate at which marine mammals and ecosystems adapt to accumulating risks.

2) Conservation measures cannot change the basic natural history traits of affected marine mammal populations in the wild (e.g., foraging patterns, distribution and movement patterns, or reproductive strategy) or enhance the rate at which they adapt to climate change.

3) The most significant direct effect of climate change will be degradation and loss of habitat, which can only be addressed by prevention.

4) Prevention (including the potential for reversal) appears to be key in the long term as virtually all other conservation measures identified to date do not address directly the expected consequences of climate change and are limited to avoiding, minimizing, or mitigating the confounding effects of increasing human presence and activities in the Arctic.

5) Other conservation measures may be useful in the shorter term to the extent that they delay irreversible changes such as extirpation and extinction. Reducing the rate of loss, however, is not a substitute for true conservation, as lower populations in smaller or degraded habitats are at higher risk. In other words, conservation measures that are limited to addressing consequences rather than the underlying causes of climate change must be part of a larger strategy to have long-term utility.

6) Specific, objective indicators are needed to establish thresholds in population or habitat loss akin to "depletion" under the MMPA. Such indicators also can be used to assess trends and measure conservation effectiveness. Recognizing that data for Arctic marine mammals are often difficult and expensive to obtain, some basic indicators could still be identified, such as sea ice extent, population trends in well-studied species such as the bowhead or beluga whale, or health and reproductive trends in often-captured species such as the polar bear.

7) Monitoring of marine mammal populations and stocks will be essential to provide an empirical measure of their response to the cumulative impact of all risk

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[6] ⟨http://www.biologicaldiversity.org/swcbd/species/polarbear/index.html⟩

Table 1. Conservation measures and their potential utility in addressing hazards to Arctic marine mammals from climate change.

Nature of hazards	Protection measures	Potential utility (effect of the proposed protection measure)
Reduced foraging conditions and prey availability (Bluhm and Gradinger 2008)		
Changes in physical and chemical environmental conditions will lead to reduction and degradation of ice-related habitat and feeding grounds, and changing distribution of marine mammal prey.	Protection of marine mammals from direct and indirect interactions with fisheries through fishery prohibitions on certain prey, restrictions on certain gear types, and time/area closures.	Fishery measures would reduce or remove a source of impacts, one that may increase in the Arctic with reduction of sea ice. Specific measures would target direct or operational effects (e.g., marine mammal bycatch) and indirect or ecological effects (e.g., competition for prey or disturbance of habitat). Fishery measures and ecosystem monitoring also will be essential to detect and minimize or avoid changes in biodiversity caused by fishing (e.g., as might occur from fishing Arctic cod, a keystone species).
Declining health and condition (Burek et al. 2008)		
Marine mammals stressed by changes in their physical and biological environment may experience slower growth (juveniles) and/or poor physiological condition. They may be more susceptible to disease and contaminants. Exposure to disease will increase as the range of pathogens shifts or expands northward. Climate change impacts may be exacerbated by increasing levels and types of contaminants from added regional human activities as well as global sources of pollution.	Captive care of animals with slow growth or poor condition.	Captive care would allow for veterinary medical treatment of individuals and provision of adequate nutrition. Captive care is feasible only for pinnipeds and small cetaceans. It is largely impractical in the Arctic but may be an action of last resort for stocks or populations approaching extinction.
	Cleanup of existing contaminants and prevention of further contamination.	Reduction of pollutants is necessary to avoid confounding the effects of climate change. Within the Arctic, the cleanup of existing contaminated sites and prevention of further contamination will require action at local, regional, national, and international levels.
	Vaccination to minimize susceptibility to disease.	Vaccination may reduce susceptibility directly and exposure indirectly if it helps prevent spread of disease. However, vaccination likely will be of limited utility because administration of vaccine would be costly and logistically difficult. In addition, vaccines are not available for many marine mammal diseases.
	Protect multiple stocks/populations of each species to ensure recovery potential.	Protection of multiple stocks, populations, and habitats will reduce the consequences of a disease outbreak or other single event. Conservation of multiple stocks is essential to retain intra-species diversity and distribution.
Reduced reproduction		
Reproduction may decline if growth and condition are compromised, reproductive habitat is degraded or lost, or reproductive capacity is compromised by contaminants or disease.	Protection of key reproductive habitat.	Protecting key reproductive habitat would reduce or remove a major threat to species conservation and retain the potential for species recovery over time. Several species appear to have strict habitat requirements for reproduction (ringed seal, bearded seal, polar bear). Short of prevention, nothing can be done to conserve ice-based reproductive habitat. If seal species and walruses attempt to reproduce on land, then measures to protect them from human activities and other predators (bears, wolves) may be possible and essential, although they also may be controversial depending on the status of bear and wolf populations.
	Cleanup of contaminated sites and prevention of further contamination.	See *Declining health and condition.*
	Vaccinations for disease.	See *Declining health and condition.*

Table 1. Continued.

Nature of hazards	Protection measures	Potential utility (effect of the proposed protection measure)
Reduced survival		
Survival may decrease due to poor condition of animals unable to forage effectively; increased susceptibility and exposure to contaminants and disease; increase in commercial, sport, and subsistence hunting; increased vulnerability to predators (e.g., killer whales); ship strikes from increased vessel traffic; and interactions with fisheries.	Clean-up of contaminated sites and prevention of further contamination.	See *Declining health and condition*.
	Vaccination for disease.	See *Declining health and condition*.
	Hunting bans or limits.	Reduction of hunting pressure would reduce or remove one source of mortality. Bans or limits of commercial, sport, and subsistence hunting may be essential for declining species with no tolerance for additional sources of mortality. Although marine mammal hunting is an integral part of many Arctic cultures, the long-term survival of some species and thus their availability to future generations of hunters may require hunting restrictions. Loss of species will benefit no one.
	Predator removal.	Removal of predators (e.g., killer whales) may help conserve species or populations that are on the brink of disappearance. Such removal is likely to be highly controversial and of uncertain utility. Control or removal of bears and wolves near haul-out sites also may be highly controversial.
	Vessel corridors, speed limits, and observer programs.	Ship strikes are a major concern for some endangered marine mammals outside the Arctic (e.g., North Atlantic right whales and Florida manatees), and removal or reduction of this threat to Arctic marine mammals may be important for species or stocks on the brink of extinction. If sea ice extent decreases, shipping will almost certainly increase in Arctic waters. Techniques that have been used elsewhere (e.g., vessel corridors, speed limits, observer programs) may be effective in reducing ship strikes.
	Fishery regulations to avoid direct and indirect interactions.	See above, this section.
	Regulations on oil, gas, and mineral extraction; tourism; military activities; coastal development.	Reducing or removing risks associated with increased human activities, particularly industrial development, would provide species with an additional margin of safety. Mortality is more likely to be secondary to loss of habitat from these activities; direct mortality is likely to be limited unless marine mammals (e.g., polar bears) become concentrated in areas of human activity. Most development is already subject to environmental regulation, although cumulative impacts and incremental losses of habitat are seldom adequately addressed.
Loss of habitat (Laidre et al. 2008)		
Habitat will be lost and degraded by the physical changes in the Arctic (e.g., loss of sea ice) as well as human activities that occur secondary to climate change.	Marine protected areas to avoid or minimize the secondary effects of human activities.	Protected areas would reduce or remove human activities in specific locations, reducing risks and perhaps helping to protect vital life history stages or events such as reproduction. Such areas may require extensive zoning, including buffers, as well as dynamic management to preclude human alteration of important or potentially important marine mammal habitats. Marine protected areas are controversial in some regions and enforcement can be problematic. Under climate or other environmental change, key habitat characteristics may move, requiring that protected areas be adjusted as well if they are to remain effective.

TABLE 1. Continued.

Nature of hazards	Protection measures	Potential utility (effect of the proposed protection measure)
Reduced evolutionary potential		
Populations, stocks, and species may be extirpated throughout portions of their range or driven extinct, causing a loss of genetic diversity.	Identify and seek to conserve genetic diversity within each species.	Understanding the extant intraspecific diversity of Arctic marine mammals is necessary to identify specific conservation units and targets. Research on genetic diversity is needed for many species.
	Identify and seek to conserve populations and stocks of species in different habitats and subject to different selective forces.	Maintaining multiple populations in different habitats will facilitate species adaptation to rapidly changing selective forces, thereby promoting long-term conservation. Persistence over evolutionary time is, in part, a function of the variability in selective forces to which each species is exposed (cf. metapopulation theory; Hanski and Gilpin 1991). Climate change constitutes a major change in selective forces, one that is acting over much shorter time frames than most.
	Prevent fragmentation and isolation of habitats.	Retaining intact, connected habitats will promote genetic exchange among populations and reduce the risk of a catastrophic event. Reproductive habitat in particular should be protected. Fragmentation and isolation may be less of an issue with mobile mammal populations in a marine environment, but may occur as populations decline, reproductive habitat is degraded, potentially disruptive human activities expand (e.g., shipping), or coastal areas are developed.
Increasing human activities (Hovelsrud et al. 2008)		
May contribute to or exacerbate all of the above hazards.	Will require a broad range of measures as indicated above for various human activities.	Evident in all sections of this table.
Cumulative effects (Moore and Huntington 2008)		
Cumulative impact will be determined by the sum of the independent (additive) and synergistic (interacting) effects of all the above hazards.	Prevention	Prevention would remove climate change as a threat to Arctic marine mammals. It is indeed the only measure that can do so completely. It requires, however, a substantial societal commitment.
	All measures above.	The measures described above will address specific secondary threats, particularly human activity. They are therefore necessary, but not necessarily sufficient for addressing the full effects of climate change.
	Monitoring of population status.	Monitoring of marine mammal population status and trends will be essential for tailoring the available conservation measures to secondary effects, thereby maximizing their utility and efficacy in conserving marine mammals faced with the consequences of climate change.

Notes: In all cases, prevention is the only way to completely remove the threats posed by climate change but would require substantial societal commitment. To avoid repetition, we have not listed prevention in each section of the table, but only under cumulative effects.

factors, natural and anthropogenic. To date, studies of marine mammal stocks in the Arctic generally have been insufficient to determine stock structure, status, trends, or the influence of individual risk factors on status and trends. The current level of research support limits informed decision making about the status of Arctic marine mammals now and, if not remedied, will undermine informed decision making in the future.

8) In view of the time lag between climate change cause and consequence, the uncertainty regarding full

consequences and the potential severity of those consequences, climate change must be addressed with proactive, adaptive, and precautionary management aimed at prevention of adverse effects.

LOOKING FORWARD

Climate change will have adverse and possibly irreversible repercussions. Loss of sea ice habitat and the productive food web associated with it and increasing human presence and activities are likely the most significant threats to Arctic marine mammals. Cumulative effects of these and other factors may well include extirpation of populations and even extinction of marine mammal species. Measures to minimize or mitigate the effects of climate change on Arctic marine mammals are few and, at best, can address only the secondary effects of climate change, including those resulting from additional human presence and activities in the Arctic. As part of a larger strategy, such measures may make the difference between persistence and extirpation or, in the worst case, extinction. Prevention through reductions in greenhouse gas emissions appears to be the only approach that can ensure the long-term conservation of Arctic marine mammals and Arctic ecosystems as we know them.

Until very recently, the reluctance to take strong preventative action to address climate change stemmed in part from uncertainty about the probability of serious long-term consequences. Therein lies the dilemma of climate change: its consequences are an outcome of complex interactions among components of the earth–ocean–atmospheric system, and the effects are subject to considerable time lags (decades and perhaps centuries; Meehl et al. 2005). However, waiting for absolute certainty and full knowledge about the consequences of climate change will preclude not only preventive measures, but perhaps any effective response.

We should have anticipated this dilemma. Many of the concerns raised in the 1960s and 1970s and leading to important conservation legislation were based on recognition of the fundamental clash between conservation of the environment and increasing human abundance and consumption-oriented economies. Postponing decisions regarding climate change may only add to the difficulty. The world's human population is expected to reach 9.2 billion by 2050, an increase of 2.8 billion or 43% of estimates for 2005 (according to the U.S. Census Bureau, *available online*)[7] and will likely continue to increase after that. The environmental effects of that growth in numbers may be further exacerbated by per capita changes in consumption patterns, both in developed and developing countries. Thus, future decisions regarding Arctic conservation could well be made in an atmosphere of growing demand for goods and services, continuing environmental decline, and increasing global strife. Unfortunately, if the value that human societies place on conservation remains the same in the future as is evident today, then conservation of Arctic regions is likely to remain a laudable, but secondary, objective in the face of growing socioeconomic pressures and political concerns. By delaying action, we are foisting a burden on future generations that we are unwilling to address ourselves. It will be under the weight of this burden that future generations must address global climate change, and their task will be harder than ours, not easier (Stanley 1995).

Societies, communities, and individuals are confronted with difficult choices that will determine the fate of Arctic marine mammals and ecosystems. Our lives are filled with similar circumstances (e.g., health care) where we take actions, form habits, or adopt whole lifestyles to avoid the possibility of adverse consequences years and even decades later. Such situations are ripe for precautionary decision making because waiting for absolute certainty often precludes effective response. Failure to act now to address climate change may promote short-term gains, but may come with long-term costs to ecosystems and the future generations that will depend on them. Conversely, aggressive measures taken today may impose short-term socioeconomic costs, but are likely to avoid more costly long-term threats. Absent such measures, society's ability to respond effectively may be lost before the full implications of our inaction become apparent.

Altering our direction to reduce the factors that contribute to climate change will require reexamination of our values. It will require a new perspective that places us squarely within ecosystems and willing to live within their natural limitations. It will require that we critically examine our personal and social choices and aspirations with respect to family size, resource consumption, and lifestyles. If we are willing to accomplish these tasks, then there may still be hope for Arctic regions and species as we know them.

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