Ursus

A circumpolar monitoring framework for polar bears

--Manuscript Draft--

Manuscript Number:	URSUS-D-11-00026R1
Full Title:	A circumpolar monitoring framework for polar bears
Short Title:	Polar bear monitoring framework
Article Type:	Perspectives/Essays/Reviews
Keywords:	POLAR BEAR; URSUS MARITIMUS; MONITORING; ADAPTIVE MANAGEMENT; CLIMATE CHANGE; HARVEST; POPULATION PARAMETERS; POPULATION SIZE; SEA ICE HABITAT; HABITAT LOSS; TRADITIONAL ECOLOGICAL KNOWLEDGE
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weather and have limited access. Polar bear survival is dependent on adequate temporal and spatial availability of sea ice to access their prey. Sea ice availability has been declining for decades and will continue to do so as long as greenhouse gas concentrations rise. At the same time, human intrusions and pollution levels in the Arctic are expected to increase. A circumpolar understanding of the cumulative impacts of current and future stressors is lacking, long-term trends are known from only a few subpopulations, and there is no globally coordinated effort to monitor effects of stressors. Here we describe a framework for an integrated circumpolar monitoring plan to detect ongoing patterns, predict future trends, and identify the most vulnerable polar bear subpopulations. We recommend strategies for monitoring subpopulation abundance and trend, reproduction, survival, ecosystem change, human-caused mortality, human-bear conflict, prey availability, health, stature, distribution, behavioral change, and the effects which monitoring itself may have on polar bears. Monitoring intensity for each subpopulation is assigned through adaptive assessment of the quality of existing baseline data and research accessibility. A global perspective is achieved by recommending high-intensity monitoring for at least one subpopulation in each of four major polar bear ecoregions. Collection of data on harvest, where it occurs, and remote sensing of habitat, should occur with the same intensity for all subpopulations. We outline how local traditional knowledge may most effectively be combined with the best scientific methods to provide comparable and complementary lines of evidence. We also outline how previously collected intensive monitoring data may be sub-sampled to guide future sampling frequencies and develop indirect estimates or indices of subpopulation status. Adoption of this framework will inform management and policy responses to changing worldwide polar bear status and trends.

9 May 2012

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A circumpolar monitoring framework for polar bears

Running brief title: Polar bear monitoring framework

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ABSTRACT

Polar bears (*Ursus maritimus*) occupy remote regions that are characterized by harsh weather and have limited access. Polar bear survival is dependent on adequate temporal and spatial availability of sea ice to access their prey. Sea ice availability has been declining for decades and will continue to do so as long as greenhouse gas concentrations rise. At the same time, human intrusions and pollution levels in the Arctic are expected to increase. A circumpolar understanding of the cumulative impacts of current and future stressors is lacking, long-term trends are known from only a few subpopulations, and there is no globally coordinated effort to monitor effects of stressors. Here we describe a framework for an integrated circumpolar monitoring plan to detect ongoing patterns, predict future trends, and identify the most vulnerable polar bear subpopulations. We recommend strategies for monitoring subpopulation abundance and trend, reproduction, survival, ecosystem change, human-caused mortality, human-bear conflict, prey availability, health, stature, distribution, behavioral change, and the effects which monitoring itself may have on polar bears. Monitoring intensity for each subpopulation is assigned through adaptive assessment of the quality of existing baseline data and research accessibility. A global perspective is achieved by recommending high intensity monitoring for at least one subpopulation in each of four major polar bear ecoregions. Collection of data on harvest, where it occurs, and remote sensing of habitat, should occur with the same intensity for all subpopulations. We outline how local traditional knowledge may most effectively be combined with the best scientific methods to provide comparable and complementary lines of evidence. We also outline how previously collected intensive monitoring data may be sub-sampled to guide future sampling frequencies and develop indirect estimates or indices of subpopulation status. Adoption of this framework will inform management and policy responses to changing worldwide polar bear status and trends.

Key words: adaptive management, climate change, habitat loss, harvest, monitoring, polar bear, population parameters, population size, sea ice, traditional ecological knowledge.

1. INTRODUCTION

1.1 BACKGROUND: THE CURRENT SITUATION

Polar bears (*Ursus maritimus*) are distributed throughout the ice-covered waters of the circumpolar Arctic. Because they feed on prey they catch from the sea ice surface, polar bears are considered ecologically to be marine mammals.

The earliest international concerns for conserving polar bears were focused on controlling the number of bears being harvested every year. Early Eurasian explorers viewed polar bears as fearless marauders (Larsen 1978), and for centuries Arctic travelers killed as many polar bears as possible (Seton 1929). Although the uncontrolled killing of polar bears by Arctic explorers decreased during the 1900s, polar bears continued to be harvested in large numbers through the middle of the 20th century. In addition to continued harvesting by local residents of the Arctic, trophy hunting flourished in some regions. In recognition of the polar bear's increasing vulnerability to human activities, the five nations (the Soviet Union, Canada, Denmark, Norway, and the United States) with jurisdiction over polar bear habitat negotiated the Agreement on the Conservation of Polar Bears (the Agreement). The Agreement was signed in 1973 and came into effect in 1976 when it was ratified by three countries, the minimum for ratification, and by the two remaining countries shortly thereafter. Under the terms of the Agreement, each signatory nation is required to conduct research, and to cooperate in management and research of shared populations that overlap jurisdictional boundaries.

Most polar bear subpopulations continue to be hunted. Although concerns over human-bear interactions, disturbance associated with industrial development, and pollutants have grown locally and regionally (Vongraven and Peacock 2011)**,** most worldwide management efforts have remained focused on harvest. Based upon movements, genetic patterns, and management considerations, 19 polar bear subpopulations are currently recognized worldwide (Obbard et al. 2010:31). Harvest varies among subpopulations and management jurisdictions.

The largest polar bear harvest occurs in Canada where it is regulated primarily through quotas set for each subpopulation and limited to aboriginal peoples (Prestrud and Stirling 1994, Lunn et al. 2010). When it ratified the Agreement, Canada allowed for a "token" number of bears to be harvested by non-aboriginal hunters for sport. In practice, sport hunting of polar bears in Canada is guided by preferences of Inuit hunters, and animals killed in these hunts form part of the quota assigned to a community. Hunting is banned in Svalbard although a limited number of bears are taken each year in defense of life and property (Vongraven et al. 2010). Hunting in Greenland is limited to "professional" hunters who derive all of their income and sustenance from hunting and fishing. A quota system was recently adopted in Greenland, but has yet to be fully accepted by the hunters and in some areas harvests are thought to be excessive (Hansen 2010). Hunting was banned in Russia under the former Soviet government. Though technically not allowed, considerable illegal harvest by both Native and non-Native peoples has occurred in portions of the Russian Arctic in recent years (Belikov et al. 2010). In the United States, the harvest in the Southern Beaufort Sea subpopulation is regulated by an agreement between Inupiat hunters in Alaska and Inuvialuit hunters in Canada (Treseder and Carpenter 1989, Brower et al. 2002). The "Agreement between the Government of the United States of America and the government of the Russian Federation" was developed recently to regulate harvest and more generally assure conservation and management of the Chukchi Sea subpopulation (DeBruyn et al. 2010). Finally, a bilateral "Memorandum of Understanding" was agreed upon between the governments of Canada and Greenland in 2009, with the objective to "manage polar bears within the Kane Basin and Baffin Bay management units to ensure their conservation and sustainable management into the future" (Anonymous 2009a:2). This agreement was intended to end a long-lasting unsustainable harvest due to the lack of sound cooperative management of these shared subpopulations.

Historically, polar bear harvest management has been based on the premise that stable habitats enabled a sustainable harvest. Projection models (e.g., Taylor et al. 2008a) guided the setting of harvest levels that were thought to be sustainable. However, the harvest level and the quality of information to support harvest management varies considerably among subpopulations. Large-scale natural fluctuations in the reproduction and survival of ringed seals (*Pusa hispida)*, the primary prey of polar bears, have been documented (e.g., Stirling 2002). Although similar natural fluctuations in prey abundance almost certainly occur in most, if not all subpopulations, little is known of their magnitude or frequency. These natural fluctuations, although not fully understood, along with the warming induced declining trend in suitable habitat, emphasize the importance of taking a precautionary approach to the establishment of maximum allowable harvest levels. However, the degree to which such precautions are included in existing harvest management is mixed.

Long-term studies of polar bears in Hudson Bay, Canada, the Beaufort Sea region shared by Alaska and Canada, and Svalbard have provided valuable information on status and trends of polar bears. However, the other subpopulations have not been studied to the same extent, have had shorter or periodic efforts, or have so recently been examined that trend evidence is unavailable. Existing inter-jurisdictional management agreements are few and recent, and different policy positions within and among jurisdictions, differential funding, and widely varying logistical challenges mean that few data sets are consistent enough to facilitate quantitative comparisons among different subpopulations of polar bears.

The lack of comparable monitoring data across the range of the polar bear has long been recognized. Conservation risks resulting from this lack of data were low when the habitat for polar bears appeared to be relatively stable. When managers felt able to assume adequate habitat to support healthy polar bear subpopulations, each jurisdiction could prioritize its local concerns (e.g., harvest quotas or oil and gas permitting) over regional or global concerns. For example, if allowed harvest levels in one subpopulation were found to be excessive, managers could re-adjust their strategies to bring their local areas back into balance with what they thought the habitat could sustain. Status descriptions of individual polar bear subpopulations over the last decade illustrate this management paradigm (Lunn et al. 2002, Aars et al. 2006, Obbard et al. 2010).

Anthropogenic global warming, and the realization there is more natural variability in polar marine ecosystems than was previously thought, requires changes to this historic polar bear management paradigm. In the long term, global warming induced habitat loss means there is no sustainable harvest for any population. It means that without mitigating the rise in atmospheric greenhouse gas concentrations, polar bears will disappear not only from some subpopulations, but possibly throughout their range (Amstrup et al. 2010, Amstrup 2011). However, stating that all subpopulations ultimately will decline and making projections of how and when each may reach critical thresholds are different things. The latter depends on having meaningful population level monitoring statistics throughout the circumpolar range of polar bears.

As polar bear numbers decline during the next century, boundaries separating long-recognized subpopulations may change. Therefore, the current system of individually managing subpopulations supported by habitats that were formerly thought to be stable will need to be modified. Our ability to make effective changes will depend on having comparable long-term data from across the range of polar bears. The Parties signatory to the Agreement recognized this need at their meeting in Tromsø, Norway, in 2009 where they "welcomed ongoing efforts to monitor status and trends for polar bear populations, and agreed on the need to strengthen monitoring throughout the range of polar bears, and to coordinate and harmonize national monitoring efforts" (Anonymous 2009b:16).

Despite this recognition, there still are no monitoring plans shared among the five polar bear nations that would facilitate a coordinated response to both gradual and sudden changes in polar bear populations that will occur as a result of global warming and other population stressors. Here we propose a monitoring framework that will address this shortcoming.

1.2 THE MONITORING FRAMEWORK

1.2.1 CHALLENGES

Polar bears are dependent upon sea ice for access to their prey. Their dependence on habitat that melts as temperatures rise means that climate warming poses the single most important threat to the persistence of polar bears over the long term (Stirling and Derocher 1993, Derocher et al. 2004, Obbard et al. 2010:85). Arctic sea ice extent is linearly related to global mean temperature that, in turn, is directly related to atmospheric greenhouse gas concentrations (Amstrup et al. 2010). Therefore, without greenhouse gas mitigation, no polar bear subpopulations will be self-sustaining in the long term (Amstrup et al. 2010). To date however, evidence for the adverse effects of warming has been limited to certain regions of the circumpolar range (Stirling et al. 1999; Durner et al. 2009; Regehr et al. 2007, 2010; Rode et al. 2010, 2012). Similarly, projections of future sea ice change differ among subpopulations and regions (Perovich and Richter-Menge 2009). It is also reasonable to hypothesize that polar bears living in historically colder regions of the Arctic where, until recently, multi-year ice has been fairly extensive might derive transient benefit from a milder climate that resulted in more extensive annual ice over the continental shelf and in interisland channels in the Canadian Arctic Archipelago (Derocher et al. 2004).

The assurance that warming and habitat losses will continue as long as greenhouse gas concentrations rise (Amstrup 2011), and the anticipated regional variations in warming-induced habitat loss provide the critical backdrop for the development of a plan for future polar bear monitoring. However, habitat loss is not the only threat to the future status of polar bears. Previously, over-harvest was of great concern (Taylor et al. 1987b, Larsen and Stirling 2009). Although continuing habitat loss precludes long-term sustainability, many polar bear subpopulations could provide a harvest that can be maintained in the short term. Therefore, management must attempt to assure a balance, even if transient, between potential yield and ultimate levels of harvest (Peacock et al. 2010, 2011). Harvest is currently thought to be unsustainable in some populations, balanced in others, and of largely unknown status in the rest. In many cases, harvest documentation and the population data necessary to assess the impact of harvest are both insufficient to allow managers to assure harvests are sustainable. Given the cultural and economic importance of polar bear hunting in many regions, understanding the potential for and the impact of hunting continues to be a vital part of management and underlines the importance of developing an overall framework for monitoring polar bear subpopulations.

The global rise in contaminants also is a factor in monitoring the status of polar bears. Although polar bears live in remote Arctic regions, atmospheric and oceanic circulation patterns bring a variety of toxic substances into these locales from human population centers around the world. The contaminant burdens among polar bears vary among regions (e.g., Norstrom et al. 1998, McKinney et al. 2011). More importantly, even where contaminant burdens are known, the effects of contaminants on polar bear physiology and health are only partially understood (Sonne

2010). The potential for contaminants to affect Arctic systems is predicted to increase as climate warming alters global circulation and precipitation patterns (Macdonald et al. 2005) so that predicting local and regional effects will become more complicated and uncertain. Therefore, understanding patterns in and effects of pollution in the polar bear's environment is an important part of a monitoring plan.

Expansion of industrial activities in the Arctic is expected to continue. In the Beaufort Sea of Alaska, for example, polar bears have been exposed to activities related to hydrocarbon exploration and development for over 40 years. Hydrocarbon exploration and development is expanding to the north in Norway, and the largest untapped oil and gas reserves north of the Arctic Circle are thought to occur in and near polar bear habitats of the Russian far north (Gautier et al. 2009). Significant portions of polar bear range are already experiencing development, but with warming-induced sea ice decline, previously inaccessible areas will become vulnerable to future development. The direct effects of human activities, the increased potential for negative human-bear encounters, and the increased potential for local pollution are all concerns that must be monitored if we are to understand the future consequences for polar bears and manage associated impacts.

As human populations grow and their distributions change throughout the Arctic, polar bears will face increased risks from a variety of human-bear interactions. Although human-bear interactions are reasonably straightforward to document, we have a long way to go to understand the effects of such interactions. The role these cumulative stresses, resulting from a more crowded Arctic, may play in the future of polar bears must be included in the development of monitoring plans.

As we are becoming increasingly aware of the coming changes in the Arctic, we also are poignantly aware of the shortcomings in our knowledge base. Our current scientific understanding of polar bears and their reliance on sea ice habitats is the result of long-term research and monitoring projects in only a few subpopulations. Thus, it is likely that the information gathered to date in those studies is inadequate to fully understand the complex ecological ramifications of climate warming and other stressors. Sustained long-term monitoring that can be compared across the circumpolar range of the polar bear will be essential to understand ongoing effects of climate warming and the other population-level stressors. Developing and implementing a plan that harmonizes local, regional, and global efforts will be necessary to detect and understand how climate warming and other population stressors may differentially affect populations and habitats.

Because polar bears live in extreme, remote environments, they are costly to study, and few jurisdictions have been able to devote the resources necessary to document long-term trends. Current knowledge is inadequate for a comprehensive understanding of the present and future impacts of many individual stressors, and the cumulative effects of all ongoing and future stressors are unknown (Laidre et al. 2008). Here, we provide a framework for an integrated circumpolar monitoring plan that will enable managers to detect ongoing patterns, predict future trends, and identify the most vulnerable subpopulations.

1.2.2 THE FRAMEWORK

The monitoring framework described in this document represents the collective scientific opinion of the co-authors for the most effective ways to monitor polar bears on a circumpolar level. We encourage the polar bear Range States (Canada, Greenland, Norway, Russia, and USA) to use it to develop appropriate and realistic monitoring plans, based on resources and priorities for each country. The proposed framework suggests how the best available scientific methods, Traditional Ecological Knowledge (TEK), and Community-based Monitoring (CBM) should be integrated into a comprehensive plan across the circumpolar Arctic.

The main elements of the monitoring framework document are:

- A monitoring approach that is based on the four ecoregions (Amstrup et al. 2008, 2010) that describe sea ice-differences and the ecological responses of polar bears to those differences.
- A tiered monitoring approach (recommending monitoring intensities and methods that differ among subpopulations).
- Recommended monitoring parameters – background and monitoring schemes.

2. MONITORING FRAMEWORK OBJECTIVES

The objectives for this monitoring framework have been adopted from the background paper (Vongraven and Peacock 2011). Recognizing the need for more effective monitoring, we describe the framework for a long-term polar bear monitoring plan that aims to:

- rank the world's 19 subpopulations with regard to their monitoring need and potential;
- select representative subpopulations for high and lower intensity monitoring;
- identify parameters that must be monitored to understand worldwide patterns in polar bear status;
- identify a range of estimators and indices, appropriate for different monitoring intensities among subpopulations, that may illuminate trends in critical parameters;

- identify how high intensity efforts can be used to calibrate lower intensity efforts; and
- identify research needed to establish the most effective monitoring methods and frequencies.

3. A TIERED MONITORING APPROACH

To conduct monitoring that will provide accurate and precise information about polar bear population status and well-being in all 19 presently acknowledged subpopulations is a complicated, expensive, and demanding task. Polar bears generally occur at low densities over vast areas and live much of the year in an extreme, remote environment often accessible only through elaborate and expensive logistics. Because the cost of comprehensive monitoring will be high, some jurisdictions may find it difficult to maintain the necessary long-term commitment. Thus, we recommend a tiered monitoring approach in which selected subpopulations within each ecoregion will be monitored at high intensity and other subpopulations will be monitored at lower intensity. Subpopulations to be monitored at high intensity are based on a high level of existing information, research accessibility, and being ecologically representative of the larger ecoregion in which they occur. If monitoring efforts are coordinated among different subpopulations, this approach will allow meaningful extrapolation between the intensively monitored areas and those receiving lower intensity monitoring within the same ecoregion.

This tiered monitoring approach is applicable to only some of the suggested monitoring metrics (e.g., subpopulation size and trend, survival rates, and reproductive parameters). In contrast, habitat monitoring using remote sensing, and, in some cases, methods that use harvest and CBM can be applied to subpopulations regardless of the intensity at which they are being monitored for demographic parameters.

3.1 POLAR BEAR SUBPOPULATIONS

Polar bears are distributed throughout the ice-covered waters of the circumpolar Arctic. They occur in areas where the temporal and spatial distribution of sea ice are adequate to ensure that sufficient energy reserves can be obtained to allow survival and maintenance through periods when ice may be absent or insufficient to facilitate successful hunting.

At present, 19 population units of polar bears (Fig. 1), called subpopulations, are recognized throughout the circumpolar Arctic by the IUCN/SSC Polar Bear Specialist Group (PBSG). For current subpopulation status see Obbard et al. (2010:31-80). We use the term “subpopulation” according to IUCN terminology (IUCN 2010) when it refers directly to polar bear subpopulations and “population” when it refers to general theory and methodology (e.g., “population dynamics”). See Vongraven and Peacock (2011) for more discussion on the use of these terms.

3.2 POLAR BEAR ECOREGIONS

Although 19 different subpopulations have been defined, ecological similarities allow clustering of subpopulations into larger geographic regions within which their habitats are more similar than different (Fig. 2; Amstrup et al. 2008). Ecoregions are defined by “observed temporal and spatial patterns of ice melt, freeze, and advection, observations of how polar bears respond to those patterns, and how general circulation models (GCMs) forecast future ice patterns in each ecoregion” (Amstrup et al. 2008:215, 2010: Online Supplementary Information).

We acknowledge variation in habitat within an ecoregion, potential for change in assignment in the future, and other categorizations of polar bear subpopulations (e.g., Thiemann et al. 2008a). Nevertheless, we adopt the ecoregion approach as a heuristic model for a framework within which circumpolar monitoring of polar bears may occur (Vongraven 2011). Under an adaptive management framework if these designations become less relevant as ice ecology and dynamics change, then the global distribution of effort should change. See Table 1 for descriptions of the ecoregions and the subpopulations composing each ecoregion.

The Arctic Basin (AB) was acknowledged as a separate catch-all subpopulation by the PBSG in 2001 (Lunn et al. 2002). This designation was chosen to account for bears that may reside outside the existing territorial jurisdictions. The AB subpopulation was left out of the analyses made by Amstrup et al. (2008), because: 1. The Arctic Basin is characterized by deep and unproductive waters (polar bears prefer sea ice over the shallower waters of the continental shelf < 300 m depth where higher densities of seals provide more hunting opportunities), and 2. Tracking studies indicate that few bears are year-round residents of the central Arctic Basin. It should be noted, however, that to date there has been no dedicated monitoring or research in the AB and that the AB may play a different role for polar bears under a scenario of climate warming.

Note on "ad hoc" subpopulation Norwegian Bay Convergent: A Canadian High Arctic subpopulation entity, or rather *ad hoc* monitoring region, Norwegian Bay Convergent (NWCon), has been added in the Convergent Sea Ice Ecoregion. This is due to the realization that this area will probably be an important, possibly one of the most important, future refugium for polar bears. See full argument in Section 3.5.

3.3 MONITORING INTENSITIES

There is great variation in accessibility, existing available information, and probability of gathering future information among subpopulations. Ideally, a monitoring plan should identify basic and easily-collected metrics for each monitoring element that can be reasonably, realistically, and comparatively measured in all or most subpopulations. Such metrics must provide sufficient power and resolution to reveal changes in polar bear status at the ecoregion or circumpolar level. For subpopulations that are more accessible or for which substantial data already exist, monitored metrics can provide more statistically robust assessments of status and trend. In subpopulations where research access is good and resources are available it is important to continue research on ecological relationships and causal mechanisms that determine trends.

We recommend high-, medium-, and low-intensity levels of population-level research and monitoring for polar bear subpopulations (see Tables 2, 3a, 3b). These assignments are based on the level of existing knowledge (e.g., quality of baseline data sets, availability of TEK), accessibility for science-based methods, and CBM for each subpopulation of polar bears. Table 3a summarizes the accessibility and baseline information upon which assignments were made. This table also summarizes the various threats in each subpopulation. Though several assessments have provided evidence for the threat of climate warming to polar bears, we also summarize direct effects of harvest, poaching, industrial activity (including marine and terrestrial exploration and development, and ice-breaking), and pollution. We also recommend annual harvest monitoring, CBM, and the collection of TEK to occur at intensities commensurate with community access (these levels of intensity may not be the same as intensities recommended for population-level scientific research).

Metrics in the medium- and low-intensity sampling areas must be measured in a way that maximizes their comparability with the more intensively monitored subpopulations within each ecoregion. For example, data derived from CBM approaches need to be collected simultaneously with data derived from scientific monitoring approaches in medium and high-intensity monitored units to facilitate calibration of data derived from CBM where only low-intensity monitoring is possible. This calibration will allow development of parallel lines of evidence among subpopulations. Trends in monitoring elements at the ecoregion level can be estimated by extrapolation from reference, or high-intensity subpopulations, to medium- and low-intensity subpopulation areas, and by comparison to monitored metrics among subpopulations within the same ecoregion. Trends at the global level can be estimated by amalgamation of information from each ecoregion. Finally, we recommend that a high-intensity program also be developed in parts of the Convergent Sea Ice Ecoregion, which is predicted to be a future refugium for polar bears under current scenarios of climate warming (Durner et al. 2009). For further discussion, see Section 3.5.

We recommend that estimates of subpopulation size and assessments of trend for subpopulations monitored at high-intensity be developed at intervals no longer than five years. However, power analyses of data from subpopulations with long time series of population estimates may help further clarify the optimal length of intervals between study efforts (see Priority study #1, Section 6.1). We suggest that subpopulations designated as medium-intensity be monitored in an adaptive framework based on threats and information needs (Section 3.4). Low-intensity monitoring has been recommended primarily for those subpopulations where research access is difficult. However, this designation does not imply that these subpopulations do not have high levels of threats or that monitoring of them might not be valuable should funding be available.

3.4 ADAPTIVE MONITORING

The present rate of change in sea ice habitats due to climate warming is unprecedented (IPCC 2007, Stroeve et al. 2007). At the same time, the pressure from anthropogenic drivers is increasing. Consequently, future changes in ecosystems and habitats are likely to be so rapid and severe that existing monitoring schemes will not adequately reveal trends. Therefore, we recommend that an adaptive framework be applied to the subpopulations designated for medium-intensity monitoring. Adaptive monitoring "provides a framework for incorporating new questions into a monitoring approach for long-term research while maintaining the integrity of the core measures" (Lindenmayer and Likens 2009:483). For example, subpopulations not currently showing indications of decline will be increasingly affected by ice habitat decline (e.g., Davis Strait). New data collection may reveal that human-caused mortality may have more impact than previously assumed (e.g., levels of poaching in the Chukchi Sea). If threats become severe enough, monitoring in these subpopulations should be increased to address emerging or more severe management concerns. In more simplistic terms, this implies that subpopulation monitoring frequency and intensity will be modified as needed, based on the assessed threat level, or other factors influencing the well-being of subpopulations. Assessment of threat levels and monitoring schemes will be undertaken regularly (see Section 7.2).

Lastly, for this monitoring framework to have long-term utility, we must measure its success. We call for a periodic examination, made available to the public and the Parties to the Agreement, of what monitoring has been conducted relative to the overall framework recommended in this plan. As new results become available, the plan should be refined and revised, including reassessment of ecoregional and monitoring-intensity designations.

3.5 DESIGNATION OF SUBPOPULATIONS IN HIGH-MEDIUM-LOW

In parsing recommended monitoring intensity among subpopulations it is critical that at least one subpopulation in each ecoregion receive the highest intensity monitoring possible. This maximizes the opportunity to calibrate lower intensity methods applied elsewhere within each ecoregion, and maximizes the opportunity to extrapolate trends to the ecoregion. Because the last vestiges of sea ice habitat are projected to occur in the far north of the Archipelago Ecoregion and adjacent Convergent Sea Ice Ecoregion (Durner et al. 2009), a new *ad hoc* subpopulation is designated in the Queen Elizabeth Islands region north of the Norwegian Bay subpopulation (Table 4), called Norwegian Bay Convergent (NWCon). We recommend that monitoring begin in this region as soon as possible (see Section 3.3). The strong baseline of information supports that the Northern Beaufort Sea subpopulation also be considered as a high-intensity monitoring area representing the Convergent Sea Ice Ecoregion. The designated high-, medium- and low-intensity subpopulations are shown in Fig. 3.

4. RECOMMENDED MONITORING PARAMETERS

This section describes what and how to monitor in the high-, medium-, and low-intensity monitoring subpopulations. The discussion is organized according to biological parameters that must be monitored to understand trends in population status. For each parameter, we describe why it should be monitored, how it could be monitored in a standardized manner, and how it could or should be monitored related to the different monitoring intensities.

4.1 SUBPOPULATION SIZE AND TREND

The question most often asked of polar bear researchers and managers is “how many polar bears are there?” Policy-makers and the public view the number of animals in any population and the trend in that number as the most straight-forward way to understand the status of that population. In many circumstances, the second most often asked question is how many bears are being harvested. Knowing the number of bears in a subpopulation is one of the most important parameters needed (along with survival and reproductive rates) to inform the setting of quotas for harvest. Knowing the trend in population size and the ratio of population size to harvest provides an understandable assessment of whether a harvest is sustainable and provides direct empirical evidence of what needs to be done to bring the system into balance. Beyond concerns of harvest, knowledge of population trend provides a yardstick of subpopulation status. Estimates or indices of subpopulation size and trend therefore are key components of a monitoring plan.

Despite its desirability, population size is the most difficult parameter to assess for polar bears. Polar bears occur at low densities scattered over very large geographic areas and are the most mobile of non-aquatic mammals (Amstrup et al. 2000, 2004). They are camouflaged when in their sea ice environment and are largely solitary. Interannual variation in movements and distribution, and the inability, within many subpopulations, to sample polar bears throughout their activity areas, complicate direct estimates of population size and trend. Similarly, indices of population size and trend using empirical observations of population composition or harvest data can be compromised by sex and age selection in harvest, variable environmental conditions, and lack of consistent replication. Including population size and trend assessments in a meaningful monitoring strategy is therefore necessary, yet challenging.

4.1.1 WHY MONITOR SUBPOPULATION SIZE AND TREND

The challenges in developing population size and trend information were historically not a critical shortcoming. If insufficient data or poor interpretation led to overharvest, population recovery could follow release from excessive harvest pressure (Amstrup et al. 1986). However, habitat availability is no longer stable. Although all subpopulations ultimately will decline if the increase in greenhouse gas emissions is not arrested, the effects of warming will vary in both space and time. Understanding these differences and how on-the-ground management may be able to best respond will depend on monitoring strategies that can be compared among all geographic regions and subpopulations.

4.1.2 HOW POLAR BEAR POPULATION SIZE AND TREND SHOULD BE MONITORED

Ideally, we would like to know the number of animals in each polar bear subpopulation at any point in time. Population size can be estimated by methods such as mark-recapture (M-R) and line-transect surveys. In these approaches abundance is estimated directly by evaluating ratios of marked and unmarked animals among multiple capture occasions (Amstrup et al. 2005a), or by animal counts calibrated with mathematical detection functions (Buckland et al. 2001). Indirect approaches to population estimation depend on age-structure data or other demographic information that is proportional to the actual population size. Population trend can be determined by comparison of estimates over time (Regehr et al. 2007, Stirling et al. 2011), or by projection of the population growth rate based upon estimated reproduction and survival (e.g., Taylor et al. 2002, Hunter et al. 2010). In many wildlife species, population size and trend have been assessed indirectly by various reconstructions of observed population composition or with indices to the population trend (Caughley 1977, Skalski et al. 2005).

4.1.2.1 DIRECT ESTIMATES OF POPULATION SIZE AND TREND

Two main quantitative methods have been used to assess polar bear population size: M-R, and aerial surveys. Under some circumstances components of these methods may be combined (e.g., multiple-source M-R) to provide the best possible estimates.

Much of what we now know about polar bears we know from a limited number of long-term physical M-R studies. Physical M-R requires capture efforts that are repeated regularly over (historically in the case of polar bears) multi-year periods. M-R estimates of subpopulation size are based on ratios of marked to unmarked individuals (Amstrup et al. 2005a). Physical M-R requires chemical immobilization and handling of individual bears. Polar bears are located by helicopter search, physically captured (with an immobilizing agent delivered by a dart projectile syringe), and permanently marked for future identification. This work is expensive and perceived as invasive by some. With adequate sample size and spatial distribution, estimates of population size can be obtained with two sampling periods. These could be multiple events within one year or season or two separate years. However, the interannual variation in movements, and the huge geographic areas that must be sampled mean that most M-R efforts require multiple years of data to arrive at accurate and precise population size estimates for polar bears. As polar bears have long life expectancies and reproduce slowly, information about population trends typically requires longer studies, or multiple projects scattered over multi-year time intervals.

Despite its cost, physical M-R has been the standard method for estimating population size for polar bears. In addition to direct estimates of abundance, capture-based methods can provide direct estimates of reproduction and survival rates. This allows estimates of trend to be projected from vital rates as well as measured from changes in estimates of population size over time. Additionally, when bears are physically captured, their sex, age, and physical and reproductive condition can be evaluated. Indicators of population level changes, made possible by the physical handling of bears, can be apparent well before direct estimates of population trend are available (Stirling et al. 1999), and they provide a separate data stream on growth, reproduction, and survival of young that can help understand trends in the population (Amstrup et al. 1986, Rode et al. 2010, Stirling et al. 2011). Just as importantly, the physical capture of large numbers of bears allows construction of population sex and age structure. Reconstructing the population composition from sex and age composition allows for indirect assessments of vital rates and population trend (Caughley 1977, Skalski et al. 2005). This can provide a basis for extrapolation from areas of intensive monitoring where M-R work is performed to less intensively monitored areas where only indices to composition may be available (see below).

An alternative to physical M-R is remote (Taylor and Lee 1994) or genetic M-R. In genetic M-R the marks are the genetic identities of individual bears. Genetic M-R has been used for over a decade to estimate population parameters in other wildlife, notably black (*U. americanus*) and brown (*U. arctos*) bears (Woods et al. 1999, Kendall et al. 2009), but only recently has been employed in polar bears to independently estimate population size (Government of Nunavut and Greenland Institute of Natural Resources, unpublished data), or to contribute to multiple-source M-R (Herreman and Peacock 2011). Tissue samples can be collected either actively or passively, and a genetic fingerprint of the sampled bear and its gender is developed. In the active sampling method, bears are located by helicopter and darted as in physical M-R using a genetic sampling dart that removes a small plug of skin and hair when it strikes the animal. The dart falls to the ground after impact and is collected. Therefore, this approach requires pursuing the animal with a helicopter as in physical M-R, but does not require drugging or physically manipulating the animal. In passive genetic M-R, hair samples are collected from individuals as they pass through traps (constructed of barbed wire or equivalent strung around something that attracts bears to a site, or in areas naturally frequented by bears) designed to snag hair samples as bears pass by (Woods et al. 1999). DNA is extracted from the roots of individual hairs and, where visitations to such traps are predictably frequent and where visitors represent an unbiased sample of the population, M-R population estimates or estimates of numbers in local areas (Herreman and Peacock 2011) may be derived.

Line-transect or distance sampling methods (Buckland et al. 2001) are a third method of estimating abundance of polar bears (Wiig and Derocher 1999, Aars et al. 2009, Stapleton et al. 2011). Flight paths are identified and flown over polar bear habitats, and observed bears are tallied along with their distance from the flight path and other variables. Detection functions (statistical models representing the sightability of bears) are applied to the number of bears seen to estimate how many bears were in the sampled area at the time of survey.

Distance sampling methods can be combined with M-R methods by using double observers (MRDS; Laake 1999). Aars et al. (2009) provide an example of MRDS using aerial counts to estimate polar bear abundance. Lastly, strip-transect methods, where distance observations are not incorporated into sighting probabilities (Crête et al. 1991), and observations in the strips are extrapolated to areas in between strips, can also be used to estimate local abundance or density of polar bears. Though a single aerial survey may provide an estimate of subpopulation size, such surveys must be replicated over time to estimate trend.

4.1.2.2 INDIRECT ESTIMATES OF POPULATION SIZE AND TREND

Where direct and high intensity methods of population assessment are not logistically possible, population status may be reconstructed from a variety of indirect measurements or indices. In harvested populations, where harvest is unbiased or biases are known, and where returns are reliable, the harvest sex and age composition can be used to estimate survival rates and reconstruct the population. Indices are measurements that, although indirect estimates of size or trend, are presumed to be proportional to size or trend. Tabulation of animal sign (e.g., tracks, dens), composition counts (numbers of young per female observed during surveys conducted at the same times and locations each year), and catch per unit of effort data, are examples of indices.

Many wildlife species, for which direct estimates are unavailable, have been managed successfully with indices of population size and trend (Caughley 1977, Skalski et al. 2005).

The large movements, solitary behavior, and volatile substrate upon which polar bears live, mandate caution in the use of indices for population assessment. Indices of population size and trend have seen limited recent use in monitoring of polar bears, but there are some notable examples of success (e.g., Stirling et al. 2004). Although polar bear harvest records are abundant, biases in harvest data from inaccurate reporting and varying levels of effort and efficiency often prevent a straightforward relationship with population size and trend (Peacock and Garshelis 2006). Such biases are particularly relevant for monitoring polar bears. An historic example of application of a flawed index to polar bear population trends was the management of the aerial trophy hunt in Alaska with hunter-reported catch per unit effort data. The resulting excessive harvest during the 1950s, 1960s, and early 1970s (Amstrup et al. 1986), emphasized the need to understand strengths and weaknesses in an index, before relying on it to make management decisions. In addition to effort and reporting issues, strict regulations regarding harvest composition may complicate life-table or other indirect population reconstruction approaches for polar bears. The construction of life tables from polar bear captures (Amstrup 1995), however, suggests that population reconstruction from harvest data may have value if sampling biases can be corrected (e.g., by comparison to capture data) and if consistent sampling and reporting can be achieved. Regardless of regionally varying challenges, the impracticality of universally applying high intensity methods, means that indices of abundance or density used for other wildlife species (e.g., occupancy modeling or extrapolation of numbers to larger areas based on habitat resource selection functions), must be explored if we are to develop monitoring practices comparable across the whole polar bear range.

4.1.3 INTENSITY OF MONITORING

Tables 5 and 6 outline the methods and frequencies for 3 tiers of monitoring intensity. Long-term M-R monitoring has occurred most consistently in the Western Hudson Bay and Southern Beaufort Sea subpopulations. In these subpopulations more than anywhere else in polar bear range, we have the opportunity to document changes that occur as sea ice habitats progressively deteriorate and the opportunity to test the accuracy of projected changes. The successes in these subpopulations make it clear that an objective of future monitoring must be to implement similar high intensity monitoring in one or more representative subpopulations within each of the four polar bear ecoregions. Therefore, other subpopulations that could receive high intensity monitoring are the Northern Beaufort Sea subpopulation in the Convergent Sea Ice Ecoregion, and the Lancaster Sound subpopulation in the Archipelago Ecoregion.

Ideally, high intensity monitoring will be employed in 3 other subpopulations because of ongoing and anticipated changes in those subpopulation regions. The Barents Sea, on the opposite side of the Divergent Sea Ice Ecoregion from the Beaufort Sea, also has a high level of baseline data. Levels of many pollutants there are higher than elsewhere, research access and capability is good, and it is closest in proximity to areas of the western Russian Arctic where we know little about polar bears. High intensity monitoring in the Barents Sea would strongly complement the understanding of the Divergent Sea Ice Ecoregion developed in the Southern Beaufort Sea.

There also is a considerable baseline of data for the Southern Hudson Bay subpopulation. The ecological circumstances in Southern Hudson Bay are similar to those that prevail in Western Hudson Bay and they are not entirely segregated (Crompton et al. 2008). Southern Hudson Bay polar bears, which must spend the ice-free period on the Ontario coast, are showing similar trends to Western Hudson Bay bears that summer on the Manitoba coast further north, such as the declines in body condition in all age and sex classes (Obbard et al. 2006). However, the sea ice breaks up in Southern Hudson Bay significantly later than it does in Western Hudson Bay (Stirling et al. 2004) so there may be a delay of a few years before it can be determined whether all the consequences documented in the former population can be quantified in the latter. This creates a strong circumstance for testing the reliability of predictions based on one population in the Seasonal Sea Ice Ecoregion (Western Hudson Bay) to another (Southern Hudson Bay), probably within a short period of time. Equally important is the opportunity to evaluate whether polar bears in a similar, but not identical subpopulation, in the same ecoregion might also differ in their responses.

Because no sustained long-term work has been done in the northern portions of the Archipelago Ecoregion, and because we hypothesize that polar bears in more northerly regions may experience transient benefits from a warming environment, it is critical that intensive monitoring begin soon in the portions of this ecoregion north of Lancaster Sound. We recommend this monitoring occur within the Norwegian Bay subpopulation boundaries and in the adjacent portion of the Convergent Sea Ice Ecoregion (Norwegian Bay Convergent). Few bears are thought to currently reside there, but this may be the last vestige of polar bear habitat as sea ice continues to decline. Monitoring efforts should expand from the recommended efforts in Lancaster Sound, and provide a baseline upon which observations of future changes can build.

The quality of past and present estimates of size and trend in the remaining subpopulations is mixed. As sea ice retreats, access to these regions will be changing just as the trends in population status also will be changing. Fig. 3 identifies current recommendations for monitoring intensities in these subpopulations. To maximize the value and comparability of our monitoring, the intensities recommended in Fig. 3 will periodically need to be adjusted periodically to keep pace with ongoing changes in Arctic environments.

4.1.4 FREQUENCY OF MONITORING

The difficulties in deriving reliable estimates of subpopulation size and trend mean that more frequent monitoring always will be more informative than less frequent monitoring, and it is critical to distinguish the frequency of monitoring from the intensity of monitoring. Fig. 4 illustrates the decline of subpopulation size over time in Western Hudson Bay, modeled annually on the basis of physical M-R data (Regehr et al. 2007). This is the most consistently monitored subpopulation of polar bears in the world. With continuous high-intensity monitoring, a statistically significant declining trend is apparent despite interannual variation. The statistical power to detect trend would be lower if we had only estimates of numbers (e.g., from an aerial survey, or periodic physical or genetic captures) and only for selected years (e.g., from 1990–1995 and 2000–2005). Similarly, the ability to detect a trend is reduced when only one source of information or only indirect measures or indices (e.g., track counts, mother with cub counts) is available. Therefore, the goal in all areas must be to develop continuous or near continuous monitoring. The kinds of data collected will vary among subpopulations, but the desired frequency of efforts will not.

Obtaining a direct estimate of population size every 5 years may be sufficient for subpopulations classified as high intensity. However, the lower precision and greater potential for bias in lower intensity methods means they must be replicated more frequently, preferably annually (Tables 5, 6), to obtain reliable indicators of size and trend. Further, it is essential that lower intensity methods be applied diligently where high intensity methods are also employed. Understanding the similarities and differences between the outcomes of high intensity methods and lower intensity methods provides valuable calibration of the outcomes of lower intensity methods. That in turn, provides greater confidence in the outcomes derived where only the lower intensity methods have been employed. The great differences in accessibility and logistical challenges mean it is unlikely that equal effort will ever be applied uniformly among polar bear subpopulations. Calibration of methods is necessary, therefore, to achieve our goal of implementing globally comparable monitoring.

4.2 REPRODUCTION

Reproductive rates in polar bears and other bear species vary temporally and spatially but are generally low because they are K-selected species that have delayed maturation, small litter sizes, and long mother-offspring association (Bunnell and Tait 1981). Reproductive rates in K-selected species, such as bears, are partially related to the proximity of the population to carrying capacity. Carrying capacity will vary spatially and temporally and food supply variation between years or areas is correlated with reproduction. To date, however, there are no studies of polar bears that clearly indicate density-dependent changes in reproduction (Derocher and Taylor 1994), although high density was suggested to be a possible factor affecting body condition in Davis Strait (Rode et al. 2012).

4.2.1 WHY MONITOR REPRODUCTION?

Variation in reproductive rates affects trends in population abundance. Correspondingly, reproduction is one of the most studied and best understood demographic parameters in most subpopulations (e.g., Lønø 1970, DeMaster and Stirling 1983, Larsen 1985, Larsen 1986, Watts and Hansen 1987, Taylor et al. 1987b, Ramsay and Stirling 1988, Derocher et al. 1992, Derocher and Stirling 1994, Rode et al. 2010). Because polar bears have low reproductive rates, with females usually giving birth only every three years, accurate measures of these rates require at least three years of monitoring. In all subpopulations where assessment has been undertaken, elements of reproduction are monitored to varying degrees. Some subpopulations have long time series and others have episodic data collection. Monitoring reproduction over shorter periods may reflect short-term or transient dynamics. For example, a three-year population inventory may include three good years of reproductive output, three bad years, or a mix of both (cf. Priority study #1, Section 6.1). Reproductive rates generated from three years can be useful for the calculation of current population growth, but longer-term monitoring of reproductive parameters is useful to understand temporal trends. The low reproductive rate of polar bears means that populations can only sustain low rates of harvest, and monitoring of recruitment is essential to ensure harvest sustainability.

Climate warming has affected some polar bear subpopulations by reducing the carrying capacity of existing habitat to support populations and will continue to do so increasingly in future years. Earlier break-up has been correlated with reduced body condition that is linked to reproductive performance (Stirling et al. 1999, Molnár et al. 2011). This pattern has been well documented in the Western Hudson Bay subpopulation (Stirling et al. 1999, Stirling and Parkinson 2006, Regehr et al. 2007) and similar patterns are emerging in more northern subpopulations (Regehr et al. 2010, Rode et al. 2010, 2012). Changes in reproductive rates and recruitment are expected to be one of the earliest and most identifiable changes in response to climate warming and thus are critical for monitoring.

4.2.2 HOW TO MONITOR REPRODUCTION

Reproduction can be determined by systematic observation of individuals or from cross-sectional data collected during M-R population estimation with the latter being more common for polar bears. A suite of parameters can be monitored in subpopulations, but there is a wide degree of variation in the effort and ability required to collect the information (i.e., monitoring potential) and the costs of obtaining the information. Further, these parameters vary in their utility to understand subpopulation status (i.e., monitoring utility).

4.2.2.1 INTERBIRTH INTERVAL

Interbirth interval (the number of years between successive litters) is an important reproductive parameter for monitoring due to its effect on population growth rate and should be determined in all subpopulations subject to high- and medium-intensity monitoring. Interbirth interval in polar bears varies from 1 to 5 years with a 3-year interval being the norm for weaning of offspring at 2.5 years of age (Ramsay and Stirling 1988). Interbirth interval is determined by cub survival and age of weaning. If cubs die before weaning, females often have shorter reproductive intervals. However, shorter interbirth intervals have also been associated with early weaning. Therefore, to be useful for monitoring population status, monitoring of interbirth interval should include an estimation of cub survival. A reproductive interval of 1 year is indicative of total litter loss, whereas a 2-yr interval was previously associated with weaning of offspring at 1.5 years of age in Western Hudson Bay yet is now uncommon and rarely seen in other subpopulations (Derocher and Stirling 1995, Stirling et al. 1999). Interbirth interval is a complex population parameter and is measured by following the reproductive success of individuals. If individual adult females are followed by telemetry and resighted at least once a year for two years or more, it is possible to assess cub survival and reproductive interval

(Amstrup and Durner 1995, Wiig 1998, Derocher and Stirling 1996). A large number of bears (e.g., > 20) is needed to provide sufficient insight into this parameter for most populations. Alternatively, interbirth interval can be calculated from M-R sampling although the estimation of the parameter is dependent upon sufficient recaptures.

4.2.2.2 LITTER PRODUCTION RATE

Litter production rate is a derived parameter that integrates a population age structure and the number of cubs produced per female per year (Taylor et al. 1987a). This parameter should be standard in all monitoring programs of high and medium intensity because it is integral to understanding subpopulation dynamics and for demographic projections. The metric requires a large random (or non-selective) sample of the adult females. Age-specific litter production rates should be determined, but pooling of ages might be necessary for smaller sample sizes. A decline in litter production rate can occur for a variety of reasons (e.g., lower pregnancy rate, lower cub survival) and thus additional information is needed to understand observed trends. Declining litter production rate is usually a cause for concern as it implies lower recruitment rates. Monitoring pregnancy rates can be used to gain additional insight into the reproductive dynamics of a subpopulation if individuals are handled after the mating season and a blood sample is collected (Derocher et al. 1992). Changing pregnancy rates could be related to environmental conditions or a host of other factors (e.g., pollution). Further, a depletion of adult males in a population could also lower mating success (see Molnár et al. 2008), thus, consideration of additional population variables is necessary to interpret pregnancy rates.

Reproductive success is closely linked to interbirth interval. Adult females that successfully wean their cubs, usually at two and a half years of age, are deemed to have been successful, resulting in the recruitment of individuals to the population. Reproductive success would be monitored along with interbirth interval and cub survival but most studies of reproductive success take a lifetime perspective that is possible using genetic methods in high intensity subpopulations. Genetic methods will also allow determination of paternity (e.g., Zeyl et al. 2009) that may become important in the management of small or declining populations. Mating ecology, broadly considered as the behavioral aspects of breeding, has limited potential as a monitoring parameter given that is it especially difficult to collect and has little statistical power. Nonetheless, monitoring the ages of adult males paired with breeding females may be helpful for assessing effects of male harvest because a trend toward younger males could indicate excessive removal of mature males (Molnár et al. 2008). However, such changes would likely be difficult to detect due to low statistical power. As an integrative parameter, reproductive success and mating ecology can yield insight into population status and trend although the information required for monitoring these parameters preclude their use in all but the most intensively studied subpopulations.

4.2.2.3 LITTER SIZE

Litter size is a common and easily collected parameter in all subpopulations and should be monitored at a standardized time because post-den emergence cub mortality is common (Derocher 1999). Partial litter loss reduces mean litter size and variation in the date of observation, either between years or between subpopulations, renders comparisons difficult. However, litter size is relatively unimportant in determining population growth rate (or sustainable harvest) relative to adult female survival although it still ranks high when compared to other population parameters (Taylor et al. 1987b) and is necessary for population projections. Changes in litter size have been used to estimate survival (DeMaster and Stirling 1983) although monitoring cub survival through repeated observations of telemetry-equipped females is more accurate (Amstrup and Durner 1995). A modeling analysis of litter size indicated that the observed litter size is insensitive to major changes in cub production (Molnár et al. 2011). Monitoring the size and body mass of cubs in litters may provide greater insight into population status (e.g., Rode et al. 2010) than litter size. Although litter size is easy to monitor, it provides little insight into subpopulation status.

4.2.2.5 AGE OF FIRST REPRODUCTION

Age of first reproduction in polar bears can be defined either as the age at which a female first becomes pregnant or the age at which she produces her first cub. The age at which females produce their first cubs varies both among subpopulations and over time within the same subpopulation in response to changes in environmental factors (Ramsay and Stirling 1988), but ranges from 4 to 7 years. Because there may be a shorter interbirth interval in young females, which due to inexperience may lose their cubs before weaning, the age of first attempted reproduction may be lower than the age of first successful reproduction. A decline in carrying capacity is likely to result in an increase in age of first reproduction possibly because of altered growth rates or stored body fat. In contrast, improving environmental conditions (i.e., food abundance or availability), or lower population density, could result in a reduction in the age of first reproduction. Age of first reproduction is often determined in population studies. It has a slow response time in relation to environmental perturbations, however, and its influence on population growth rates is limited. Measurement of this parameter can come from M-R studies (i.e., noting the youngest age at which females are accompanied by cubs) or by following individual females from four years of age onward to confirm the first time cubs are present. In harvested subpopulations, an estimate of the age of first reproduction may be obtained from analyses of reproductive tracts (Rosing-Asvid et al. 2002). In general, age of first reproduction is not monitored for males. Due to the low contribution to subpopulation growth rate and slow rate of change, age of first reproduction is considered a low priority for monitoring.

4.2.2.6 REPRODUCTIVE SENESCENCE

Reproductive senescence can be described as an age-related decline in reproductive output that results in progressive reduction of litter size, cub mass, cub survival, or an increase in the interbirth interval (Derocher and Stirling 1994, Schwartz et al. 2003). There is debate about whether adult female polar bears decline in reproductive output beyond 20 years of age (Ramsay and Stirling 1988, Derocher and Stirling 1994). Because there are few females of this age in any population their relative contribution to the subpopulation is small so monitoring is likely only warranted in association with other aspects of reproduction. Nevertheless, it can be useful in estimating generation time according to the IUCN Red List criteria (IUCN 2010).

4.2.2.7 DEN COUNTS

Den counts have been used as a rough index of a subpopulation's reproductive success although they must be used in conjunction with other data. An increase or decrease in den abundance could be a consequence of several different factors. For example, denning areas can shift because of a redistribution of pregnant females (Fischbach et al. 2007, Andersen et al. 2012), changes in population abundance or demographics, changes in food availability, or changes in access to denning areas as a result of climate warming (e.g., Derocher et al. 2011). Similarly, high cub mortality in one year could result in more females denning in a subsequent year. For these reasons, counting dens is not a recommended population monitoring metric unless conducted in concert with additional parameters that allow for the biological reasons for possible changes to be reliably interpreted.

4.2.2.8 ADDITIONAL CONSIDERATIONS

Infanticide has been observed in several subpopulations (Taylor et al. 1985, Lunn and Stenhouse 1985, Derocher and Wiig 1999, Stone and Derocher 2007) although its potential significance in population dynamics is unknown. Given the opportunistic nature of observing infanticide, it has low potential for monitoring subpopulation status although recording of such events may provide auxiliary or corroborating information on a subpopulation when evaluated over time.

4.2.3 RECOMMENDATIONS FOR MONITORING REPRODUCTION

Recommended parameters for monitoring of polar bear reproduction in the different tiers are presented in Table 7. The most informative studies on trends in polar bear reproduction will come from the most intensively studied subpopulations with long time series (ca. >10 years). Short term studies of the standard population inventory approach used in Canada (ca. 3 years) is capable of giving short-term insight on the reproductive status for less intensively monitored subpopulations. For monitoring polar bear reproduction, the most important parameters to measure are litter production rate, interbirth interval, recruitment success, litter size, and age of first reproduction. These vital rates parameters are essential to use in conjunction with estimates of population size and are necessary to assess population status in subpopulations with high-intensity monitoring. Because reproductive parameters in concert with survival rates determine population growth rate, adequate population monitoring for intensively studied subpopulations will optimally rely on a combination of methods for estimating reproduction, survival, and subpopulation size.

For less intensively monitored subpopulations, some aspects of reproduction can be usefully monitored (e.g., litter size, den abundance) but interpretations made using such data will be less robust. Overall, monitoring that relies on aerial surveys will provide less information on reproduction in comparison to M-R methods, because they cannot provide age-structure data or the tracking of individuals.

4.3 SURVIVAL

Age and sex-specific survival rates are critically important life history traits for population monitoring and ones that can be directly affected by harvest, human-bear interactions, environmental variation, environmental degradation resulting from industrial pollution such as oil spills, and climate warming. Survival rates of ursids are generally high (Bunnell and Tait 1981) but vary substantially across different life stages (Amstrup and Durner 1995). Age and sex-specific survival rates are some of the more expensive parameters to estimate and they require intensive research to quantify with sufficient accuracy and precision to facilitate detection of significant change over time.

4.3.1 WHY MONITOR SURVIVAL?

Sex-specific adult survival rates are essential for determining and monitoring population trend. Thus, monitoring of this parameter is a priority in all subpopulations whenever possible. However, survival rates cannot be accurately determined unless individual animals can be followed over time.

4.3.2 HOW TO MONITOR SURVIVAL

There are two primary means by which survival rates of polar bear can be monitored: radio-telemetry and M-R methods. Most studies using M-R also incorporate harvest recovery of marked animals (e.g., Taylor et al. 2005, 2009; Peacock et al. in press). Both methods have been applied to monitoring survival and have provided estimates (Amstrup and Durner 1995; Derocher and Stirling 1996; Taylor et al. 2005; Regehr et al. 2007, 2010). Change in litter size has also been used to estimate survival of dependent offspring (DeMaster and Stirling 1983) although this method is less robust and has seen limited use.

Age classes used for monitoring survival fall into the following: cubs (den emergence to one year of age), yearling (1-2 years of age), subadult (2-4 years of age), and adult (often on an age-specific basis where sufficient data exist or, if not, pooled by age class). Most detailed studies of individual subpopulations provide quantitative assessments of age and sex-specific survival that can be compared between subpopulations. The primary causes of mortality in polar bears are linked to harvest, sea ice conditions, starvation, infanticide, and natural age-related declines (e.g., Blix and Lentfer 1979, Taylor et al. 1985, Amstrup and Durner 1995, Derocher and Stirling 1996). It is important to evaluate the causes of mortality because the ability to detect changes will be influenced by an understanding of their origins. For example, harvest mortality may vary little between years in areas with a constant annual quota, whereas mortality linked to sea ice conditions or prey availability could show substantial interannual variation.

Linking survival to sea ice conditions (e.g., Regehr et al. 2007, Hunter et al. 2010, Peacock et al. in press) provides a powerful example of what can be learned through application of a quantitative approach to population monitoring. However, it should also be stressed that such analytical power is only possible from the detailed data collected from sustained physical M-R studies. Non-invasive methods, such as aerial surveys to estimate abundance, cannot provide the data to understand why survival rates have changed. In subpopulations where a sufficiently large sample of animals can monitored by telemetry over time, survival estimates can be ascertained (e.g., known-fates analysis). Given the expense of collecting survival data, it is recommended that this parameter only be considered for the more intensively monitored subpopulations.

4.3.3 RECOMMENDATIONS FOR MONITORING SURVIVAL

A summary of recommended parameters for monitoring survival in polar bears is given in Table 8. Historically, the highest priority in monitoring survival rates has been placed on adult females. With habitat declining in many areas, however, declining offspring survival will provide the earliest indications of declining population welfare. Therefore, monitoring cub and yearling survival is increasingly critical. In subpopulations with high-intensity monitoring, survival of both adult females and their offspring should be emphasized. Where funding allows, monitoring of juvenile survival (< 4 years of age) should be implemented as this will provide critical insight into variability in recruitment rates. Optimal monitoring methods will require M-R analyses combined with telemetry studies. Provided sample sizes are large enough, such a database allows for estimation of survival rates on either an age-specific or an age class basis. Genetic M-R studies cannot provide estimates of survival of age classes because the age of individuals sampled cannot be verified. Survival estimates will be biased when derived from short data sets given the nature of long-lived species. Because interannual variation in juvenile survival is large, effective analyses of trends can only be undertaken in longer-term studies (i.e., >5 years). In some cases, subpopulation trend (which incorporates both survival and reproduction) can be monitored as a collective metric instead of evaluating survival and reproduction separately. This can be useful in populations where M-R estimates of survival are unavailable. In such cases, indices of survival can be inferred from analyses of the age structure of harvested or captured polar bears to determine trends from age structure (e.g., Amstrup et al. 1986, Derocher 2005). However, care must be taken with this approach to ensure that all model assumptions are upheld. Even small biases can have compounding effects when estimating population growth rate. Importantly, small biases in the calculation of adult survival can have significant implications for such things as estimation of sustainable harvest. In cases where M-R data are unavailable, multiple lines of evidence, which may be weaker individually (e.g., body condition, abundance over time, change in age at harvest), can be used for assessing trend, without actual estimates of survival.

4.3.3.1 POPULATION PROJECTIONS

Population modeling of polar bears, incorporating reproductive rates, demographic inputs, and hunting removals, has been used to estimate population growth rates in several subpopulations (e.g., Taylor et al. 1987b, 2005, 2006). Given the spatial and temporal variability in Arctic ecosystems we now know that reproductive rates collected over short periods may be influenced by transient or short-term effects. Therefore, although reproductive rates can be used to derive the current rate of population growth, projections into the future (e.g., > 5 years) should be used cautiously. If reproductive parameters, and their possible changes, can be correlated with environmental variables, the potential for longer projection increases. Such a modeling approach is a reasonable means of estimating population trend when two conditions are met: 1) the reproductive and survival rates being used are unbiased, and 2) the conditions under which these rates were collected are similar to those that are likely to prevail through the period of the population projection. Because sea ice conditions are now changing rapidly in many subpopulations, projection models incorporating reproductive and survival rates beyond a few years should be used with considerable caution because of the risk they may provide spurious results (Molnár et al. 2010). Incorporation of changing ice conditions, however, may provide valuable insights into population trend if the relationship between ice conditions and reproduction can reasonably be estimated (Hunter et al. 2010). Modeling of polar bear reproduction in demographic models has limited monitoring potential, although it can be used for short-term population management and to detect short-term population trend.

4.4 HABITAT AND ECOSYSTEM CHANGE

Broad categories of polar bear habitat include 1) sea ice hunting habitat, 2) land used during the summer ice minimum or open water period in seasonal ice regions, and 3) maternal denning habitat. Polar bears only occur in the northern hemisphere where sea ice is a dominant feature in the environment. Over much of their range polar bears are able to remain with sea ice throughout the year, hence their distribution fluctuates in accordance with the annual patterns of sea ice formation and melt. Sea ice is a ubiquitous feature in the Arctic and its composition, and temporal and spatial extent determine the distribution and trend of subpopulations. Polar bears do not use all sea ice equally, rather they respond to variations in concentration, ice age (thickness), floe size, and the proximity of sea ice edges and land fast ice (Arthur et al. 1996; Ferguson et al. 2000a; Mauritzen et al. 2003; Durner et al. 2004, 2009; Freitas et al. 2012). Because ringed seal distribution during late autumn to spring is dependent on snow accumulation for subnivian resting or birth lairs (Kelly et al. 2010) and polar bears use habitats that maximize their ability to capture seals (Stirling and Øritsland 1995), snow deposition is an important determinant of the habitats that polar bears choose. In addition to sea ice composition and snow distribution, the distribution of sea ice relative to ocean depth is important in many regions of polar bear range because bears show their greatest selection for ice that lies over the continental shelves (Durner et al. 2009).

Polar bears may use land at any time of year but primarily they do so most often where the sea ice melts completely, or almost completely. In those subpopulations, most polar bears will spend the entire summer and early autumn ice-free periods on land. The areas selected by polar bears appear to be primarily those that are adjacent to where the last sea ice melts in early summer (Stirling et al. 1999, 2004; Gleason and Rode 2009). Although sea ice is the most important habitat because it allows polar bears to hunt ice-dependent seals, time spent on land may also be important to conserve energy during periods of food deprivation (Clark et al. 1997, Ferguson et al. 2000b).

In most of their range, polar bears use land for maternal denning but in the Beaufort Sea many females historically used sea ice as a substrate for denning. There is some evidence that polar bears near Svalbard may den on sea ice (Larsen 1985, Andersen et al. 2012) but this has not been quantified. Importantly, use of sea ice for denning in the Beaufort Sea has declined as a result of decreases in sea ice stability due to climate warming (Amstrup and Gardner 1994, Fischbach et al. 2007). A prerequisite for maternal denning is landscape features (including sea ice) that accumulate snow of a sufficient depth to allow bears to dig dens that remain secure throughout the winter. In some subpopulations, such as Western and Southern Hudson Bay, polar bears den on land and dig dens in frozen peat banks (Kolenosky and Prevett 1983, Clark et al. 1997, Richardson et al. 2005). Not all dens are used for parturition as non-pregnant polar bears may den to conserve energy during inclement winter weather (Ferguson et al. 2000b) or to escape summer heat (Clark et al. 1997, Ferguson et al. 2000b).

4.4.1 WHY MONITOR POLAR BEAR HABITAT AND ECOSYSTEM CHANGE?

Arctic sea ice is essential for the persistence of polar bear subpopulations. The distribution and timing of ice relative to critical phases of polar bear life history has been linked to subpopulation status and trend (Hunter et al. 2010, Regehr et al. 2010, Stirling et al. 1999). Polar bears in western Hudson Bay abandon sea ice shortly after the average concentration of ice drops below 50% (Stirling et al. 1999). An increasing duration of ice-free days in western Hudson Bay between the 1980s and the first decade of this century was the most likely cause of a decline of the subpopulation (Regehr et al. 2007). In the Southern Beaufort Sea subpopulation, ice-free days (i.e., average sea ice concentration below 50%; Regehr et al. 2010) over the continental shelf were the most important driver of subpopulation growth. Absence of or reduced suitability of sea ice over the continental shelf has led to increased nutritional stress and poorer body condition and survival of some age and sex categories of polar bears (Rode et al. 2010). We may assume, based on these studies, that sea ice habitat is a useful proxy of subpopulation status and distribution (see Sahanatien and Derocher 2012) when other monitoring data, such as capture-recapture or distance sampling, are unavailable.

Availability of sea ice habitat is linearly related to global temperature (Amstrup et al. 2010). Hence, as temperatures rise, there will be a reduction in the range-wide extent of polar bear habitat (Amstrup et al. 2010). Although the relationship between sea ice and temperature is linear, the shape of the relationship between sea ice availability and polar bear status is uncertain and probably non-linear (Molnár et al. 2010). In fact, transition from a marine environment composed predominantly of multiyear sea ice environment to one with a greater proportion of annual sea ice may increase optimal habitat in some regions (Durner et al. 2009) and help to maintain some subpopulations (Stirling et al. 2011). Thinner ice is more likely to deform and build ridges necessary for snow accumulation (Sturm et al. 2006) sufficient for ringed seal lairs (Kelly et al. 2010). Regardless of the uncertainties in the rate at which polar bear abundance may decline, a decrease in range-wide habitat will result in fewer polar bears. This knowledge along with the understandings of polar bear-sea ice relationships developed in intensively studied subpopulations provides the ability to extrapolate across regions with similar patterns of ice change.

A changing environment will affect more than the sea ice on which a polar bear must stand. Warming oceans will likely cause the occurrence of non-indigenous species in Arctic seas (Stachowicz et al. 2002). Food web changes in the marine environment may occur with changes in the physical aspects of sea ice and the underlying water column (Grebmeier et al. 2006). This will likely be expressed as a redistribution of species as southern species move into northern regions. Most marine introductions of non-indigenous species occur as an indirect consequence of climate warming. Shipping and release of ballast waters has been identified as the most important pathway for fish and invertebrate introductions (Molnar et al. 2008), hence increased opportunities for shipping through the Northwest Passage and northern Russia may also increase the opportunity for the introduction of exotics. Few harmful alien species have been reported within the range of the polar bear (Molnar et al. 2008). However, in much of the Arctic including the Canadian Archipelago, northern Greenland, and northern Asia, there are no data to assess the potential impacts of non-native species on polar bear habitat (Molnar et al. 2008). Nevertheless, recent evidence shows an expansion of subarctic fishes into Arctic waters and suggests possible negative consequences to polar cod (*Boreogadus saida*; Renaud et al. 2012) ─a fish that provides an important conduit for energy between primary producers and apex predators (Benoit et al. 2008). In rare cases, an increase in uncommon prey species may benefit polar bears. This may be occurring in Baffin Bay and Davis Strait, where decreasing sea ice concentration has led to an increase in hooded seals (*Cystophora cristata*) and harp seals (*Pagophilus groenlandicus*; Stirling and Parkinson 2006), both of which are prey of polar bears. Local increase of these two species likely has had a positive effect on the subpopulations of Baffin Bay and Davis Strait (Stirling and Parkinson 2006), but as sea ice concentration continues to decline habitat may decrease for these alternate prey species.

Knowledge of the distribution of maternal den habitat has significant management potential to protect polar bears in dens. Distribution of sea ice habitat and patterns of ice breakup have a significant effect on the distribution of maternal dens (Fischbach et al. 2007). Sufficient snow cover is also important to protect nursing mothers and their newborn cubs for the 4-5 months during winter (Durner et al. 2003). Insufficient or unstable snow due to warm winter weather can result in den collapse and death of its occupants (Clarkson and Irish 1991).

4.4.2 HOW TO MONITOR POLAR BEAR HABITAT AND ECOSYSTEM CHANGE

The large spatial extent of polar bear subpopulations and the rigors of the Arctic environment preclude our ability to make continuous direct observations of polar bears and changes in their environment. However, there are remotely collected environmental data that lend themselves well to monitoring polar bear habitat and ecosystem change on both a hemispheric and regional level. Additionally, habitat models developed from telemetry data collected from polar bears in subpopulations monitored at high and medium intensity may be used to assess habitat change within subpopulations and may be extrapolated to similar subpopulations with low monitoring intensity. A summary of recommended methods to monitor habitat and ecosystem change relevant to polar bears is presented in Table 9. We now present several sources of environmental data that have been useful for monitoring habitat and environmental change, and include discussions on their strengths and weaknesses. We provide a brief description of Resource Selection Functions (RSF) as a means to identify habitat important for polar bears, and as a tool for predicting the distribution of such habitat. We then discuss changes in food webs and ways that this could be monitored, then move on to identifying and monitoring maternal den habitat, and conclude with the importance of relating demographic trends to habitat and environmental change.

4.4.2.1 PASSIVE MICROWAVE IMAGERY OF HEMISPHERIC SEA ICE CONCENTRATION AND EXTENT

Physical features on the Arctic Ocean surface (i.e., sea ice extent and concentration) may provide useful metrics for monitoring polar bear habitat when other data and modeling tools are unavailable. Satellite-borne passive microwave (PMW) imagery provides a simple measure of sea ice concentration and distribution and has been effective for identifying and describing coarse-grained habitat features use by polar bears in much of their range (Arthur et al. 1996, Mauritzen et al. 2003, Durner et al. 2006, 2009). PMW daily estimates of sea ice extent and concentration have been available free of charge since 1979 and have become the standard observational data for monitoring sea ice (e.g., Stroeve et al. 2007 and citations therein). These data are provided as coarse-grained (i.e., SMMR and SSM/I; 25 × 25 km pixel; National Snow and Ice Data Center, Boulder, CO, USA; ftp://sidads.colorado.edu/pub/; Comiso 1999) or finer-grained (i.e., AMSR-E, 2002-2011; 6.25 × 6.25 km pixel; University of Bremen; http://www.iup.uni-bremen.de:8084/amsr/; Spreen et al. 2008) grids of the entire Arctic. PMW estimates of sea ice are unaffected by daylight or cloud cover, hence these are a robust and consistent source of sea ice data. Limitations of PMW data arise from their inability to detect fine-grained habitat features to which polar bears respond (for examples of fine-grained habitat features see Stirling et al. 1993) and also because pixel estimates < 15% ice concentration are considered unreliable and therefore are classified as open water by most researchers (e.g., Stroeve et al. 2007 and citations therein). Additionally, the coarse spatial resolution of PMW data and its propensity for generating spurious data along shorelines limit its use in regions with high interspersion of water and land, such as the Canadian Archipelago Ecoregion. Despite these limitations, PWM data are a powerful tool for monitoring polar bear habitat and environmental change in ecoregions composed mostly of ocean and large seas. PMW imagery (i.e., SMMR and SSM/I) is consistently available throughout the range of polar bears and throughout the history of polar bear radio-telemetry data (from 1985 onward). Also, PMW is most similar to the data resolution and composition of General Circulation Model (GCM) projections of future sea ice, making it suitable to predict changes in polar bear habitat (Durner et al. 2009). For much of the Arctic, habitat models derived from PMW data are a useful first step for monitoring the polar bear sea ice environment.

4.4.2.2 INTERPRETED CHARTS OF REGIONAL SEA ICE CONCENTRATION, EXTENT AND COMPOSITION

As mentioned, polar bears respond to fine-grained habitat features (Stirling et al. 1993, Stirling 1997) that cannot be detected by PMW sensors. However, indices of fine-grained habitat features are available to users from the National Ice Center (NIC; Suitland, Maryland, USA; http://www.natice.noaa.gov/) and the Canadian Ice Service (CIS; Ottawa, Ontario, Canada; http://www.ec.gc.ca/glaces-ice/). Both agencies provide geographic information system (GIS) format files of weekly to bi-weekly regional estimates of sea ice concentration, ice stage (age or thickness), ice form (floe diameter), and the distribution of landfast ice. Ambiguities of ice estimates at the ocean/land interface, which are common with PMW data, are not an issue with sea ice charts. Both the NIC and CIS syntheses include satellite imagery with ranges of spatial and temporal resolutions ─from coarse-grained PMW daily estimates of hemispheric sea ice concentration and extent to fine-grained (50 × 50 m pixel) SAR-derived estimates of sea ice age and surface roughness (Geldsetzer and Yackel 2009). Available GIS files includes all northern hemisphere waters since 1997 (NIC) or waters within or adjacent to Canada since 1968 (CIS). Both the NIC and the CIS produce sea ice charts from satellite imagery that they interpret through customized algorithms and manual inspection (Soh et al. 2004, Clausi et al. 2010). In doing so, the NIC and the CIS free the users from performing their own classification of sea ice from satellite imagery. The GIS data available from both agencies has been effective for polar bear sea ice habitat studies in the Canadian eastern Arctic (Ferguson et al. 2000a) and the Beaufort Sea (Durner et al. 2004).

4.4.2.3 BATHYMETRY

Ocean depth data are available for most of the range of polar bears (International Bathymetric Chart of the Arctic Ocean, Jakobsson et al. 2000). Ocean depth is a significant covariate in polar bear habitat with bears selecting for sea ice over continental shelves more than sea ice over Arctic Ocean basins (Durner et al. 2004, 2006, 2009). A preference for shelf sea ice is likely a reflection of the high biological productivity of shallow Arctic waters (Sakshaug 2003) and greater availability of seals (Stirling 1997). Ocean depth data should be included in monitoring polar bear habitat.

4.4.2.4 SNOW EXTENT AND DEPTH

Snow is an important feature during much of the year for polar bears. Sufficient snow accumulation is necessary for successful polar bear maternal denning (Durner et al. 2003) and ringed seal reproduction (Kelly et al. 2010). Snow cover may be an important feature for how polar bears of different age and sex categories distribute themselves on sea ice (Stirling et al. 1993). Snow accumulation on sea ice has seasonal and regional patterns (Warren et al. 1999, Sturm et al. 2002) and is dependent on roughness of the underlying substrate (Sturm et al. 2002). The extent and depth of snow play an important role in sea ice thermodynamics, in particular snow has a high albedo (Barry 1996) and is a good insulator (Sturm et al. 1997). Multi-decadal records of snow depth on Arctic sea ice show decreasing depth with time, most likely as a result of lower precipitation during later years (Warren et al. 1999). In contrast, 21st century projections suggest increasing terrestrial snow depth (Deser et al. 2010) in several regions used by polar bears for maternal denning. Because of the dependency on snow by polar bears and their prey, and because of observed and projected changes in Arctic snow deposition, it is reasonable to assume that snow coverage extent and depth may be a useful covariate for monitoring habitat and environmental change.

Several data sources are available for mapping snow cover extent, including MODIS/Aqua snow cover estimates (NSIDC; http://nsidc.org/data/docs/daac/modis_v5/myd10c2_modis_aqua_snow_8-day_global_0.05deg_cmg.gd.html; Hall et al. 2007) and SSM/I-SSMIS EASE-Grids estimates of snow cover on land (NSIDC; http://nsidc.org/data/nise1.html; Nolin et al. 1998). Pan-Arctic estimates of snow depth on sea ice are available from AMSR-E imagery (NSIDC; ftp://n4ftl01u.ecs.nasa.gov/SAN/AMSA/AE_SI12.002/). For a comprehensive list of available satellite-derived estimates of snow cover see: http://nsidc.org/data/snow.html#SNOW_COVER, and http://nsidc.org/data/snow.html#SNOW_DEPTH.

Though it is logical to assume that snow data may be useful to assess maternal den habitat suitability and the distribution of ringed seals and polar bear sea ice habitat, the value of satellite-derived snow distribution data for monitoring polar bear habitat is untested. As of this time, remotely-sensed snow extent and depth data have not been used as covariates for polar bear habitat selection. Additionally, available snow data suffer from several limitations including all are coarse-grained (finest resolution is MODIS at 0.05 degrees), cloud and daylight dependent (MODIS), provide only an index of presence or absence of snow on land (SSM/I and MODIS), or omit large regions of potential polar bear habitat (AMSR-E). This limitation is especially evident in consideration of polar bear maternal den habitat, as the features selected are small relative to the resolution of available imagery of snow cover (Durner et al. 2003, Richardson et al. 2005). Evaluations of remotely-sensed snow data for predicting polar bear habitat use needs be done before depending on these data for monitoring polar bear ecosystem and habitat change.

4.4.2.5 AN ANALYTICAL APPROACH TO MONITORING POLAR BEAR HABITAT AND ENVIRONMENTAL CHANGE

Standardized methods of developing habitat models (resource selection functions, or RSFs) for polar bears have been developed for several subpopulations (Ferguson et al. 2000a, Mauritzen et al. 2003, Durner et al. 2004, 2006) and for a large part of polar bear range (Durner et al. 2009). RSFs are also useful for predicting the distribution of terrestrial den habitats (Richardson et al. 2005). RSFs have been developed from satellite radio-telemetry data of adult female bears and readily available sea ice data in geographic information system (GIS) format (see previous sections on remotely-collected sea ice data). Several different forms of RSF are available but discrete choice models (McDonald et al. 2006) provide a good solution when habitat availability varies between subsequent choices by an animal and between animals, as is typical for polar bears (Arthur et al. 1996).

Regardless of the choice for model building, the resulting RSF gives a value that is proportional to the probability of selection (Manly 2002). The RSF lends itself well to GIS applications and can be used to predict the distribution of a population of animals on a landscape (Boyce and McDonald 1999). As polar bears occur in four primary ecoregions (Amstrup et al. 2008), ecoregion-specific RSFs should be explored. Though a specific RSF has allowed predictions and projections of subpopulation distribution in the Divergent and Convergent Sea Ice Ecoregions (Durner et al. 2009), other RSFs may be necessary for estimating subpopulation distribution within the Archipelago and in the Seasonal Sea Ice Ecoregions. Ice modeling developed specifically for these regions would be necessary.

An RSF, with its covariates, may be thought of as a map with each environmental covariate a contributing sub-map. In the form of an exponential equation, where the exponent is the sum of the product of covariates and their parameter estimates, the RSF provides a practical way to estimate the subpopulation distribution (Durner et al. 2009). Applying the RSF to sea ice data can give the user a near-real time estimate of the distribution of polar bears either within regions or across their range.

RSFs may be feasible only in subpopulations that have medium to high scientific access potential. RSFs already have been built for several medium to high scientific access subpopulations, and these may be used for habitat monitoring (Durner et al. 2009). Habitat monitoring may be conducted for subpopulations with low scientific access potential by reasonable extrapolation of RSF from well-studied subpopulations. Ongoing research in the Seasonal Sea Ice Ecoregion, archived telemetry data in the Archipelago Ecoregion, and existing RSFs in other regions has the potential to allow habitat monitoring over most of the range of polar bears.

4.4.2.6 MONITORING FOOD WEBS FOR HABITAT CHANGE

Food webs may be another means to monitor habitat and environmental change in subpopulations. Northward expansion of fish into Arctic waters may change food webs (e.g., Renaud et al. 2012). Other studies suggest that changes in the composition and abundance of seal species preyed upon by polar bears may temporally benefit some subpopulations (Stirling and Parkinson 2006). Stable isotope (Bentzen et al. 2007) and fatty acid analysis (Iverson et al. 2006) of polar bear and prey tissues can provide information on the polar bear prey base within subpopulations, and this can help to identify shifts in food webs. This will be most feasible in subpopulations that receive high or medium-intensity monitoring. Development of a standardize protocol for CBM, through the collection of hunter-harvested samples, would augment scientific endeavors or provide the sole means of collecting tissue samples. Aside from direct chemical estimates of diet and food webs, assessment of non-indigenous species in polar bear habitats will require systematic recording of irregular and occasional observations by researchers and subsistence-dependent residents of coastal communities.

4.4.2.7 MONITORING POLAR BEAR MATERNAL DENNING FOR HABITAT CHANGE

Knowledge of the distribution of maternal den habitat is built upon observations through direct on-ground sighting by residents and scientists, ground and air-surveys of likely habitat, and VHF and satellite radio-telemetry (Durner et al. 2010). Both anecdotal reports and systematically collected data have been useful to identify the habitat features important for maternal denning (see Durner et al. 2003 and citations within). Denning habitat distribution on land has been determined successfully through manual interpretation of airborne-derived high-resolution landscape photographs (Durner et al. 2001, 2006). Habitat models (i.e, RSFs) are also a powerful tool for predicting the occurrence of terrestrial den habitat (Howlin et al. 2002, Richardson et al. 2005). Trends in sea ice den habitat may be estimated by monitoring sea ice conditions as changes in the composition of sea ice has been linked to changes in den distribution. Documenting whether and how polar bear denning responds to such habitat changes requires radio-telemetry or other intensive monitoring and research approaches (Fischbach et al. 2007, Derocher et al. 2011).

4.4.2.8 LINKING HABITAT CHANGE TO POLAR BEAR SUBPOPULATION STATUS AND TREND

Habitat availability and change have been linked to polar bear demography or condition in two subpopulations. However, in other subpopulations, where habitat has declined, there have not been concomitant documented changes in population size or survival (Obbard et al. 2007, Stirling et al. 2011). This is likely the result of complex interacting factors including increase in prey (Stirling and Parkinson 2006), lower rates of change in ice habitat (Obbard et al. 2007), or declining harvest rates. Further, lack of significant links between ice habitat and demography may result from low statistical power. Nonetheless, quantitative links between habitat and demographic parameters are complex and must be refined. Without better understanding of links between habitat features and polar bear demography or productivity, quantifying the relationship between ice decline and polar bear status will be difficult. Continued research in those subpopulations that undergo intensive monitoring, or periodic research in subpopulations with a medium level of monitoring, will provide the best data to draw relationships between the environment and demographics.

4.5 HUMAN-CAUSED MORTALITY

Human-caused mortality of polar bears includes legal harvest, legal kills associated with the defense of life and property, illegal harvest, accidents (e.g., consuming dangerous items), and mortality associated with research. Legal harvest is often set at annual limits determined by governments, co-management boards, local communities and treaties. In some regions, harvest may be legal but the levels are unregulated. Illegal harvest is defined as those kills occurring outside the terms or limits set by authorities, or in regions where polar bear harvest is not permitted.

Polar bears are legally harvested in Canada, Greenland, and the United States, under provisions set by the Agreement and respective national legislation (see Table 3a for an overview of which subpopulations are legally harvested). In most regions, legal harvest activities are closely monitored (Table 10). For many subpopulations harvest levels are based on scientific assessments of status, whereas some subpopulations are harvested based on information sourced primarily from TEK and local interests. In some regions, unmonitored harvest or lack of information on subpopulation status prevents a quantitative assessment of the sustainability of the harvest. Consequently, harvest levels may be unsustainable in some subpopulations. The effects of harvest on polar bear subpopulations are well documented (e.g., Taylor et al. 1987b, 2009), including the ramifications of sex-selective harvest (Derocher et al. 1997, Taylor et al. 2008b, Molnár et al. 2008), similar harvest-risk assessment studies should continue because the effects of harvest will interact with those of climate warming.

In Russia and Norway, in 1956 and 1973, respectively, the hunting of polar bears was prohibited by national legislation, with exceptions provided for defense kills. In 2000, Russia signed an agreement with the United States that recognized the right of native Chukotkans to harvest polar bears for subsistence from the Chukchi Sea subpopulation (Anonymous 2000). A shared, regulated harvest level has been determined by the bilateral international commission and will be implemented by the United States in 2013. Russia is currently determining whether the legal harvest will be reinstated in Chukotka.

In 1973, the Agreement restricted the harvest of polar bears to local people. Accordingly, most polar bears are harvested by Indigenous people for nutritional and cultural subsistence. There also are commercial interests associated with the harvest of polar bears. When ratifying the Agreement on 14 December 1974, the Government of Canada interpreted (Canadian Letter of Interpretation filed at ratification) “Article III, paragraph 1, sub-paragraphs (d) and (e) as permitting a token sports hunt based on scientifically sound settlement quotas as an exercise of the traditional rights of the local people.” In practice, Inuit communities have allocated portions of their total harvest allotment to non-native sport hunters on the basis of local preferences, as the “token” level has not been defined by Canada (Lunn et al. 2010). The financial return from these hunts in Canada provides income for some local people. The sale of parts of polar bears harvested legally within Canada and Greenland, or converted into handicrafts within the United States, is also permitted. Currently, legal international trade only involves polar bear parts exported from some subpopulations in Canada. There is a voluntary temporary ban of export of polar bear parts from Greenland.

4.5.1 WHY HUMAN-CAUSED MORTALITY SHOULD BE MONITORED

Compared to the 1960s and 1970s, polar bear harvest management is vastly improved and several subpopulations have experienced demographic recovery due to harvest regulations (Amstrup et al. 1986, Derocher 2005). Annual, legal, human-caused mortality of polar bears is currently between 700 and 800, or 3-4% of the estimated size of the total population of about 20-25,000 animals (Obbard et al. 2010:31). This figure includes defense kills. Poaching, or illegal hunting of polar bears, is of concern in some locations, but not generally across the circumpolar region. For example, Kochnev (2004) reported illegal hunting in eastern Russia could account for up to 300 bears per year in the 1990s. Current estimates may be less (A. Amirkhanov, E. Shevchenko, S. Kavry, personal communication), but poaching still is a serious concern in that region.

Harvest monitoring is important for the quantification and mitigation of the effect of human-caused mortality on polar bears. Harvest level is a concern in some subpopulations, and inconsistent, poorly documented or undocumented information weaken monitoring efforts in other subpopulations. In some areas, harvest monitoring is inconsistent and makes it challenging to determine harvest effects. In cases where harvest is not expected to be the proximate reason for population decline, monitoring harvest is necessary to arrive at this conclusion. In addition, subpopulation inventory programs may not be frequent enough to respond to population declines. As threats such as climate warming, pollution, tourism, and human development continue to grow it will be necessary to review the way polar bear harvest is managed.

The quality of information and sampling from the harvest of polar bears varies by subpopulation. In some regions, notably in Nunavut and the Northwest Territories of Canada, harvest is well monitored, and includes sampling and measurements of harvested bears. In other regions, collection of data from ongoing harvests must be implemented or improved.

4.5.2 HOW HUMAN-CAUSED MORTALITY SHOULD BE MONITORED

Table 11 outlines the data and samples that should be collected annually from harvested polar bears. Parameters listed as essential are necessary to understand the harvest level (number, sex) and to serve as mark-recovery information (e.g., tags or tattoo number) for population demographic studies. Collection of a fat sample, which is not now being uniformly collected, could provide genetic identity of the harvested animal as well as information on its condition and feeding patterns-information relevant to monitoring and ecological studies. Age derived from a tooth would provide useful information for a variety of ecological studies; especially in assessment of population dynamics and status. A hunter-assessed body condition index (Stirling et al. 2008b) could be a useful and inexpensive TEK metric as an annual assessment of condition of polar bears. Harvest data should be obtained annually from all harvested subpopulations at all monitoring levels. Where only medium- or low-intensity scientific monitoring is recommended, harvest data and samples are especially important, as they may constitute the majority of, or only, information available. Standardized collection and recording of harvest data and tissue samples may be developed to provide indices of the general subpopulation status (e.g., health, stature, trend), in addition to information to specifically describe the harvest. Analysis of samples or harvest data should be improved to better understand the ecology and the status of subpopulations throughout the circumpolar Arctic (see Priority study #2, Section 6.2). CBM will be critical for collection of harvest information.

4.6 HUMAN–BEAR CONFLICT

Human–bear conflict has been variously defined (Schirokauer and Boyd 1998, Wilder et al. 2007, Hopkins et al. 2010), though there is no widely accepted definition. Most recently Hopkins et al. (2010) defined a human–bear conflict as occurring when a bear has 1) exhibited stress-related or curious behavior, causing a person to take extreme evasive action, 2) made physical contact with a person (e.g., to assert dominance, while acting defensively or taking human food) or exhibited clear predatory behavior, or 3) was intentionally harmed or killed (not including legal harvests) by a person (e.g., poached, wounded or killed in defense of life or property).

4.6.1 WHY HUMAN–BEAR CONFLICT SHOULD BE MONITORED

Human-bear conflicts compromise human safety and can result in property damage. Although the majority of these situations do not result in human injury or fatality, a much larger proportion results in the bear's death. Many environmental unknowns prevent conflict records from providing direct evidence of trends in population abundance (e.g., Howe et al. 2010), but if systematically recorded they may provide indices to changes in habitat that are linked to overall population status. Regardless of its possible links to population status, monitoring of human–polar bear conflict is necessary to inform our understanding of how to mitigate the negative effects of such conflicts on both people and polar bears (Fleck and Herrero 1988, Stenhouse et al. 1988, Dyck 2006).

The potential for human–bear conflict increases as polar bears spend extended periods of time on land during open water seasons. A meeting of the Parties to the Agreement (the Range States) in Tromsø, Norway in March 2009, recognized that human–polar bear interactions will increase in the future due to expanding human populations, industrial development, tourism, and a continued increase in the proportion of nutritionally stressed bears on land due to retreating sea ice. The Range States agreed on the need to develop comprehensive strategies to manage such conflicts and that the expertise developed for the management of other bear species should be consulted in the development of strategies specific to polar bears. The Range States also agreed that it is important for countries to share expertise regarding effective management of human–polar bear interaction and welcomed ongoing efforts to monitor subpopulation status and trends. They further agreed on the need to strengthen monitoring of conflicts, and to coordinate and harmonize national monitoring efforts. The Range States tasked the USA and Norway with leading an effort, in collaboration with polar bear experts and managers from the other parties, to implement a system to effectively catalogue human–polar bear interactions.

4.6.2 HOW HUMAN-BEAR CONFLICT SHOULD BE MONITORED

To address this emerging issue, the Polar Bear–Human Information Management System (PBHIMS; http://www.pbhims.net) was developed to standardize the collection of conflict data across the circumpolar regions. This system enables analysis of human–polar bear interaction data and provides a scientific framework for preventing negative human–polar bear interactions. Data stored in the system include human–polar bear conflicts, polar bear observations, human–polar bear conflict mortalities, and polar bear natural history data. Scanned images of original report forms, narratives, and photos can be attached to each incident to provide additional detail. Data are also entered into Google Earth and can be exported to ArcGIS for subsequent spatial analysis.

To provide continuous monitoring of human–polar bear conflict data across the necessary range of scales (i.e., local community to range-wide) a uniform system should be adopted by the

Range States. We recommend that the Range States adopt such a system (i.e., PBHIMS), and conduct a meta-analysis to provide insight into trends and occurrence of human–polar bear interactions. Such an analysis would identify and then mitigate conditions that foster negative human–polar bear interactions, which should result in increased human safety and reduced polar bear mortality.

In addition to adoption of such a monitoring system, the Range States should continue to work with residents through governments and local organizations to develop community polar bear conservation plans that address safety issues and seek to establish effective means of deterring polar bears (e.g., polar bear patrols), and management of attractants as tools within communities to identify and prevent potential conflict situations.

A summary of recommended monitoring methods is given in Table 12.

4.7 DISTRIBUTION

The distribution of polar bears may be viewed at three spatial levels: 1) global, 2) ecoregion-specific, and 3) subpopulation. A circumpolar monitoring plan must consider these different spatial levels because physical, biological, and management factors, as well as the availability of scientific and TEK data vary at the ecoregion and subpopulation scales.

The sea ice environment undergoes large seasonal fluctuations in extent, from an average of 14 million km^2 during winter to 7 million km^2 during summer (Perovich and Richter-Menge 2009). This results in large seasonal changes in the distribution of the world's population of polar bears. Within ecoregions that retain sea ice during the summer ice minima, polar bears can remain with sea ice throughout the year (Durner et al. 2009). Subpopulations in the Seasonal Sea Ice Ecoregion face complete loss of sea ice habitat and polar bears there must spend extended periods on land in summer and autumn (Stirling et al. 1999). Both the annual variability of sea ice and the distribution of seals influence polar bear distribution (Ferguson et al. 1999). Large changes in subpopulation distribution occur as a result of the increased temporal and spatial extent of open water during summer and autumn (Stirling and Parkinson 2006, Schliebe et al. 2008).

4.7.1 WHY POLAR BEAR DISTRIBUTION SHOULD BE MONITORED

An understanding of polar bear distribution is necessary for addressing management issues (e.g., Amstrup et al. 2005b, USFWS 2010). Effective surveys of subpopulation size depend on an understanding of subpopulation distribution (Aars et al. 2009). Projections of 21st century sea ice habitat suggest that the future distribution of polar bears will be greatly reduced (Durner et al. 2009). Also, changes in distribution can signal important habitat modifications that may precede population level changes in size or vital rates. An early indication of habitat loss or alteration, especially for large mobile animals, can be distribution changes and extralimital observations. Consistent monitoring of the occupied range can be an important indicator that changes are occurring. Changes driven by reduced habitat availability or altered habitat character will lead to altered population status. Consistent records of changing distribution can inform management of anticipated changes in the impacts of direct human removals (Peacock et al. 2011), interactions with industrial developments, and other aspects of human commerce in the Arctic (e.g., mineral extraction; Gautier et al. 2009). Knowledge of these influences on habitat is necessary to mitigate the impacts of climate warming induced habitat loss (Amstrup et al. 2010). It is also important to understand polar bear distribution within subpopulations for the design of population studies (e.g., aerial survey and M-R).

4.7.2 HOW DISTRIBUTION SHOULD BE MONITORED

Robust and quantitative estimates of subpopulation distributions have been made through the analysis of satellite radio-telemetry data (Bethke et al. 1996, Mauritzen et al. 2002, Amstrup et al. 2004). Satellite telemetry reduces potential bias in estimating polar bear distribution (Taylor and Lee 1995) because the data usually include long-term (i.e., ≥ 1 year) individual movement records. Subpopulation distributions estimated from satellite telemetry locations are also unbiased because polar bear location data are largely independent of when and where researchers conduct fieldwork. Estimating subpopulation distribution and change in distribution could be accomplished by continuous satellite telemetry in high-intensity monitored subpopulations or by periodic satellite telemetry in medium-intensity monitored subpopulations. Radio-telemetry data can be used to quantify subpopulation boundaries, which in turn is directly relevant to understanding trends in abundance, harvest, and overall welfare (Amstrup et al. 2004).

Satellite radio-telemetry is a resource intensive technique that may not be available for all subpopulations. Other methods, however, may provide a qualitative assessment of distribution. Distribution of polar bears can be qualitatively assessed through spatially-explicit M-R (physical or genetic) and the returns of tagged animals in the harvest (Taylor and Lee 1995). Distributions estimated in this way can be spatially biased because the data are collected only where the scientists or hunters encountered the bear (Taylor and Lee 1995). This bias increases the uncertainty of distribution estimations and reduces the ability to monitor distribution change of the entire subpopulation, though distributions estimated in this manner have been useful in a management context (Taylor and Lee 1995). Counts of polar bears from systematic aerial transects may provide indications of distribution change in portions of subpopulation (Schliebe et al. 2008), and therefore alert resource managers of possible environmental changes. Similar to M-

R studies, aerial surveys are typically constrained to short periods when weather conditions are suitable for aircraft and sometimes to portions of the potential subpopulation range (Evans et al. 2003, Aars et al. 2009).

Identification of optimal sea ice habitat may be a useful proxy of distribution when other monitoring data, such as radio-telemetry or aerial surveys, are not possible. Sea ice habitat is a driver of polar bear distribution (Durner et al. 2009; see also Section 4.4). RSFs are a standardized tool for examining remotely collected environmental data, for example satellite imagery of sea ice, to identify habitats most likely to be used by wildlife and to predict their distribution (Boyce and McDonald 1999). An RSF may be the only means to predict the distribution of polar bears in subpopulations that cannot be accessed by scientific research (see Section 4.4). Durner et al. (2009) extrapolated an RSF across multiple subpopulations in the polar basin and showed that RSFs were robust to temporal changes in sea ice extent and composition. Though this has allowed predictions of subpopulation distribution in the Divergent and Convergent Sea Ice Ecoregions (Amstrup et al. 2008), other RSFs may be necessary for estimating distribution within the Archipelago and Seasonal Sea Ice Ecoregions. Estimating subpopulation distribution in ecoregions with low scientific access potential may be possible by reasonable extrapolation of RSFs from well-studied ecoregions. Methods recommended for different levels of monitoring intensity are summarized in Table 13.

4.8 PREY DISTRIBUTION AND ABUNDANCE

Polar bears primarily depend on the most ice-adapted seals, ringed seals and, to a lesser degree, bearded seals (*Erignathus barbatus*) for their survival in most parts of their range. Stirling and Øritsland (1995) demonstrated a significant relationship between estimates of the total numbers of bears and ringed seals over large geographic areas in Canada. Stirling (2002) summarized how changes in ringed seal reproduction in the Beaufort Sea resulted in marked responses in reproduction and cub survival in polar bears. In some subpopulations, other prey species such as harp seals, hooded seals (*Cystophora cristata*), walruses (*Odobenus rosmarus*), harbor seals (*Phoca vitulina*), and sometimes belugas (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) can be important and their importance may change over time (Thiemann et al. 2008b).

4.8.1 WHY PREY DISTRIBUTION AND ABUNDANCE SHOULD BE MONITORED

As the climate continues to warm, there will be significant changes in the temporal patterns of sea ice break-up and freeze-up. The seasonal ice distribution will change, and the duration of ice-free periods, when most marine mammals are inaccessible to polar bears, will increase. Monitoring changes in abundance and availability of prey, and possible changes in their importance to polar bears, will be critical to understanding, and possibly predicting, changes in the survival, reproductive success, and population size of individual subpopulations. Population size of ringed seals, and the proportion of ringed seals in polar bear diets in different subpopulations, will be among the most important ecological factors to monitor. In some areas, data exist that can be used to compare the present, or future, to the past (e.g., Chambellant et al. 2012), but in most areas a quantitative baseline has yet to be established.

An additional, though difficult and unpredictable topic to monitor with respect to seal species, is the occurrence of epizootics that might seriously affect the prey of polar bears and polar bears themselves (USGS 2012). For example, at the time of writing this report, there is an ongoing outbreak of skin lesions in ringed seals from Russia, Alaska, and western Canada. How serious this outbreak may be is as yet unknown but it is of concern and is currently being monitored through a coordinated international effort (NOAA 2011).

4.8.2 HOW PREY DISTRIBUTION AND ABUNDANCE SHOULD BE MONITORED

Monitoring should focus on estimation of the distribution and abundance of prey, their reproductive productivity, and their importance to polar bears. The huge size of polar bear home ranges and financial and logistic limitations prevent application of the more intensive methods in many subpopulations. Here, however, we describe a variety of approaches, with differing degrees of potential resolution, which will afford the maximum opportunity to understand trends in prey availability.

1) *Repeating quantitative aerial surveys on the distribution and abundance of seals undertaken in the past.* A number of quantitative surveys, particularly for ringed seals have been conducted (e.g., Stirling et al. 1982, Kingsley et al. 1985, Lunn et al. 1997, Bengtson et al. 2005, Krafft et al. 2006). Replicating some of these surveys may provide broad, but coarse scale, comparisons of ringed seal distribution and abundance over large geographic areas. Use of helicopter belly-mounted cameras and computer-assisted analysis may also allow systematic collection of information on the distribution and abundance of prey during polar bear capture and survey operations.

Such surveys are expensive and are only justified in relation to high-intensity monitoring subpopulations, especially where reasonable baseline surveys have been conducted, and where subpopulations are known to be having difficulties (e.g., Western Hudson Bay, Southern Beaufort Sea), or where large-scale ecological change has occurred (e.g., the replacement of multi-year ice by annual ice in Viscount Melville Sound). If new or improved methodological designs are to be useful they must be implemented in a way that facilitates direct comparisons with previous surveys. As sea ice changes progress, it will be necessary to designate areas where new and improved regional scale surveys are appropriate.

2) *Indices of ringed seal reproduction and numbers in intensive study areas of localized interest.* Smith and Stirling (1978) demonstrated the feasibility of using trained dogs to quantitatively assess variation in ringed seal reproduction among years. The method, although applicable and repeatable, is labor intensive and therefore limited to small geographic areas. It may provide indices to trends occurring in larger areas of which localized areas are representative. Ferguson et al. (2005) noted a correlation between reduced ringed seal productivity and snow depth. Though a relationship likely exists, and may be measurable in a localized focus area, it also is probably impractical at a larger scale. Similarly, the use of aerial photography to quantify the distribution and abundance of ringed seal breathing holes in the fast ice, just after the snow melts but before the ice breaks up was demonstrated by Digby (1984).

Recording of species killed by polar bears and collection of samples from kills encountered during the course of intensive polar bear studies also can provide a quantifiable index to changes in diet, or lack thereof. Although rigorous protocols will be required for quantification, diet changes recorded during other research endeavors can likely reflect changes in prey availability, and may be an early indicator of changes in prey distribution and abundance.

3) *Community-based monitoring of ringed seal reproduction and condition.* In settlements where ringed seals are harvested for local use, harvest sampling can provide direct and dynamic information on condition and reproduction (Smith 1987, Harwood et al. 2000, 2012). Such seal data have been related to changes in polar bear reproductive success (e.g., Stirling 2002, 2005). Recording changes in composition of the human harvest of polar bear prey, in areas where local

people hunt marine mammals, and systematically collecting tissues from harvested animals, may provide estimates of changes in abundance, distribution, and availability of polar bear prey that can be compared and contrasted with samples collected during research projects (as in 2 above).

4) *Indirect monitoring of diet.* In recent years, stable isotopes have been used to study polar bear diet (Bentzen et al. 2007, Hobson et al. 2007, Cherry et al. 2011). This method provides information related to the trophic level of the prey and their relative importance. A more effective approach to date is the application of quantitative fatty acid signature analysis (QFASA) (Iverson et al. 2004). By analyzing samples of fat from a polar bear (obtained during capture or harvest), the proportion of various prey species being consumed can be identified (Iverson et al. 2006; Thiemann et al. 2007a, 2008b, 2011). Done at intervals, this technique can monitor prey accessibility (Thiemann et al. 2009). This method requires building a region-specific reference set of fat specimens from all available prey species (Thiemann et al. 2007a,b). Diet also can be inferred from morphological and molecular analyses of fecal samples (Iversen 2011). The information can be used to analyze spatial and temporal change in diet composition. The potential to combine stable isotopes, fatty acids, fecal samples, and field observations should be explored.

Sampling of ringed seals harvested during the open water period, and collection of fat samples from bears killed by Inuit hunters represents a cost-effective method of obtaining specimens. Areas designated for high and medium-intensity monitoring, are those where polar bears use a wide variety of species and where changes in habitat are either already well underway or projected to occur in the foreseeable future (e.g., Davis Strait, Foxe Basin, Baffin Bay, Western Hudson Bay, Southern Hudson Bay, or Svalbard). There, fat samples would be collected for 2-3 years at a time, with collection bouts separated by ≤ 5 years. Fat sampling for QFASA analyses in low frequency areas probably can occur at ca. 10-year intervals unless changing conditions result in elevated concerns about subpopulation status. Monitoring methods recommended for varying intensities of monitoring are summarized in Table 14.

4.9 HEALTH

For humans, health has been defined as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity (WHO 1948). Alternatively, health is the level of functional and (or) metabolic efficiency of a living being. In humans, it is the general condition of a person in mind, body and spirit, usually meaning to be free from illness, injury or pain. A similar definition may be applied to animals.

4.9.1 WHY MONITOR POLAR BEAR HEALTH?

For many years the health of animal populations has been assessed with the tools of population dynamics: estimation of trends in abundance, mortality, and reproductive rates. However, for species such as bears with long generation times, this approach can be expensive and may be too slow to provide an early warning about the impact of environmental stressors such as pollution, human activities, and climatic warming (Primack 1998). Further, although evident in some individuals, signs of compromised health (e.g., disease, loss of condition, failed reproduction) may be difficult to recognize and quantify at the population level. Therefore, efforts to link environmental stress with population health remain somewhat speculative. Compromised health in individuals is typically preceded by a stress response, a normal adaptive response in which an animal uses energy to cope with some threat to its well-being. However, when a threat is extreme or prolonged, the stress response can have a deleterious effect on animal health and result in a physiological state described as “distress” (Moberg 1999). In distress, an animal uses energy at the expense of other biological functions including reproduction, tissue growth and maintenance, and immune response. Distress alters biological function (e.g., failed reproduction, stunted growth, decreased immunity) and, if unchecked, eventually results in death. If polar bears are energetically stressed from loss of hunting opportunities due to changes in sea ice, the manifestation of this will first be seen at the individual level as declines in body condition. Population level effects such as reduced reproductive success or declines in survival rates may follow. Therefore, monitoring health and body condition of individuals can provide early warning of changes negatively affecting subpopulations. Changes in the environment (i.e., declines in sea ice distribution or duration) have been linked to changes in body condition, reproduction, and survival (Regehr et al. 2007, Rode et al. 2010), emphasizing the need to monitor animal health.

4.9.2 HOW TO MONITOR POLAR BEAR HEALTH

4.9.2.1 BODY CONDITION

One way to examine animal health is to evaluate body condition or body composition. Body condition indices can be estimated using various methods if animals are physically handled. These include subjective fatness ratings, length to weight ratios, and body composition measured by isotopic water dilution or bioelectrical impedance analysis (BIA) (Farley and Robbins 1994; Hilderbrand et al. 1998; Stirling et al. 1999, 2008b; Cattet et al. 2002; Robbins et al. 2004; Cattet and Obbard 2005; Molnár et al. 2009).

Isotopic water dilution and BIA offer the best opportunity to quantify body composition for comparison between studies and provide the best insights to nutritional ecology (Hilderbrand et al. 1998, Robbins et al. 2004). However, isotopic water dilution requires that animals be immobilized for 1.5 to 2.5 hrs (Hilderbrand et al. 2000) and is therefore not recommended as a routine field technique for monitoring body condition of polar bears. BIA has been used to investigate the nutritional ecology of black bears and brown bears (Farley and Robbins 1994, Hilderbrand et al. 1998, Hilderbrand et al. 2000, Robbins et al. 2004). BIA measurements take less than 15 min, but training and experience are required to obtain accurate, repeatable estimates and to standardize measurement conditions (Hilderbrand et al. 1998). BIA requires an accurate measurement of the bear's body mass and cannot be used reliably on injured, dehydrated, or dead bears (Robbins et al. 2004). In addition, bears must be still and relaxed during BIA measurements, bears must be isolated from wet or cold substrates to ensure no loss of electrical conductivity to the substrate, and gut fill can overestimate body mass leading to an underestimate of fat content. BIA measurements have been taken during polar bear fieldwork but the problems identified above have not been resolved satisfactorily (S. Amstrup, G. Durner, and K. Rode, personal communication, February 2012). Therefore, BIA measurements are not recommended as a standard monitoring tool. Nevertheless, Robbins et al. (2004) advocate BIA to measure body composition of bears. Whether researchers are able to include BIA measurements in field protocols will depend to a large extent on time available, whether the measurement issues can be resolved, and other study priorities that must be completed during the time an animal is handled.

Body condition indices and trends in measurements of skull width, body length, or body mass have been used to assess the status of several subpopulations (Derocher and Stirling 1998a,b; Stirling et al. 1999; Obbard et al. 2006; Rode et al. 2010, 2012). For some indices, animals must be handled and measured (length and girth [Stirling et al. 1999], or length and body mass [Cattet et al. 2002, Cattet and Obbard 2005]), for others a subjective rating is more accurate if animals are handled (Stirling et al. 2008b) but can be used to assess condition of observed bears. Several equations to estimate body mass from axillary girth have been developed (e.g., Kolenosky et al. 1989), however, such morphometric–body mass relationships are likely subpopulation-specific (Durner and Amstrup 1996), and can change over time (Cattet and Obbard 2005). Therefore, predictive body mass equations should be developed for each subpopulation and periodically validated. Comparisons of body condition temporally or among age and sex classes within a subpopulation, or spatially among several subpopulations can be made using various body condition indices (e.g., Cattet et al. 2002) or by estimating energy stores (Molnár et al. 2009).

Approaches that do not entail handling bears may be desired for work in some subpopulations. Using a subjective fatness index (Stirling et al. 2008b), information on body condition can be obtained from animals darted remotely with biopsy darts, from animals observed during aerial surveys, or from harvested animals.

4.9.2.2 ENVIRONMENTAL STRESS

To date, the measurement of environmental stress in wildlife has been problematic, largely because many of the physiological variables used to assess environmental (or long-term) stress are also affected by acute (short-term) stresses associated with capture and handling, or by various other physiological processes in addition to stress (Moberg 2000). More recently, improved techniques for detecting long-term stress have been developed (Alexander and Irvine 1998, Iwama et al. 1999, Southern et al. 2002). One example is the measurement of corticosteroid-binding globulin (CBG), a protein in the blood circulation that specifically binds cortisol. Blood serum levels of CBG are lowered during long-term stress in a variety of species, and their concentration provides a more sensitive assessment of stress than the measurement of total cortisol alone. CBG is an effective indicator of long-term stress in brown bears (Chow et al. 2010), and has been measured in polar bears (Chow et al. 2011).

Use of cortisol (the primary stress hormone associated with the hypothalamic-pituitary-adrenal axis) in hair is a sensitive, reliable, and non-invasive measure of long-term stress. Hair cortisol concentration (HCC) is a biomarker of long-term stress in humans and domestic animals, and was recently validated for polar bears (Bechshøft et al. 2011, Macbeth et al. 2011). Application of this technique may provide insights into potential linkages between the environment and population performance in polar bears.

Other techniques are directed toward assessment of the cellular stress response. These homeostasis-restoring processes have evolved in all living organisms, are triggered within hours of a significant perturbation, and persist until recovery (Bechert and Southern 2002). For example, heat shock proteins (Hsps), a family of proteins crucial for allowing cells to cope with stress (Feder 1999), are induced when long-term endogenous or exogenous stressors affect the protein machinery. Hsps are unaffected by short-term stress such as capture and handling. Cellular stress is evident before biological function is altered and may provide a sensitive early warning of increased environmental stress and compromised health.

Consistent monitoring of CBG and Hsps in blood of captured animals, like monitoring of physical measurements, must be conducted over the long run to assess whether levels reflect directional change or interannual variation. It will be important to test whether these stress indicators are related to subsequent physical changes or vital rates. Similarly, as with physical measurements, changes in these compounds must be linked to stress sources to be useful for monitoring. Such methods are cost-effective and easily incorporated into monitoring programs.

4.9.2.3 CONTAMINANTS

Many studies of polar bears have found high levels of contaminants such as mercury (Dietz et al. 2006), organochlorines (Norstrom et al. 1998, Muir et al. 1999, Verreault et al. 2005, Muir et al. 2006), and perfluoroalkyl substances (Smithwick et al. 2005). Some studies indicate negative relationships between exposure to contaminants and health or reproductive parameters (e.g., Wiig et al. 1998; Haave et al. 2003; Oskam et al. 2003, 2004; Sonne et al. 2006). However, these studies were correlative in nature and do not demonstrate cause and effect (on reproduction or survival) relationships. Therefore, information from controlled studies of farmed Norwegian Arctic foxes (*Vulpes lagopus*) and housed Greenland sledge dogs (*Canis familiaris*) have been used as supportive weight of evidence in the clarification of contaminant exposure and health effects in polar bears (Verreault et al. 2008, Sonne 2010). Studies indicate that hormone and vitamin concentrations, and liver, kidney and thyroid gland morphology as well as reproductive and immune systems of polar bears are likely to be influenced by contaminant exposure (Sonne 2010). Furthermore, exclusively based on polar bear contaminant studies, bone density reduction and neurochemical disruption and DNA hypomethylation of the brain stem may occur (Sonne 2010). Based on these studies, it remains important to continue to monitor levels of various contaminants in polar bear tissues as part of a comprehensive monitoring program to assess health of individual bears.

4.9.2.4 DISEASE

The presence and frequency of diseases in polar bears is poorly known and no definite health problems have been identified. Plasma samples from polar bears from Svalbard and the Barents Sea were screened for antibodies to *Brucella* (Tryland et al. 2001), and for antibodies to canine distemper virus, calicivirus, phocid herpes virus, and rabies (Tryland et al. 2005). Low seroprevalence was reported for all (5.4% for *Brucella*, 8% for canine distemper virus, 2% to calicivirus, and 0% to phocid herpesvirus and rabies). Polar bears from East Greenland, Svalbard, and the Barents Sea screened for antibodies to the protozoan parasite *Toxoplasma gondii* were

21.4% seropositive (Oksanen et al. 2009). This was much higher than an earlier study from the Beaufort and Chukchi Seas and the Russian Arctic (6%; Rah et al. 2005), though a subsample from the Russian Arctic showed a prevalence of 23% (7 of 30). More recently, Jensen et al. (2010) documented an increase in the prevalence of *T. gondii* in Svalbard polar bears and speculated this might be due to warming ocean waters enabling oocysts to have higher survival. Though no health or reproductive effects have yet been demonstrated, it would be prudent to monitor for *Brucella*, morbillivirus, and *Toxoplasma* periodically (every 10 years), especially since the latter may be increasing in prevalence (Jensen et al. 2010). Consideration should be given to screening subpopulations that have not been screened. Methods recommended for monitoring polar bear health are summarized in Table 15.

4.10 STATURE

Stature is used here as a broad term to describe any measurable aspect of the physical size including measurement of skeletal size and body mass.

4.10.1 WHY MONITOR POLAR BEAR STATURE?

Among vertebrates, variation in physical stature results from either density-dependent (e.g., direct competition for resources) or density-independent factors (e.g., environmental variation) that influence the availability of energetic resources. Although density-dependent changes in polar bear stature have not been documented, evidence from other bear species (Zedrosser et al. 2006, Czetwertynski et al. 2007), other large vertebrates (e.g., Kjellander et al. 2006), and ice-dependent marine mammals (Hammill and Stenson 2011) indicates that density can play an important role in limiting populations. Because polar bears are not territorial and typically occur at low densities on the sea ice, it is likely that density-independent factors such as changes in prey availability in relation to sea ice distribution will have the greatest influence on observed changes in stature. However, concurrent monitoring of subpopulation size in relation to changes in stature will allow researchers to assess the importance of density-dependent processes.

Monitoring reductions in polar bear body size (e.g., skull length and width and body length) can provide an indication of nutritional stress during growth that may have fitness consequences. Changes in resource availability in any one year may influence mass and growth rates of young bears in that year. Also, because polar bears are long lived and continue to grow for many years, increased variation in resource availability can have a dampening effect on long-term growth rates and adult size. If they encounter a mixture of favorable and unfavorable environmental conditions as they are maturing, bears may be able to survive but will be unable achieve the growth rates and potential size they could have had conditions been better. Because a symptom of global warming is more variable climate and weather fluctuations, one of the early effects could be reduced stature of adults over time.

Body stature has been related to reproductive success for bear species and other large mammals (Clutton-Brock et al. 1988, Noyce and Garshelis 1994, Hilderbrand et al. 1999). Both Atkinson et al. (1996) and Derocher (2005) documented reductions in cohort body length in polar bears, but to date these changes in stature have not been related to changing subpopulation demographics. In addition to measuring changes in body size, measuring changes in body mass and body condition are of particular importance because changes in these metrics are most likely to influence survival and reproduction (Derocher and Stirling 1995, Stirling et al. 1999, Rode et al. 2010). Body condition of bears can be estimated using many methods (see Section 4.9.2.1). Measuring changes in the physical stature and body condition of adult female polar bears could help provide valuable insight into future demographics as lighter female polar bears produce smaller litters with lighter cubs (Derocher and Stirling 1995) that are less likely to survive (Derocher and Stirling 1996). In summary, measuring stature provides insight into both historic and current shifts in the availability of energetic resources in addition to providing potential valuable insight into demographics.

4.10.2 HOW TO MONITOR POLAR BEAR STATURE

Monitoring polar bear stature should be a mandatory component of all programs that involve handling of polar bears. Table 16 describes a set of metrics for monitoring spatial and temporal variation in polar bear stature and Table 17 summarizes methods for monitoring stature at varying levels of intensity. All of the measurements with the exception of body mass can be obtained with a tape measure, small diameter nylon rope, and calipers. Weighing polar bears, although time consuming, can provide valuable information on the condition of animals. Thus, the importance of obtaining body mass of captured bears, or a sample of captured bears, must be compared to the advantages of collecting other condition metrics from a larger number of animals. For subpopulations with low intensity monitoring, where harvest occurs, hunters should be given a sheet in their harvest kit demonstrating how to measure the straight-line body length and axillary girth of bears along with rope to measure both. Hunters would need to stretch the length of rope from the tip of the nose to the last vertebrae on the bear's tail, cut it, and return it with their harvest collection kit. A similar process should be followed for measuring axillary girth. Skulls and bacula should be collected from harvested bears, where possible, to obtain measurements of skeletal growth.

Analyzing skeletal material from museum collections can also be important for long-term monitoring of body size (Yom-Tov et al. 2006, Bechschøft et al. 2008). The continued collection of such material is important for long-term monitoring of polar bear stature.

4.11 HUMAN ACTIVITY

Human activities, not including hunting or other sources of direct mortality, of concern to the welfare of polar bears include mineral exploration and development, tourism (polar bear and non-polar bear), scientific research (non-polar bear), shipping, and infrastructure development to support these.

4.11.1 WHY MONITOR HUMAN ACTIVITY?

Historically, the remoteness of the Arctic marine environment probably provided adequate protection for both polar bears and their habitat. This situation has changed in recent decades and human presence in previously remote geographic areas will increase as disappearing sea ice makes much of the Arctic more accessible. Oil and gas exploration and development, including offshore drilling, is already occurring in the Arctic. Loss of sea ice, habitat fragmentation, and technological developments will make the Arctic more accessible and human activity will likely increase (Arctic Council 2007, 2009). An increase in human activity in areas inhabited by polar bears will increase the probability for disturbance of bears and human–bear conflicts (see Section 4.6).

Although the threats and impacts of oil and gas activities on polar bears are fairly well known (Øritsland et al. 1981; Hurst and Øritsland 1982; Stirling 1988, 1990; Isaksen et al. 1998; Amstrup et al. 2006a), how polar bears will be affected by other types of human activity is poorly understood (Vongraven and Peacock 2011). Polar bears are often attracted by the smells and sound associated with human activity. Polar bears are known to ingest plastic, styrofoam, lead acid batteries, tin cans, oil, and other hazardous materials with lethal consequences in some cases (Lunn and Stirling 1985, Amstrup et al. 1989, Derocher and Stirling 1991).

Polar bears appear to be disturbed by snow machines and often show avoidance behaviour (Andersen and Aars 2008). The effects of increased ship traffic, pollution from human activity, and noise on polar bears and their prey are unknown. However, ice-breaking vessels and industrial noise can increase abandonment of subnivean ringed seal structures on sea ice, and consequently may have negative impacts on seal reproduction (Kelly et al. 1988). All such data could be integrated in GIS systems for further evaluation of impacts as suggested by Brude et al. (1998) in their Dynamic Environmental Atlas developed in the environmental impact assessment of the opening of the Northern Sea Route along the Siberian coast (The North East Passage).

Human activity and disturbance can result in den abandonment by female polar bears. During the autumn, female polar bears appear to be more sensitive to disturbance and more readily abandon dens (Belikov 1976, Amstrup 1993, Lunn et al. 2004) compared to later in the winter when they appear to tolerate human activity closer to den sites (Amstrup 1993). Though there are reasons to believe that some impacts can be controlled with good management, combined effects of several negative factors acting simultaneously (e.g., climatic stress, pollution, and disturbance) can be difficult to predict and this needs increased attention from both scientists and managers. The cumulative impact of chronic human disturbance, whether from industry, tourism, infrastructure, or noise, is unknown but potentially negative. There has been little systematic collection of data from which to quantify human activity and its potential impact on polar bears and their habitat. As the type, intensity, and frequency will vary across the Arctic, it is important to begin collecting baseline data on an ongoing basis for all subpopulations.

4.11.2 HOW TO MONITOR HUMAN ACTIVITY

Methods recommended for monitoring human activity in polar bear habitat are summarized in Table 18. Regulatory permits and reporting requirements as well as spatial analysis tools will be important for quantifying human activities. The presence of human development or activity and the effects on polar bear welfare are different things. Currently, methods to quantify the effects of development are poorly implemented and require development.

1. *Permit applications* – Many human activities within polar bear habitat require proponents to submit applications for permits specific to each type of activity. All proposed exploratory or development activity, ship passage, tourism, and non-polar bear research (for polar bear research, see Section 4.13) should be recorded to document the type, frequency, intensity, timing, and areas of these activities. In addition to providing information to monitor human activity, these data could also be valuable to both managers and proponents, should activities be planned to occur in key areas important to polar bears or at sensitive times of the year.

2. *Activity that actually occurs* – Although planning documents may provide a way to monitor proposed human activities, the details, frequency, intensity, timing, observations of bears, and location, of the various types of activities that actually occur are the issue. This is particularly important if permit applications are broad in scope and activities comprise only a subset of permitted actions. For example, if a tour company applies to bring five tours to an area over a defined period, after the tours are over it is important to record how many days they were in the area, how many tourists were involved, and how many bears were observed. National contact points need to be established to collect and collate permit and activity data and to coordinate assessments of impacts.

3. *GIS applications and remote sensing* – Using the information collected above, spatial and temporal analyses should be undertaken to identify areas of concern. These types of analyses may also refine additional monitoring needs or specific research questions.

4. *Standardized methods* – Standardized methods need to be developed to assess the responses of bears to various human activities and ultimately to assess the effects of those responses.

4.12 BEHAVIORAL CHANGE[1]

There are at least two circumstances where recording of behavior (using the term broadly) might be useful, and they would require quite different approaches. Quantitative observations with which to compare the behavior of bears of different age and sex classes at the same location, and at different times, can provide insight into the ways in which change, if occurring, could be manifested. Data on hunting success could be useful input for energetics models. Consistent documentation of qualitative information on various behaviors, recorded on an opportunistic basis, would be valuable as input to expert-opinion models (Amstrup et al. 2008) and contribute to TEK studies.

4.12.1 WHY MONITOR CHANGES IN POLAR BEAR BEHAVIOR?

Potentially, the most insightful behavioral comparisons could be made using quantified activity budgets and hunting success rates. Quantitative documentation of activity budgets for bears in the Canadian High Arctic and along the western coast of Hudson Bay have illustrated the value of this work. Activity budgets, and hunting success of bears of different ages and sex classes, and with different ages of cubs, were quantified over several years (Stirling 1974, Stirling and Latour 1978, Stirling and Øritsland 1995). On the western coast of Hudson Bay, the behavior of bears on land while fasting during the ice-free period was quantified (Latour 1981, Lunn and Stirling 1985). Where these sorts of observations are possible they can provide insights into how polar bears utilize their habitat and time, and whether or not changes are occurring.

Probably the most important behaviors, which might indicate the overall health of a subpopulation, relate to human–bear conflicts and intraspecific mortality events. Systematic

[1] This section overlaps to some extent with section 4.6 Human–bear conflict.

documentation of the number of problem bears that occur in settlements, and individual-specific information on the age and body condition of problem bear kills (see Section 4.6) may be the most important single behavioral indicator of subpopulation stress in relation to climate warming and loss of ice. In Churchill, where this has been done consistently (Stirling and Parkinson 2006, Towns et al. 2009) the details of the documentation are relevant to testing of hypotheses related to whether the subpopulation is food stressed as a result of the effects of climate warming on the sea ice. Such data may also exist for Svalbard and parts of Alaska. Although similar observations are made in many settlements throughout the Canadian Arctic, in general they have not been systematically recorded. A systematic recording system is necessary to assure utility of these observations (i.e., PBHIMS; Section 4.6).

In polar bear subpopulations, observations of infanticide, cannibalism, starvation, and other behaviors suggestive of food-stress have been recorded (Lunn and Stenhouse 1985, Derocher and Wiig 1999, Amstrup et al. 2006b, Monnett and Gleason 2006, Stirling et al. 2008a). Such events are not in themselves proof of climate warming, but they are consistent with the predictions of consequences for polar bears facing climate-related problems with their habitats. Such observations only become useful for monitoring if they are consistently recorded and analyzed. TEK is valuable for long-term observations of behavioral changes in polar bears.

4.12.2 HOW TO MONITOR CHANGES IN POLAR BEAR BEHAVIOR

Recording incidental observations of human–bear conflict—These data are of high significance for monitoring of all subpopulations. Although they are inexpensive to record, their value rests on the reliability and consistency of the data. Bears killed because they threatened human life or property may be assigned a normal hunting tag, but the reason for their death needs to be recorded independently of hunting mortality. To the extent possible, past records for settlements throughout the Arctic should be re-analyzed to make them as complete as possible for the past, and mechanisms put in place to ensure complete recording in the future.

Recording incidental observations of irregular or novel behavior and intraspecific polar bear mortality—Observations of cannibalism, swimming and drowning, and infanticide have been made in subpopulations where we think food stress and body condition may be an issue. Systematic recording of these behaviors plus other irregular or novel behaviors, such as unusual hunting strategies (e.g., digging through ice; Stirling et al. 2008a), taking of alternative prey, erratic and anomalous behavior, hybrids, unusual locations (all with a measure of effort included) are all possible indicators of change in polar bear welfare. However, the value of a database of such observations is related to its completeness. The value also depends on information on observer effort.

Quantitative energy budgets—At this point, development of quantitative energy budgets is more of a research topic than one that is established sufficiently for monitoring. An initial test of its potential usefulness might be considered in the Western Hudson Bay subpopulation because there are some data from the past and we know that subpopulation is being affected by climate warming. The only other place where past data exist is in the Canadian High Arctic. A summary of recommended monitoring methods is given in Table 19.

4.13 EFFECTS OF MONITORING POLAR BEARS ON POLAR BEARS

Monitoring polar bears can involve immobilizing bears to collect samples, mark individuals and attach equipment (e.g., collars, tattoos, tooth removal, ear tags, implants), collecting samples from active bears (e.g., DNA darting or hair snags), and observing bears (e.g., aerial surveys, behavioral studies).

4.13.1 WHY MONITOR POLAR BEAR MONITORING AND RESEARCH?

Some members of northern communities, management agencies, and scientists have raised concerns about the possible impacts of polar bear research and monitoring (Dyck et al. 2007, Cattet et al. 2008). Specifically, concerns surround the lethal and sub-lethal effects of handling on polar bears, the number of bears being handled, and the possible effects of wearing a collar or other devices (e.g., impact on a bear’s ability to hunt seals, disturbance by helicopters while bears are hunting or mating, and wastage of polar bear meat when people do not want to consume harvested bears that have been drugged before harvest). In some communities, the capture of any polar bears is considered inappropriate. The frequency of captures and numbers of bears caught within a population as well as specific procedures employed when bears are captured also are sometimes issues (Inuit Tapiriit Kanatami 2009). Further, as subpopulations become increasingly stressed, the impact of pursuit and capture on individual health may increase. As a monitoring plan is designed and implemented, a component that monitors the level and effects of the research itself on polar bears must be included. Some Inuit consider chemical immobilization of bears unacceptable and they report the immobilization drug changes the taste of the meat and fat (Henri et al. 2010). Further, permanent dye applied to bears in some areas in the past to avoid recapture of the same bear in the same season rendered the hide of the bear unfit for sale. Permanent dyes, however, are no longer used.

Impacts of polar bear research vary depending on the method. Although flying at low altitude disturbs individual bears, there are no studies that document effects. In contrast, a study which requires surgery or multiple captures in a short period could have higher impacts including stress due to disturbance and possible negative energetic consequences. There is also a risk of trauma and mortality associated with handling, although this has been low in polar bear research.

Wildlife research involving animal handling requires approval by an institutional animal care committee and adherence to best practices following techniques that minimize potential impacts (e.g., Sikes and Gannon 2011). Impacts of wearing a collar on the energetics and survival of an individual bear seem to be insignificant (Messier 2000), however, fully determining the impacts would be difficult and require a study specifically designed for this purpose. Analysis of existing data may yield additional insights.

Monitoring polar bears may have impacts on individual bears although quantitative analyses are limited. Short-term effects are unavoidable (Messier 2000). Effects on individuals must be balanced with information needs for management and conservation and the risks posed by harvest. The effects relative to information needs must be judged by management and co-management authorities, and affected communities. As an example of how scientists try to reduce handling effects there is increasing use of automatic electronic release mechanisms for collars.

To date, there is little evidence of significant changes in individual survival and reproductive rates in individuals as a result of handling (Ramsay and Stirling 1986, Amstrup 1993, Messier 2000, Lunn et al. 2004, Rode et al. 2007). Nevertheless, there is a need for increased reporting about monitoring intensity for full disclosure to the public and for subsequent use in evaluating the necessity of future proposed research.

4.13.2 HOW TO DOCUMENT AND ASSESS EFFECTS OF POLAR BEAR MONITORING

The following parameters can be used to document the level of research and assess potential effects of monitoring on polar bears:

- Number of captures (by sex and age class) using immobilization drugs annually;

- Comparative stature of previously captured versus newly captured bears;
- Comparative reproductive performance of tagged and collared bears versus those not previously handled;
- Litter sizes of females that have been previously captured versus those that have not;
- Number and types of radio telemetry devices deployed annually;
- Type of treatment (and medication) and samples taken during immobilization;
- Description of any research-induced injuries, an estimate of severity, and associated actions and post-capture monitoring;
- Reporting of capture mortalities;
- Number of recaptures;
- Number of times the recaptured bears have been handled (with maximum and minimum);
- Number of sightings of marked bears during research;
- Average number of times the bears are re-sighted in a year during polar bear research;
- Number of DNA darting events annually;
- Estimated number of radio telemetry device active; and
- Number of hours flown over polar bear habitat during polar bear research

Research groups and jurisdictions that conduct monitoring efforts are the appropriate institutions to report these metrics.

5. LOCAL KNOWLEDGE AND INVOLVEMENT

An integral part of coordinated monitoring around the circumpolar Arctic is employment of both scientific approaches and locally acquired knowledge (e.g., Traditional Ecological Knowledge and Local Knowledge) and the monitoring of relevant parameters using CBM. Further, increased local involvement (whether through collection of TEK or use of CBM) has been ubiquitously requested by local communities, regional and federal governments, and a wide variety of international polar bear management commissions and groups (e.g., the Range States, bi-lateral joint commissions). This collaborative strategy is not without challenges, but good examples of such approaches exist in many parts of the Arctic (e.g., beluga and ringed seal monitoring and research in the western Canadian Arctic, coordinated through the Fisheries Joint Management Committee, based in Inuvik, Northwest Territories [Harwood et al. 2000, 2012; Harwood and Smith 2002]).

The knowledge of experienced hunters (i.e., TEK) can provide a framework for the generation of scientific hypotheses, for the explanation of research results, and can generate early warning of changes in polar bear ecology (e.g., Rode et al. 2012) in addition to extensive natural history knowledge (Van de Velde et al. 2003). Likewise, CBM can be an effective and efficient method of systematically collecting data (including TEK) and samples to be used in scientific analyses (e.g., Harwood et al. 2000). CBM can also provide local employment, and provide a mechanism for local participation in polar bear research and management.

For a number of the parameters and subpopulations identified in this monitoring plan, CBM and the application of TEK have been identified as effective approaches. The following sections describe CBM and TEK in the context of polar bear monitoring, and identify elements that make these collaborations successful.

5.1 COMMUNITY-BASED MONITORING (CBM)

Community-based monitoring refers to the training of local people to systematically collect and document scientific information, specimens, and TEK (see Section 5.2; Harwood et al. 2000) and to apply such collections where they can contribute to a more complete understanding of the subject being researched. To maximize effectiveness, CBM requires a careful training of persons collecting material and the fostering of partnerships between local communities and research communities.

CBM can encapsulate a variety of sampling and surveying programs, in which the roles of local people, local, regional, and federal government scientists and managers, and university scientists can vary. Across the circumpolar Arctic, the input of local communities in polar bear monitoring and management has varied. Since the mid-1980s in Greenland, CBM has involved polar bear hunters routinely taking various tissue samples from their kill at the request of the regional government. This practice, especially prominent in northwestern and central east Greenland, illustrates a successful cooperation between scientists from Greenland and Denmark and the local hunting communities that has contributed greatly to long-term studies aimed at understanding effects of pollution on polar bears (Sonne 2010). Analyses of the composition of the harvest (Born 1995a,b; Rosing-Asvid 2002) and studies of reproduction (Rosing-Asvid et al. 2002) also have depended on CBM in Greenland. Similar community-based harvest data and sampling programs have been ongoing for several decades in the Canadian Arctic and have provided data for abundance estimation, population delineation, foraging ecology, and contaminants (Taylor and Lee 1995, Taylor et al. 2005, Thiemann et al. 2008b, McKinney et al. 2009).

Once a community has indicated support for a CBM project, it is essential that participants be supportive and fully trained. One common challenge to CBM is a high degree of participant turnover. We recommend that projects establish a core group of participants that can instruct others, and, where practical, for the proponent to maintain a community presence if they are not from the community themselves. Equally essential to long-term community support is the reporting of results to both the participants and their communities in an accessible format (i.e., translated and in a non-technical manner, while recognizing that the northern public knows much more about polar bears than public audiences in the south).

5.2 TRADITIONAL ECOLOGICAL KNOWLEDGE (TEK)

There are many definitions of TEK, from the all inclusive cosmological definitions to the simpler view of TEK as data or information:

> "… traditional ecological knowledge is a cumulative body of knowledge, practice, and belief, evolving by adaptive process and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environments." (Berkes 1999)

and

> "… the knowledge and insights acquired through extensive observation of an area or a species. ... knowledge passed down in an oral tradition, or shared among users of a resource." (Huntington 2000)

TEK is also referred to as indigenous knowledge, aboriginal knowledge, naturalistic knowledge, and local knowledge (Berkes 1999, Grenier 1998). TEK is held by indigenous (e.g. Inupiat) and non-indigenous groups (e.g., Newfoundland cod fishers).

It is important to separate TEK from human dimensions research, such as the management preferences of local people (Kotierk 2009a, Tyrrell 2006), and CBM (see Section 5.1), which is the integration of communities with government, industry and scientists in developing and implementing monitoring programs (Fleener et al. 2004, Mahoney et al. 2009). TEK is locally-based knowledge, information and understanding, not a method of data collection.

TEK of polar bears includes polar bear distribution, movements, travel routes, habitat use, population, cub production, denning, behavior, hunting methods and success, tracking, health, and prey species. TEK has been collected and utilized in Greenland (Born et al. 2011), Canada (Harington 1968, Van de Velde 1971, Urquhart and Schweinsburg 1984, Van de Velde et al. 2003, Dowsley 2005, Keith 2005, Kotierk 2009b, Slavik 2010, Wong 2010, Maraj 2011, Sahanatien et al. 2011), Alaska (Kalxdorff 1997), and Russia (http://belyemedvedi.ru/index.html) (Kochnev et al. 2003, Zdor 2007). In these studies, TEK was collected using the semi-directed interview method or focus group discussions, with the exceptions of Van de Velde (1971), who used the participant observation method, Keith (2005) who used participant observation and interviews, and Wong (2010) who used standardized questionnaires with participant observation and interviews. In addition to studies specifically about polar bears, TEK of polar bears has been collected as part of regional or ecosystem TEK studies (McDonald et al. 1997; Anonymous 2005, 2008; Sang et al. 2004). Though many of these studies collected TEK about observations of changes in polar bear ecology, behavior, populations, and sea ice habitat most studies were not designed for monitoring trends. Thus, their primary value may be in the provision of baseline information that can be used to develop future monitoring and research projects, including CBM.

5.2.1 WHY MONITOR POLAR BEARS USING TEK?

Incorporating TEK in the research, monitoring and management of polar bears is a policy, program, and legislated requirement in most Canadian jurisdictions (Henri et al. 2010, Peacock et al. 2011). Some jurisdictions require the use of TEK for management and have a policy framework for monitoring (Anonymous 2004). TEK has been used where scientific information is lacking for regions where little is known about polar bear distribution and habitat, when immediate information is needed for environmental assessment, and where research costs are high and logistics are difficult (Kalxdorff 1997, Kochnev et al. 2003). TEK can extend the time series of polar bear information as it has for other species (Moller et al. 2004). TEK has the potential to contribute to intensive and long-term monitoring that cannot be accomplished by scientists, whose studies are often restricted to specific times of the year and shorter time frames. People holding TEK are on the ground and sea ice year round and have been for generations.

Collecting TEK about polar bears is necessarily a community-based and inter-disciplinary effort that involves the people holding the TEK, biologists, social scientists, and wildlife managers. Questionnaires, surveys and interview questions, analytical methods and the list of participants should be developed collectively. There are many resources available to guide and assist this work, and many experienced scientists to provide advice. For example, TEK has been used to parameterize a population simulation model for harvesting (Lyver et al. 2009), to model habitat use and distribution (Mackinson 2001), and to detect population trends and changing habitat use (Gilchrist et al. 2005). Sea ice and climate researchers have made considerable progress in collecting and reporting on TEK and using TEK for monitoring (Laidler and Elee 2008; Krupnik et al. 2010; Gearheard et al. 2010, 2011; Pulsifer et al. 2011; Weatherhead et al. 2010).

To facilitate trend analysis with TEK a standardized questionnaire or survey method that allows participants to elaborate, as in semi-directed interviews, should be employed. Each questionnaire or interview should include spatial information options. It is important that individuals collecting TEK are knowledgeable enough about polar bears to allow informed interactions with the participants particularly when semi-directed interviews methods are used. The ability to collect TEK in local languages (e.g., Inuktitut, Cree) is essential. If the interviewer does not speak a local language then an experienced interpreter who knows wildlife, habitat, hunting, and sea ice terminology should be used. All materials should be translated into the local language and appropriate dialect. In Arctic North America, TEK collection is best done in-person, rather than sending out a questionnaires, although mail out or web based questionnaires may be suitable in some jurisdictions. Because of the life-long experience and training required to obtain an expert level of TEK, researchers and governments should be prepared to pay participants. Finally, researchers collecting TEK should provide reports and feedback to the communities on a regular basis in an accessible manner.

5.2.2 RECOMMENDATIONS FOR MONITORING POLAR BEARS USING TEK

It is important to collect the knowledge from elders that were born and lived in coastal camps in close proximity to polar bears. The knowledge will extend polar bear information back to pre-harvest management times when climate warming exerted less influence on sea ice habitat. TEK is regional and constrained by environmental and physiographic conditions (e.g., travel on land and sea ice, season, and available light). The limits of TEK for monitoring must be understood (Krupnik and Ray 2007, Gagnon and Berteaux 2009, Wohling 2009). For example, hunters may hunt in the autumn when bears are accessible on land or in spring when bears are on the sea ice. Sometimes, TEK can be limited by lack of exact spatial and temporal information to qualify or quantify local observations (Peacock et al. 2011). Further, TEK is by definition retrospective and local people recognize the limitations of their knowledge (Grenier 1998, Laidler 2006, Sahanatien 2011). Polar bear managers and scientists must work with communities to determine which aspects of polar bear ecology can be monitored using TEK.

It may not be possible to use a single circumpolar approach for using TEK to monitor polar bears because of the diversity of cultures, languages, environmental conditions, and histories of human–bear interactions and relationships. In particular, polar bear hunting peoples will hold different TEK than those that do not hunt but live with or have conducted long term research on polar bears. In some cases, polar bear management and legislative restrictions have changed the type and quality of TEK held by people, for example the ban on hunting polar bears in dens has limited the current Inuit TEK of polar bear den distribution (Keith 2005, Sahanatien 2011).

High intensity monitoring using TEK should occur in subpopulations with several communities to compensate for scale and geographic limitations of TEK. The added value of including all communities is to understand the variability across and among subpopulations, and to provide opportunity for inter-community collaboration (Dowsley and Wenzel 2008). No monitoring or less intensive monitoring will necessarily occur where there are no communities or traditional-use areas. A summary of recommended monitoring methods is given in Table 20.

6. PRIORITY STUDIES

Some information needs for the conservation and management of polar bears supersede what can be ascertained from monitoring efforts alone. Although much of the information gathered through monitoring (e.g., samples, vital rates, and abundance) can also be used to understand underlying ecological mechanisms, there are some knowledge gaps that will require establishment of quantitative baseline data and more sophisticated ecological research.

There are two projects that should be given highest priority. The first one is vital to identify optimal sampling schemes, and the other will take advantage of a large collection of polar bear samples to provide relevant information on harvested subpopulations.

6.1 STUDY #1: ANALYSIS OF SAMPLING FREQUENCIES FROM EXISTING DATA

A monitoring effort on this scale should be preceded by a power analysis of existing data to elucidate how different sampling frequencies can affect variance, accuracy, and precision in estimates of population parameters. Long-term data sets exist from continuously conducted high intensity studies that could be used for such an analysis, (e.g., Western Hudson Bay). Such an analysis could be conducted by selecting clusters of years from subpopulations that are subject to ongoing monitoring. This study would quantify information that might be lost by monitoring less frequently or indicate that less frequent monitoring can provide similar results.

This analysis should also determine sampling efforts needed to achieve different confidence levels for estimates of abundance, trend, and status. This would provide co-management authorities, affected communities, and researchers with the needed information to scale sampling effort accordingly. Even though a high number of marked individuals in a population under study is considered desirable for long-term population monitoring, a cost-benefit analysis could provide guidance on sample size requirements for a particular desired confidence level. Such a power analysis should be initiated as soon as possible.

A related aspect that could be analyzed from existing databases is the degree to which a population could be monitored using population sampling that did not cover the entire area that bears from a particular population might use. It is possible that even if such an approach could not give an accurate total population size, it may be capable of providing reliable information on trend and possibly sufficient population information to facilitate the application of precautionary management approaches. For example, there is a large amount of population data for the Southern Beaufort Sea subpopulation, collected over many years, but not always from the entire area. An evaluation of the value of surveys of partial samples could be conducted.

6.2 STUDY #2: ANALYSES OF EXISTING SAMPLES FROM THE POLAR BEAR HARVEST

Polar bears are harvested in Canada, the USA, Greenland, and parts of Russia. There is a well-established sample collection program in Canada. There are well over 700 polar bears harvested annually, the majority of these (those harvested in Canada and to some extent in Greenland and the United States) have age, sex, date of harvest, and location data collected. Working in cooperation with subsistence harvesters and jurisdictional governments, polar bears taken by hunters have provided a wealth of material for understanding of the species (Norstrom et al. 1998; Paetkau et al. 1999; Sonne et al. 2004, 2005, 2007a, 2007b). Most of these studies involve contribution of tissue specimens to scientists for analysis. Given the large number of harvested polar bears taken each year, a broader collection program could yield improved monitoring of subpopulation status. Redoubling and coordinating efforts to collect and analyze harvest data is necessary due to the known impacts of harvest (Taylor et al. 1987b, McLoughlin et al. 2005, Molnár et al. 2008). To date, harvest samples have been valuable in contributing to the estimates of population size and survival (Taylor et al. 2005, 2008a, 2009), distribution (Taylor and Lee 1995), population structure (Paetkau et al. 1999, Crompton et al. 2008), foraging ecology (Thiemann et al. 2006), and basic biology (Dyck et al. 2004). Further, much of what we know about contaminant accumulation and variation in diet has been derived from harvest samples (Verreault et al. 2005, Thiemann et al. 2006).

Finally, given that many harvested subpopulations are monitored infrequently through capture and tagging programs, harvest of bears may provide insights into demographic parameters in periods between tagging efforts (Peacock et al. in press).

Potential areas for harvest data analyses fall into three main areas:

1) temporal patterns of age and sex of harvest;
2) spatial patterns of harvest over time; and
3) temporal and spatial patterns of body condition, diet, and contaminants generated from harvest samples.

7. IMPLEMENTATION

We have suggested a monitoring framework that would describe an ideal situation, if implemented in its entirety range-wide, where we focus on what should be done based on existing best knowledge of polar bear habitat, biology, and ecology. The implementation of any or all the parts of this framework for monitoring subpopulations will depend on the positive involvement of all jurisdictions, including federal, regional, and local levels that have management and monitoring authority for their respective subpopulations.

Adherence to all components of this monitoring framework will be challenging for some jurisdictions and management authorities due to significant logistical challenges, staff capacity, and availability of financial resources. As a consequence, representative subpopulations for each sea ice ecoregion have been identified to help focus research and monitoring efforts as efficiently as possible. Complementary to high intensity efforts in these representative subpopulations we suggest lower monitoring intensities for other subpopulations that will maximize comparability with data collected in subpopulations experiencing high intensity monitoring.

7.1 RESPONSIBLE JURISDICTIONS

Of the 19 acknowledged subpopulations, 12 are exclusively within the jurisdiction of a single Arctic country, whereas the rest are shared between two countries (Fig. 5). Within Canada, management jurisdiction is primarily at the provincial or territorial level (Fig. 6). Nunavut alone has shared or exclusive jurisdiction over 13 subpopulations, where approximately two-thirds of the world's polar bears reside. This rather complex picture, where subpopulations are unevenly shared among jurisdictions, emphasizes the need for extensive regional, bilateral, and range-wide consultations to discuss and agree on suggested long-term monitoring schemes. This monitoring framework attempts to assist in that process. It is notable that polar bears are a species of global significance and the obligations to steward their conservation is held by the five Range States.

7.2 REGULAR ASSESSMENTS

The status of all subpopulations is reviewed regularly (at approximately 4 year intervals) by the PBSG. The most recent reports and deliberations, and the subpopulation status review, are published in the proceedings of the last meeting, held in 2009 in Copenhagen, Denmark (Obbard et al. 2010). This framework describes and encourages a coordinated and differentiated long-term effort to monitor essential population parameters in a circumpolar, regional perspective. We suggest that a regular independent assessment of the status and trends at the subpopulation level be conducted. This could be done by a group consisting of polar bear experts from as many jurisdictions as possible (e.g., the PBSG, or other competent groups of experts). A five-year assessment period, with regular updates of key indicators, is suggested. As part of the implementation process we recommend continued deliberations to further focus and sharpen the monitoring framework.

8. ACKNOWLEDGEMENTS

This report is the result of a process facilitated by CAFF/CBMP[2], and funded by the US Marine Mammal Commission. A background paper (Vongraven and Peacock 2011) was presented at the 13th biennial meeting of CAFF in Akureyri, Iceland, February 1-3, 2011, and a subsequent workshop was held in Edmonton, Canada, February 19-21, 2011. The workshop was attended by 21 experts and managers from all polar bear subpopulation jurisdictions, and this document is a result of the discussions at this workshop.

We would like to thank the following people for improving the document through their participation, comments and reviews at various stages: Marsha Branigan, Larry Carpenter, Richard Elliot, Susan Fleck, Gregor Gilbert, Anatoly Kochnev, Frank Pokiak, Courtney Price, Chris Servheen, Mikhail Stishov, Jon Swenson, Fernando Ugarte, Rachel Vallender, Basile van Havre, George Wenzel, and Geoff York. Thanks also to Anders Skoglund for skillful map-making. Finally, we thank three anonymous reviewers for helpful comments.

[2] CAFF (Conservation of Arctic Flora and Fauna) is one of the working groups of the Arctic Council, and CBMP (Circumpolar Biodiversity Monitoring Program) is one of CAFF's cornerstone programs.

The findings, conclusions, and opinions expressed in this report do not necessarily represent the view of the authors' institutions or employers.

FIGURE TEXTS

Fig. 1 Polar bear subpopulations (Obbard et al. 2010 :33).

Fig. 2 The 19 polar bear subpopulations categorized according to major sea ice ecoregions. A 20th area (called NWCon for "Norwegian Bay Convergent"– see section 3.5) in the Convergent Sea Ice Ecoregion at the northern coasts of the Queen Elizabeth Islands (Canada) and Greenland is indicated (from Amstrup et al. 2008). Polar bears in this area are currently not recognized by the PBSG as constituting a separate subpopulation or management unit.

Fig. 3 Polar bear ecoregions and tiered selection of subpopulations to monitor on high and medium intensity, based on various threat and knowledge factors (Ecoregions from Amstrup et al. 2008). Note that NWCon (Norwegian Bay Convergent) represents a new designation. Polar bears occurring in this area are currently not considered to represent a separate subpopulation (Obbard et al. 2010:33) but it is suggested to monitor the area intensively as a part of monitoring the NW (Norwegian Bay) subpopulation. The reason is that the NW and NWCon are assumed to serve as refugia in the future. By extending monitoring to include NWCon the future situation in the Convergent Sea Ice Ecoregion will be monitored.

Fig. 4 Subpopulation size estimates from long term monitoring of polar bears in Western Hudson Bay, Canada (from Regehr et al. 2007). Note that annual variation in the estimates would make interpretations regarding size and trend difficult if only a few years were available. The long term declining trend, however, is clear when all years in the sample are considered.

Fig. 5 Federal exclusive and shared jurisdictions over the 19 polar bear subpopulations, a) Canada, b) Greenland, c) Russia, d) Norway, and e) USA.

Fig. 6 Canadian internal territorial jurisdictions over the “Canadian” polar bear subpopulations, a) Newfoundland and Labrador, b) Manitoba, c) Nunavut, d) NWT, e) Ontario, f) Quebec, and g) Yukon. The circumpolar catch-all subpopulation Arctic Basin has been left out.

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Figure 1
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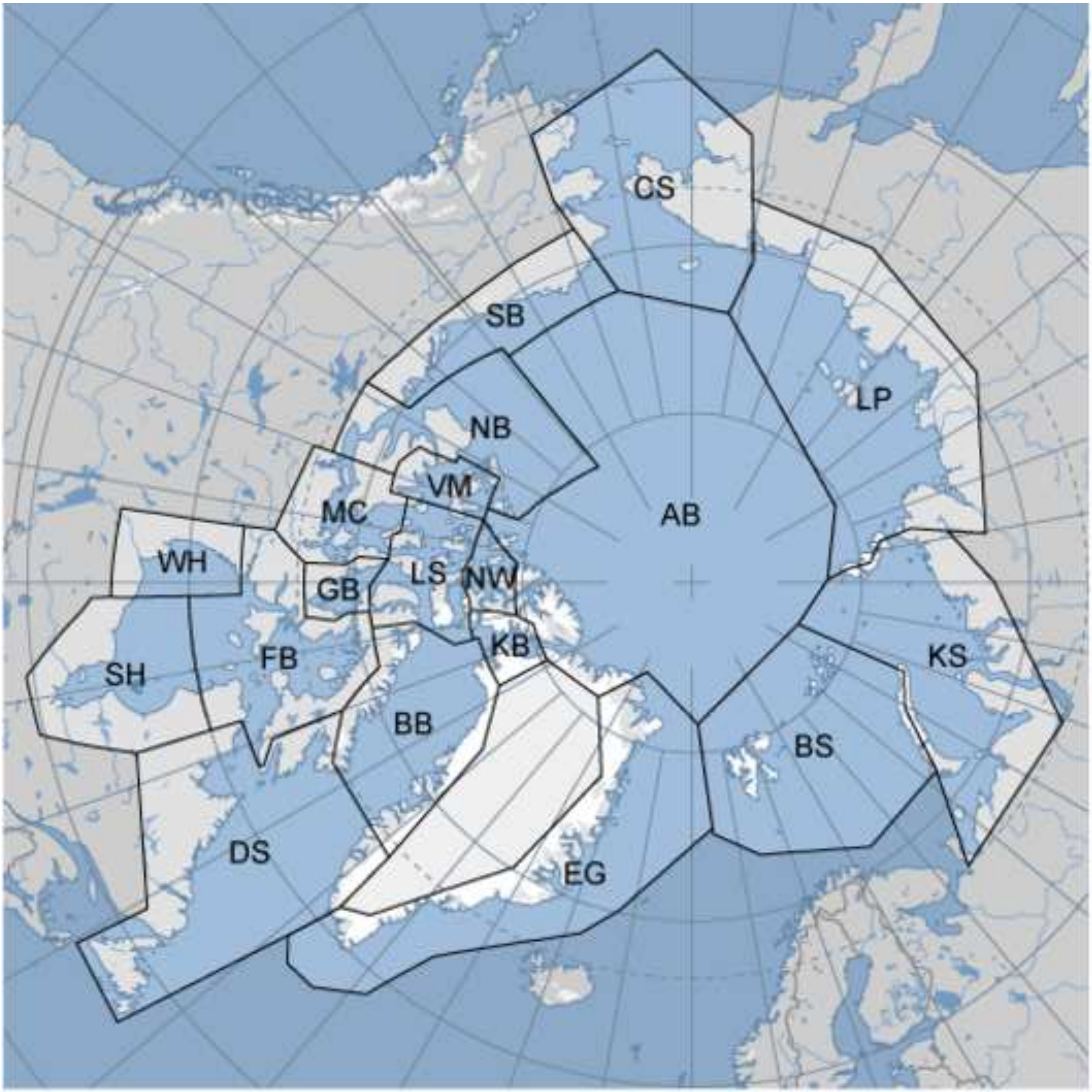

AB = Arctic Basin
BB = Baffin Bay
BS = Barents Sea
CS = Chukchi Sea
DS = Davis Strait
EG = East Greenland
FB = Foxe Basin
GB = Gulf of Boothia
KB = Kane Basin
KS = Kara Sea
LS = Lancaster Sound
LP = Laptev Sea
MC= M'Clintock Channel
NB = Northern Beaufort
NW = Norwegian Bay
SB = Southern Beaufort
SH = Southern Hudson Bay
VM = Viscount Melville
WH = Western Hudson Bay

Figure 2
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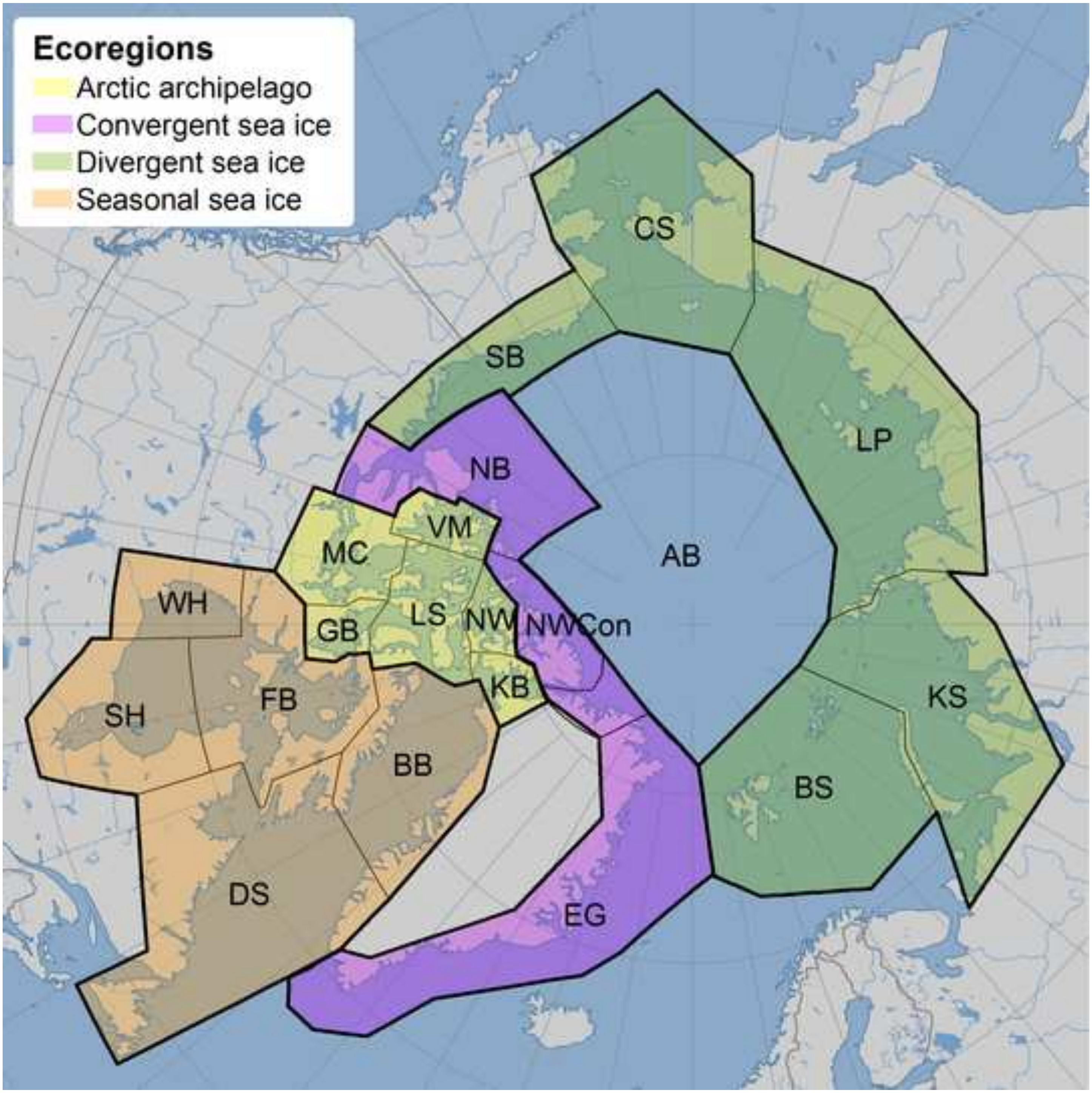

Figure 3

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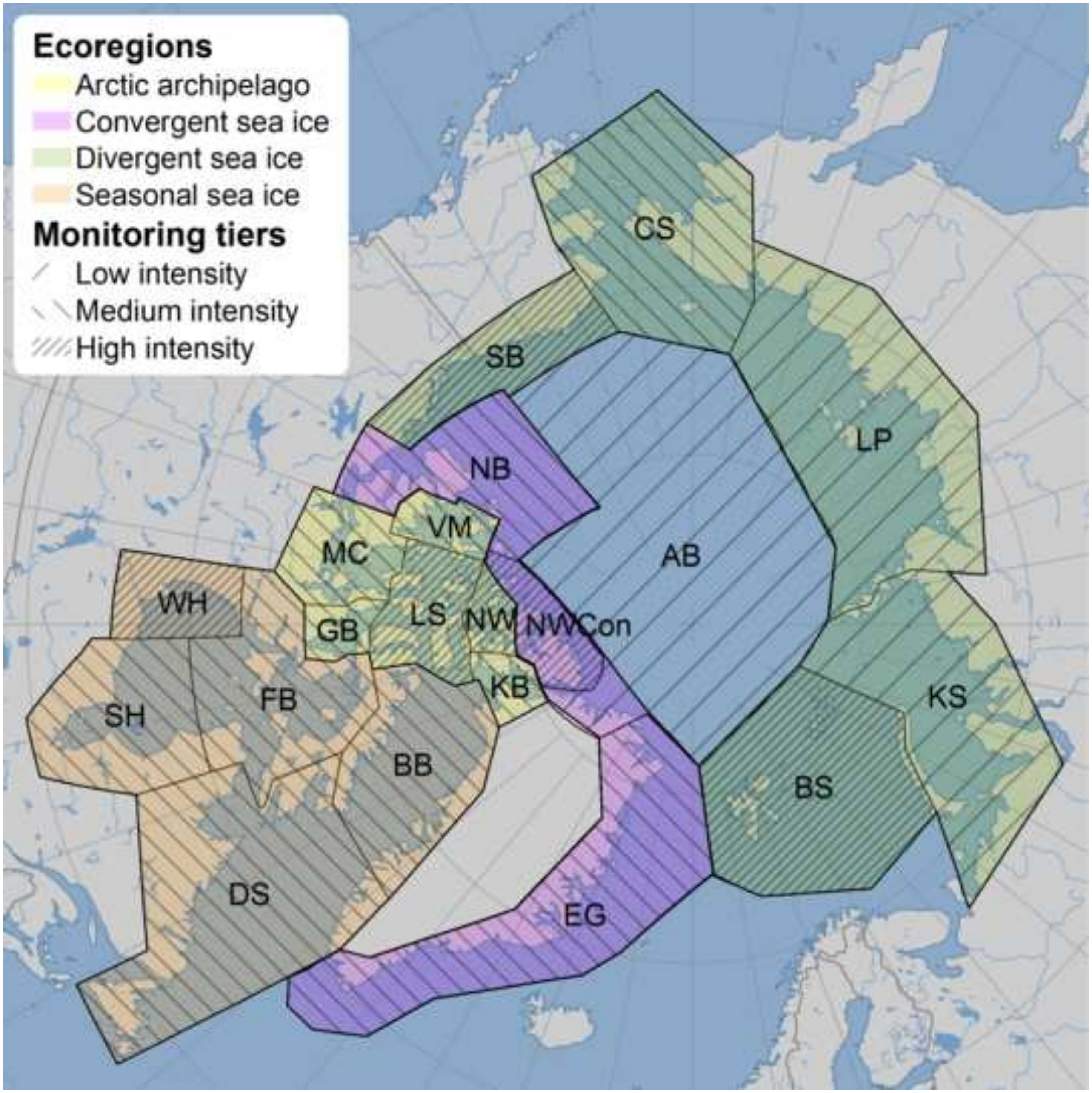

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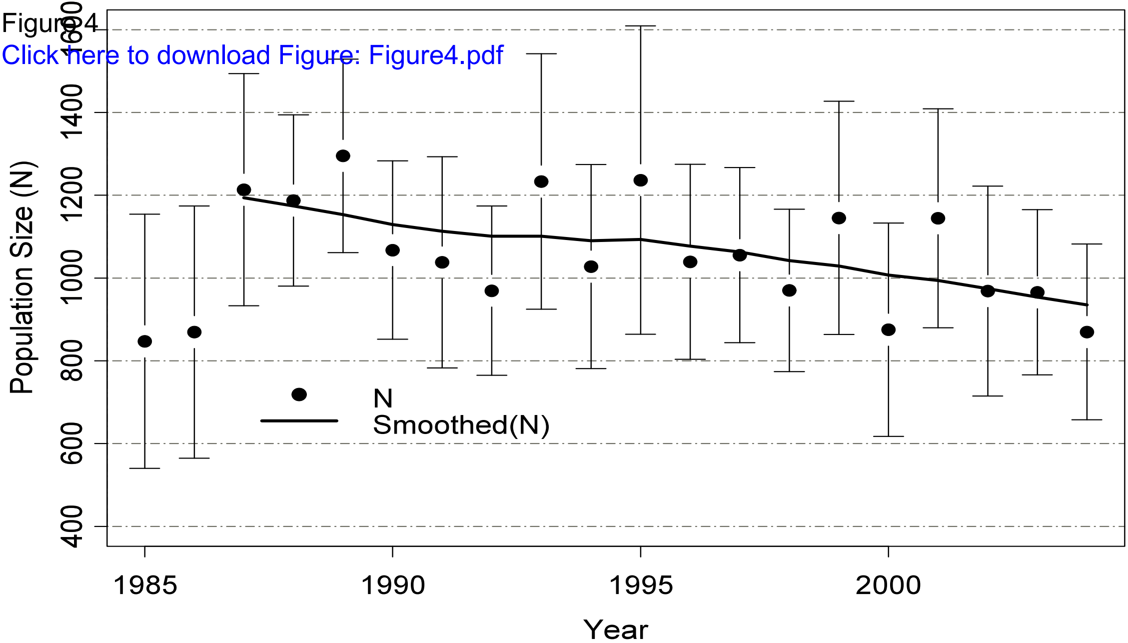

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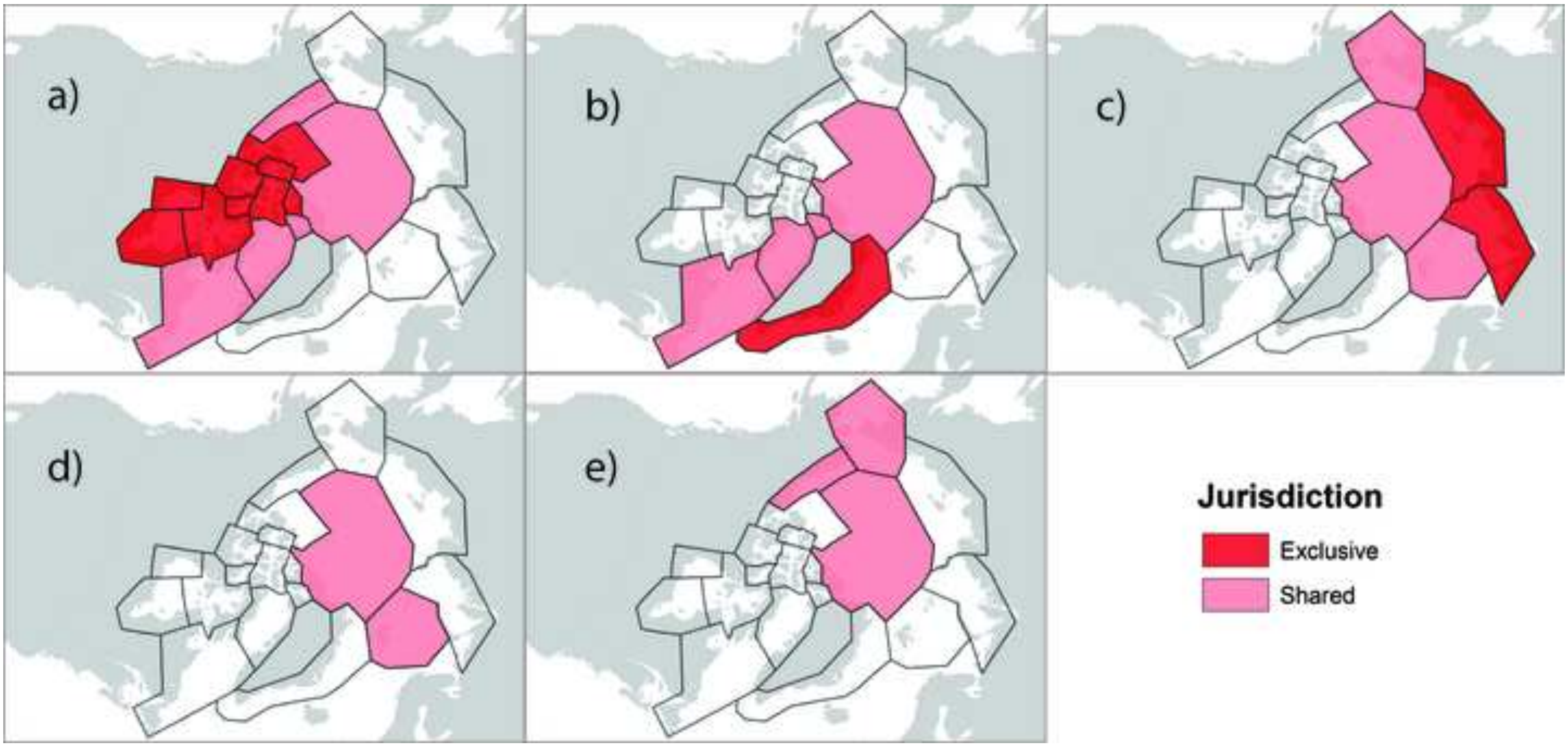

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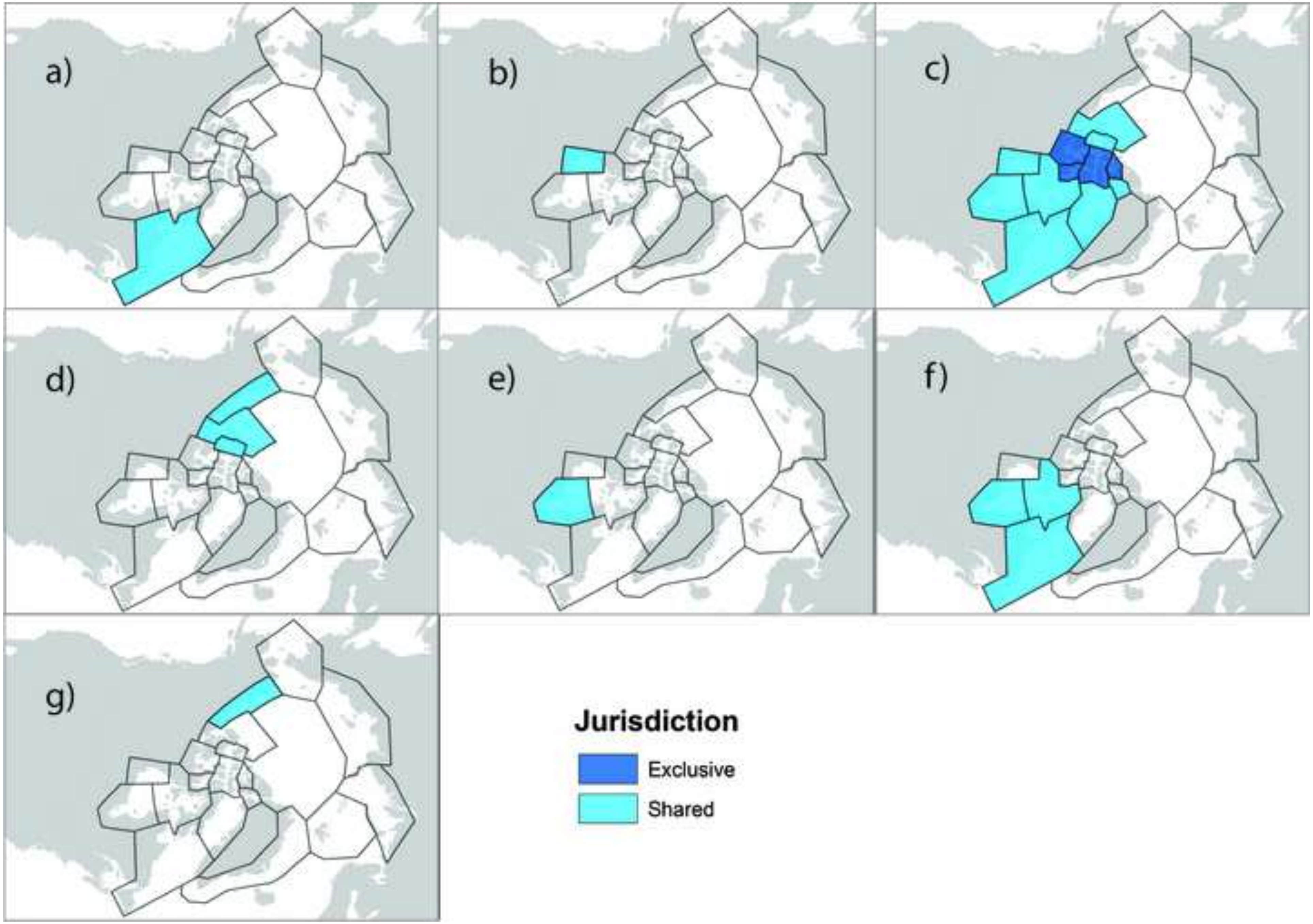

Table 1 Description of polar bear ecoregions (Amstrup et al. 2008). An *ad hoc* polar bear monitoring region called Norwegian Bay Convergent, or NWCon, has been identified in the Convergent Sea Ice Ecoregion. This area represents a future refugium that should be given high monitoring priority (see section 3.5).

Ecoregion	As described by Amstrup *et al.* 2008	Polar bear subpopulations
Divergent Sea Ice	Characterized by extensive formation of annual sea ice which is then advected into the center of the polar basin or out of the polar basin through Fram Strait. The Polar Basin Divergent Ecoregion lies between ~127° W longitude and 10° E longitude and includes the southern Beaufort, Chukchi, East Siberian-Laptev, Kara, and Barents Seas.	Southern Beaufort Sea, Chukchi Sea, Laptev Sea, Kara Sea, Barents Sea
Convergent Sea Ice	The remainder of the polar basin including East Greenland (i.e. Fram Strait, Greenland Sea and Denmark Strait), the continental shelf areas adjacent to northern Greenland and the Queen Elizabeth Islands, and the northern Beaufort Sea. This area is characterized by heavy multiyear ice with a recurring lead system that runs along the Queen Elizabeth Islands from the northeastern Beaufort Sea to northern Greenland.	East Greenland, Northern Beaufort, ***Norwegian Bay Convergent (new designation)***
(Arctic) Archipelago	Much of this region is characterized by heavy annual and multiyear (perennial) ice that historically has filled the interisland channels year-round. Polar bears remain on the sea ice, therefore, throughout the year.	Kane Basin, Norwegian Bay, Lancaster Sound, Viscount Melville, M'Clintock Channel, Gulf of Boothia
Seasonal Sea Ice	Sea ice melts entirely in the summer and bears are forced ashore for extended periods of time during which they are food deprived.	Baffin Bay, Davis Strait, Foxe Basin, Southern Hudson Bay, Western Hudson Bay

Table 2 Suggested monitoring intensities for polar bear subpopulations. The alternative terms could be helpful as an alternative way to visualize the different monitoring regimes.

Monitoring intensity	Alternative terms	Description of monitoring
High	Continuous	Ideally, there should be at least one high intensity subpopulation within each ecoregion to serve as major reference point which could, facilitate projection of likely trends in other subpopulations for which there may be less information. A high rank is based on the quality of historical quantitative baseline data, perceived threats, and (wherever possible) lower logistical costs for continued monitoring. Reference value also pertains, to geophysical and geopolitical considerations such as protected areas, ongoing or expected industrial development, or harvest, and the degree to which they might have predictive value for trends in other subpopulations in the same ecoregion. An individual subpopulation may not rank high in each category of data needed.**
Medium	Adaptive[*]	Subpopulation that also may have been subjected to periods of intense study although for shorter time periods, or which have been subjected to moderate levels of ongoing monitoring, so that there are reference data against which the results of new studies could be evaluated. It is suggested that subpopulation is monitored within an adaptive framework (see section 3.5).
Low	Opportunistic	Because of remoteness, and lower likelihood of securing resources to monitor more intensively, it may only be possible to conduct basic and more easily collected metrics in a low intensity population. Monitoring efforts will be less frequent, more opportunistic, and at a lower level of intensity. Application of remote (e.g., satellite) technology may be particularly helpful. Note that this categorization does not necessarily reflect a lower severity of threats to the subpopulation.

[*] see section 3.4
[**] see Table 3a

Table 3a
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Eco-region	Subpopulation	Quality of baseline data	Risk from climate change	Pollution	Harvest	Poaching	Industry	CBM and/ or harvest data	Access	Shared jurisdic-tion
DIVERGENT	Barents Sea	High	High	High	No	No	Low	Low	High	Yes
	Chukchi Sea	Medium	High	Low	Yes	Yes	High	High	Medium	Yes
	Kara Sea	Low	High	High	No	Yes	High	Low	Low	No
	Laptev Sea	Low	High	Low	No	Yes	Low	Low	Low	No
	Southern Beaufort Sea	High	High	Low	Yes	No	High	High	High	Yes
CON-VER-GENT	East Greenland	Medium	High	High	Yes	No	Low	High	Low	No
	Northern Beaufort Sea	Medium	Medium	Medium	Yes	No	Low	High	High	No
ARCHIPELAGO	Gulf of Boothia	Medium	Low	Low	Yes	No	Low	High	High	No
	Kane Basin	Medium	?	Low	Yes	No	Low	High	Medium	Yes
	Lancaster Sound	Medium+	Medium	Low	Yes	No	Low	High	High	No
	M'Clintock Channel	Medium	Low	Low	Yes	No	Low	High	High	No
	Norwegian Bay	Medium	Low	Low	Yes	No	Low	Low[1]	Medium	No
	Viscount Melville	Medium	Low	?	Yes	No	Low	Medium	Medium	No
SEASONAL	Baffin Bay	Medium+	High	Low	Yes	No	Medium	High	High	Yes
	Davis Strait	Medium+	High	Low	Yes	No	Low	High	High	Yes
	Foxe Basin	Medium	Medium	Low	Yes	No	Medium	High	High	No
	Southern Hudson Bay	Medium+	High	Low	Yes	No	Low	High	High	No
	Western Hudson Bay	High	High	Low	Yes	No	Low	High	High	No
	Arctic Basin	Low	High	?	No	?	Low	Low	Low	Yes

[1] CBM not practical, but harvest monitoring possible

Table 3a Attributes (described in Table 3b) of the subpopulations that were considered in determining monitoring intensity of 19 subpopulations based on PBSG (2010) and Vongraven and Peacock (2011). The table follows the region and subpopulation designations in PBSG (2010) and Amstrup et al. (2008), and assessments made are all expert opinions (see Section 1.2.2). The *ad hoc* subpopulation Norwegian Bay Convergent (NWCon) has not been added here.

Table 3b
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Attribute	Description	Possible responses
Quality of baseline data	The relative level of existing scientific information from past population monitoring; incorporates duration, intensity, and currency of existing data	High, Medium+, Medium, Low
Risk of climate change	The relative current and/or imminent negative impact of climate warming on polar bears and their sea ice-habitat	High, Medium, Low, or unknown (?)
Pollution	The relative, known-levels of toxic contaminants in polar bears	High, Medium, Low, or unknown (?)
Harvest	Are polar bears legally harvested?	Yes or No
Poaching	Is the level of illegal harvest a conservation concern?	Yes, No or unknown (?)
Industry	The current and imminent level of industrial development (marine, terrestrial, shipping)	High, Medium, Low
CBM/harvest data	The current or potential level of access for collection of harvest data and samples and/or community-based monitoring	High, Medium, Low
Access	The relative level of access for scientific research (includes consideration of costs, infrastructure and remoteness)	High, Medium, Low
Shared jurisdiction	Is the subpopulation shared between international jurisdictions?	Yes or No

Table 3b Descriptions of attributes of polar bear subpopulations used in determining monitoring intensity (Table 3a).

Table 4 Recommended monitoring intensities of the 19 subpopulations of polar bears, and presentation of which deciding factors were most crucial for categorizing research/monitoring intensities. See Table 3a and 3b for a comprehensive listing of all threats to subpopulations, and all considerations for research and monitoring of each subpopulation.

Eco-region	Subpopulation	Recommended monitoring intensity	Deciding factors for level of monitoring intensity
DIVERGENT	Barents Sea	High	High quality baseline data; high risk of climate change; good research access; high pollution levels
	Chukchi Sea	Medium	Poaching; harvest is locally important; high risk of climate change; moderate research access; shared international jurisdictions; high industrial development
	Kara Sea	Low	Poor research access
	Laptev Sea	Low	Poor research access
	Southern Beaufort Sea	High	High quality of baseline data; harvest locally important; high industrial development; high risk of climate change; good research access
CONVERGENT	East Greenland	Medium	Poor quality baseline data; high harvest; poor research access
	Northern Beaufort Sea	Medium	Good long-term research data base. Harvest is locally important; good research access
	Norwegian Bay Convergent*	High	Not an acknowledged subpopulation (former Queen Elizabeth); represents future refugia; low research access and poor baseline data
ARCHIPELAGO	Gulf of Boothia	Medium	Good research access; harvest locally important
	Kane Basin	Medium	Harvest locally important; unknown risk of climate change; moderate research access
	Lancaster Sound	High	Representative of Archipelago ecoregion with good research access; good long-term, but uneven, research data base; industrial development; harvest locally important; good baseline data
	M'Clintock Channel	Medium	Climate effects not as dramatic; harvest locally important; good research access
	Norwegian Bay	High	Climate effects not as dramatic; predicted future refugia; moderate research access and

			baseline data
	Viscount Melville	Medium	Climate effects not as dramatic; moderate research access and baseline data
SEASONAL ICE	Baffin Bay	Medium	Harvest locally important; high risk of climate change; good baseline data; shared international jurisdictions
	Davis Strait	Medium	Harvest locally important; high risk of climate change; good baseline data
	Foxe Basin	Medium	Harvest locally important; moderate baseline data and risk from climate change
	Southern Hudson Bay	Medium	Harvest locally important; good baseline data; high risk of climate change
	Western Hudson Bay	High	High quality baseline data; high risk of climate change; harvest locally important
	Arctic Basin	Low	Poor research access

* not an acknowledged subpopulation at present (PBSG 2010)

Table 5
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Table 5 Methods and frequencies for monitoring of subpopulation abundance in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	Intensity	Priority	Frequency	Comment
Physical M-R Genetic M-R Genetic M-R combined with aerial survey methods (MRDS or stripsampling)	H	Essential	Annually or for at least 3 year periods at 5 year intervals	Physical M-R require handling of bears, which provides indirect measures and indices of population status (e.g. sex and age composition, physical condition) that can be compared to lower intensity areas where only indirect methods may be available. Genetic M-R does not require handling bears but, because of that, does not provide physical assessments or complete sex and age composition information.
	M	Essential	Based on threat level	
Indirect population assessments and indices (that may be accomplished by CBM). Harvest based inference.	H	Essential	Annually or at least every 5 years	High intensity methods must be accompanied by lower intensity methods (some of which are best accomplished by applying CBM). Accomplishing these in parallel with higher intensity methods in high intensity monitoring areas is essential for calibration of lower intensity methods in subpopulation areas that may only receive lower-intensity monitoring.
	M	Essential	Based on threat level	Indirect population assessments and indices available from CBM and other lower intensity efforts are essential in populations that are not monitored with high intensity. Methods must be comparable to indirect assessments from high intensity areas.
Standardized visual observations and other indirect population assessments and indices that may be accomplished by CBM. Harvest-based inference.	L	Essential	Annually or as frequently as possible	Where more intense methods not possible, the best possible standardized effort must be made for indirect assessments. Methods must be comparable to indirect assessments from high intensity areas. Genetic M-R may be possible with community-based initiatives. High frequency to compensate for the potential for bias and imprecision in these indices, and the need for calibration requires they be conducted yearly or as frequently as possible.

Notes on Table 5

There is also a need for a power analysis of existing data to assist in finding an optimal sampling scheme for polar bear subpopulation size and trend (see Priority study #1: section 7.2).

Table 6
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Table 6 Methods and frequencies for monitoring of trend in subpopulation abundance in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears. The subpopulation trend is the same as the subpopulation growth rate (λ), and is assessed by many of the same methods as subpopulation size.

Recommended method	Intensity	Priority	Frequency	Comment
Repeated measurements of subpopulation size from mark recapture (M-R) or aerial surveys.	H	Essential	Annually or for 3 year periods at intervals of every 5 years	Individual abundance estimates must have sufficient precision to detect changes over time.
	M	Essential	A lower level but quantitative effort at 5 year intervals	
PVA from M-R data	H	Highly useful	Whenever possible	Vital rates estimates from M-R are less biased and partly independent of estimates of N, PVAs (projections based on vital rates) provide a view of growth rate that is different than estimates from observed changes over time. PVAs therefore should be constructed whenever essential data are derived. Even in areas where repeated estimates of N are not available, estimates of vital rates may be available (if not from M-R, perhaps through population reconstruction from harvest data). Caution must be exercised when projecting into the future, depending on the level of climatic disruption to sea ice expected.
	M	Highly useful	Based on threat level	
Population reconstructions from sex and age composition, other harvest inferences. Visual observations or track counts from snow machine, ATV, boat or dog-team. Repeated visual observations at known concentration sites, genetic material (e.g., hair) gathered at corrals day beds or dens, and repeated den surveys.	H	Essential	Annually or as frequently as possible	Necessary to calibrate methods to be used in less intensely studied subpopulations, in circumstances where available information may be extensive and reliable enough to possib ly provide an index to trend in numbers.
	M	Essential	At least every 5 years	
Visual observations or track counts from snow machine, ATV, boat or dog-team;	L	Essential	Annually or at least	These methods, some of which may be accomplished with CBM, must take advantage of the calibration accomplished

Repeated visual observations at known concentration sites, genetic material (e.g., hair) gathered at corrals day beds or dens, and repeated den surveys.			every 5 years	by conducting them simultaneously with higher intensity methods in high and medium intensity areas. Development of a realistic design that can be carried out in the circumstances is critical, as is adherence to it. Must be coordinated with higher intensity methods if and when available. The lower the intensity of effort, the higher the frequency of performance required for meaningful information on trend. Strive for frequencies that will support the ability to extrapolate from higher intensity monitoring areas to lower intensity areas.

Notes on Table 6

Life-table approaches need to be revisited to determine their contribution to understanding trends in abundance in high and lower intensity areas.

Lower intensity methods, such as track counts, visual observations and harvest monitoring, recorded annually and standardized can be compared to high intensity methods to assess their value for assessing trend in areas where only these methods are available.

Table 7
Click here to download Table: Table07.docx

Table 7 Methods and frequencies for monitoring of polar bear reproduction in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears. In this table, "cubs" refer to spring cubs-of-the-year.

Recommended method	**Intensity**	**Priority**	**Frequency**	**Comment**
Litter produced rate or Litter production rate	H,M	Essential	Annually if possible	Litter produced rate = No. of cubs per adult female per year (Stirling et al. 1980), or Litter production rate = No. of cubs per adult female available to mate (Taylor et al. 1987a). This metric is critical for population modeling.
Interbirth interval	H,M	Essential	For a statistically significant sample size of adult females	Valuable for detection of short and long term environmental changes.
Reproductive success	H	Helpful	As frequently as possible	No. of cubs weaned gives potential for recruitment.
Litter size	H,M,L	Helpful	As frequently as possible	Cubs per litter is relatively insensitive but consistently low values are a warning sign.
Age of first reproduction	H,M	Helpful	Based on threat level	For females. Limited value for assessment of changes in the short term.
Den abundance	H,M,L	Useful	Based on threat level	No. of dens in a defined area.
Reproductive senescence	H	Helpful	Whenever possible	Metric of long-term health of population.
Infanticide	H,M	Helpful	As frequently as possible	Low monitoring value because of opportunistic nature of observations.
Pregnancy rates	H	Highly useful	As frequently as possible	% of lone adult females also an indicator of reproductive failure or cub mortality.
Mating ecology	H	Helpful	As frequently as possible	Ratio of adult males to breeding females can be indicative of effects of harvest.

Table 8 Methods and frequencies for monitoring of polar bear survival in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears. The subpopulation trend is the same as the subpopulation growth rate (λ), and is assessed by many of the same methods as subpopulation size.

Recommended method	Intensity	Priority	Frequency	Comment
M-R survival estimation	H,M	Essential	Based on threat level	The most reliable method available
Survival of radio-collared bears	H,M	Highly useful	Based on threat level	A large sample needs to be monitored to obtain statistical validity. Only appropriate for adult females.
Litter/cub loss and cohort survival	H,M	Essential	Based on threat level	Requires annual sighting of tagged or radio-collared adult females females
No. of cubs, yearlings, and 2-year olds per adult female	H,M	Essential	Based on threat level	From capture data, and from CBM to be compared with capture data
	L	Essential	As frequently as possible	From CBM. Proportion of family groups observed.
Age structure from teeth	H,M	Highly useful	Based on threat level	From harvested or captured individuals
	L	Highly useful	As frequently as possible	From harvested (or killed) animals for life-table type analyses. No harvest in any subpopulation monitored with low intensity at present.
Examination of cohort strengths	H,M	Highly useful	Based on threat level	From capture or harvest data
	L	Highly useful	As frequently as possible	From harvest data, although there is no harvest in any subpopulation monitored with low intensity at present.
Age categories of bears visually observed	L	Helpful	Whenever possible to obtain sufficiently large number of observations	

Notes on Table 8

Age structure analyses (e.g., life table approaches) need to be revisited for their ability to assess trends and to facilitate comparisons between high and lower intensity study areas.

Table 9
Click here to download Table: Table09.docx

Table 9 Methods and frequencies for monitoring of habitat and ecosystem change in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	**Intensity**	**Priority**	**Frequency**	**Comment**
Use satellite imagery to measure seasonal ice cover over the continental shelf, length of time ice is away from shelf waters, and the distance of retreat from the shelf.	H,M,L	Essential	Annually or as frequently as possible	Because satellite imagery of sea ice is available throughout the Arctic, this method can be used in all regions regardless of sampling intensity of the polar bear subpopulation. This is probably the most valuable, comparable, and attainable index of habitat change.
Resource Selection Functions (RSFs)	H	Essential	Annually or as frequently as possible	RSFs should be conducted in all subpopulations where sufficient (i.e., multiyear to multi-decadal) data on annual movements of polar bears are collected, i.e. from satellite telemetry, observations (e.g. aerial surveys) and satellite-based environmental data.
	M	Highly useful		As for high-intensity, except that RSFs could be extrapolated from RSFs previously created or from RSFs developed in other regions.
	L	Helpful		Delineate optimal habitat through RSFs developed in other regions. There will be greater uncertainty in habitat estimates done with this method..
Monitor links between changes in sea ice habitat and a variety of physical factors (temperature, circulation etc.). Link to information of other scientific metrics (e.g., primary productivity).	H,M	Highly useful	Annually or as frequently as possible	Quantification of links between polar bear habitat and physical/biological oceanography will necessarily be multidisciplinary and require modeling.
	L	Helpful		
Survey denning distribution and changes in coastal habitats. Determine the amount of denning habitat impacted by industrial or other human activities through	H	Highly useful	Annually or as frequently as possible	Maternal den habitat distribution and likely duration of den tenure can be determined with radio-telemetry in intensively monitored subpopulations.

scientific and CBM observations.	M	Helpful		An understanding of the distribution of snow-catching topography, as a proxy for den distributions, will be necessary, due to determination of potential den habitat distribution and tenure being more difficult to assess in less intensely monitored subpopulations..
Determine denning distribution and changes in coastal habitats through CBM.	L	Helpful		Monitoring of den habitat may be possible only through CBM or through mapping of likely snow-catching features.
Document invasive or unusual species occurrence through scientific and CBM observations.	H,M,L	Helpful	Annually or as frequently as possible	Anecdotal observations may provide one of the first clues that polar bear food webs, and therefore habitats, are changing.
Use satellite imagery to measure snow accumulation and persistence.	H,M,L	Helpful	Annually or as frequently as possible	Snow is essential for polar bear maternal dens and ringed seal lairs. Current satellite imagery of snow is coarse-grained so may be limited is usefulness.

Notes for Table 10

Caution should be used when extrapolating movement data and RSFs from a subpopulation monitored with high intensity to all other subpopulations in the ecoregion.

Table 10 The quality of baseline data and sampling of the legal harvest of polar bears, and the relative level of threat due to harvest for the 19 circumpolar subpopulations of polar bears.

Subpopulation	Quality of baseline harvest data and sampling	Relative threat due to harvest
Arctic Basin	Not applicable	Low
Baffin Bay	Can be improved; sampling strategy to be improved in Greenland[1,2]	Subpopulation is considered to be declining due to level of harvest[3]
Barents Sea	Not applicable	None
Chukchi Sea	Moderate data quality in the U.S., sampling can be improved; No data or sampling for illegal harvest in Russia.	A new legal quota has been proposed in the short term if it can be implemented, although considerable uncertainties exist due to data deficiencies
Davis Strait	Can be improved[4]	Low[5]
East Greenland	Can be improved; sampling strategy to be developed[2]	Sustainability of harvest is unknown as subpopulation is considered data deficient[6]
Foxe Basin	Have improved recently[7]	Sustainability of harvest is unknown as subpopulation has been considered data deficient for population growth[3].
Gulf of Boothia	High	Low[4]
Kane Basin	Can be improved; sampling strategy to be developed in Greenland[1]	Subpopulation is considered to be declining due to level of harvest[8]
Kara Sea	Not applicable	Poaching level unknown
Lancaster Sound	High	Subpopulation is considered to be declining due to sex-ratio and level of harvest[6]
Laptev Sea	Not applicable	Poaching level unknown
M’Clintock Channel	High	Low[6]
Northern Beaufort Sea	High	Low[9]
Norwegian Bay	High	Subpopulation is considered to be declining due to level of harvest and stochasticity associated with small size[4]
Southern Beaufort Sea	Data quality moderate, sampling	Harvest mortality is in addition

	can be improved in the U.S.	to the negative natural population growth rate[10].
Southern Hudson Bay	Can be improved[4]	High. Recent harvests in Quebec (2009-2012) have resulted in total harvest from this subpopulation exceeding sustainable levels[11]
Viscount Melville	High	Sustainability of harvest is unknown as subpopulation is considered data deficient[6]
Western Hudson Bay	High	Harvest mortality is in addition to the negative natural population growth rate [8,12]

1 High quality of harvest data and sampling in Canada

2 Catch reporting has been improved in Greenland since 2006 quota were introduced,

3 Aars et al. 2006, Obbard et al. 2010

4 High quality of harvest data and sampling in Nunavut, Canada, but can be improved in Quebec (Davis Strait, Foxe Basin, Southern Hudson Bay), Ontario (Southern Hudson Bay) and Newfoundland and Labrador (Davis Strait)

5 Peacock et al. in review

6 Obbard et al. 2010

7 Stapleton et al. 2011

8 Taylor et al. 2009

9 Stirling et al. 2011

10 Hunter et al. 2010

11 M. Obbard, unpublished data

12 Regehr et al. 2007

Table 11 Harvest data and samples recommended for circumpolar monitoring of harvested polar bears. These data and samples can be used to describe the harvest in the 19 subpopulations, regardless of their population monitoring intensity. These data can also be included in evaluations of population status and for ecological research. Adapted and updated from Vongraven and Peacock (2011: Tables 2 and 3).

Metric or sample	Priority for monitoring	Description
Data and samples to be collected by hunter, government or community representative		
Number	Essential	Annual total number of human-caused mortalities for each subpopulation.
Type of human-caused mortality	Essential	Regulated (legal), illegal, defense, sport or research kill.
Sex	Essential	Sex of harvested bear. Baculum and/or tissue sample for genetic analysis can be required for proof of sex.
Field class	Highly useful	Adult, subadult, dependent cub (cub-of-the year, yearling or two-year old) and reproductive status (encumbered or unencumbered adult female).
Lower premolar tooth	Highly useful	Analysis of cementum growth layers for age.
Lip tattoo or ear-tag number	Essential	Individual identity number used in scientific research. These data are used in mark-recapture population modelling, population growth analysis, and distribution analysis.
Skull morphometrics	Helpful	Skull length, zygomatic breadth.
Body condition	Highly useful	1-5 index, axillary girth measured by rope, fat thickness at predetermined point.
Fat sample	Highly useful	Fatty-acid diet analysis, analysis of lipophilic contaminants, body condition
Tissue sample	Helpful	Genetic individual identification, genetic sex identification, stable-isotope diet analysis.
Hair sample	Helpful	Stable-isotope diet analysis,

		contaminant analysis, cortisol analysis.
Location of harvest	Helpful	Latitude/longitude and written description.
Mode of conveyance	Helpful	Boat, ATV, dog sled, snow machine, on foot.
Distance travelled	Helpful	Kilometers travelled to harvest bear or 'at camp or village'. This information is useful only when a catch-per-unit-effort study is carefully designed.
Collective statistics compiled by management agency		
Sex-ratio of harvest	Essential	Sex-ratio of the harvest is important for assessment of population growth and past and current influences of harvest and to understand selectivity of the harvest.
Age-structure of harvest	Highly useful	Age-structure of the harvest is important for assessment of population growth, past and current influences of harvest, and to understand selectivity of harvest.
CITES permits issued, hides auctioned, sport hunts	Helpful	This information is important to understand the extent of commercial use of polar bears.

Table 12
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Table 12 Methods and frequencies for monitoring of human-bear conflict in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears (PBHIMS = Polar Bear Human Information Management System).

Recommended method	**Intensity**	**Priority**	**Frequency**	**Comment**
Documentation of conflicts (cf PBHIMS)	H,M,L	Essential	Continuous recording and monitoring	H: Compilation, analysis and interpretation of data no less than yearly. M: Yearly compilation, analysis, and interpretation of current data. Begin compilation of archival data for analysis in 2-3 years. L: Compilation, analysis, and interpretation of current and archival data as frequently as possible.
Organize and analyze historic polar bear-human conflict data from archives and then maintain up-to-date records	H,M,L	Essential		
Investigate historic and current patterns of polar bear-human conflicts to address specific bear management and conservation issues.	H,M,L	Highly useful		
Monitoring at village, industrial site, vessel, and tourism levels	H,M,L	Highly useful		

Notes on Table 12

Human-bear conflicts can theoretically be monitored throughout the range of polar bears through normal reporting from communities and required reporting/monitoring at industrial sites, tourist activities, and vessel traffic.

Table 13
Click here to download Table: Table13.docx

Table 13 Methods and frequencies for monitoring of polar bear distribution in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	**Intensity**	**Priority**	**Frequency**	**Comment**
Use satellite radio telemetry data to delineate subpopulation distribution	H,M	Essential	Based on threat level	Requires multiyear to multi-decadal satellite telemetry data of subpopulations
Distribution estimated from RSFs	H,M	Highly useful	Based on threat level	RSFs derived from satellite telemetry data. The RSF distribution is a useful estimate of subpopulation distribution.
	L	Helpful	Annually or as frequently as possible	RSFs derived from other subpopulations, which will increase uncertainty. High frequency in subpopulations monitored with low intensity to maximize ability for calibration/validation.
Tag recovery, visual survey, genetic survey, CBM, aerial/ground/CBM den observations	H,M	Helpful	Based on threat level	All are limited by spatial and temporal extent of field efforts. High frequency in subpopulations monitored with low intensity to maximize ability for calibration/validation.
	L	Helpful	Annually or as frequently as possible	
Systematic observations from ship traffic (tourism, industry, research) in the Arctic	H,M	Helpful	Based on threat level	
	L	Helpful	Annually or as frequently as possible	

Table 14 Methods and frequencies for monitoring of polar bear prey distribution and abundance in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	Intensity	Priority	Frequency	Comment
Fat sample from harvested bears or those sampled by biopsy dart, or captured for mark-recapture studies	H,M	Essential	Either annual or multiyear intervals, based on threat level	Collection of specimens from the maximum number of samples is critical. Fat samples can be analyzed using stable isotopes and fatty acid analysis to quantify diet content and change over time.
Samples from prey found killed by polar bears (skin, fat, tooth; length, girth, fat thickness where possible)	H,M,L	Essential	Opportunistic	Specimens collected from all seals found killed by bears during field work facilitate real time quantification of hunting success, habitat use, tabulation of age, sex, and condition of species killed, degree of utilization and scavenging.
Tooth from harvested seals	H,M,L	Highly useful	Opportunistic at low levels but minimum 100/yr where large numbers are harvested	Age-structure of the harvest is important for assessment of health and productivity of prey population.
Satellite and aerial photos and reports from hunters on ice	H,M	Highly useful	Opportunistic	Quantify changes in fast ice break-up etc. in relation to availability or abundance of prey, movements or travel of polar bears, and effects on ability of hunters to travel and have success in hunts; mainly only useful when applied to focused studies in defined areas.
Aerial surveys	H,M	Highly useful	Opportunistic, largely dependent on availability of funding	Repetition of past aerial surveys will provide important information on change, or lack of it, in distribution, abundance, and habitat use over time. Important to establish new baselines in areas defined as important to facilitate future comparisons.
CBM-Hunter questionnaires	H,M	Helpful	Opportunistic	Identify impressions from persons familiar with the area that will aid in identification of possible changes and subsequent design of quantitative studies to address

				specific questions.
Fecal samples	H,M,L	Helpful	Opportunistic	Allows identification of prey from hair samples; will aid confirmation of prey taken at specific location and relative time.

Notes to Table 14

There is a need to conduct area-specific calibration of fatty acid and stable isotope techniques.

Table 15
Click here to download Table: Table15.docx

Table 15 Methods and frequencies for monitoring of polar bear health in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears. There is currently no harvest or capture effort in any of the subpopulations suggested to be monitored with low intensity.

Recommended method		Intensity	Priority	Frequency	Comment
Captured bears	Mass and straight-line body length – Body Condition Index	H,M	Essential	Annually	BCI can be used to compare changes in body condition within subpopulations over time, or among subpopulations
	Axillary girth and zygomatic width		Essential	Annually	Can be used to predict mass provided subpopulation-specific predictive equations are developed and checked periodically to determine whether morphometric relationships have changed
	Condition scale 1-5 (1 vs 2 scale for aerial observations)		Essential	Annually	Useful method to monitor body condition when morphometric measurements are not available
	Stress levels (hair cortisol concentration)		Highly useful	When possible	More research needed, but technique shows promise
	Pathogens and contaminants in blood feces		Highly useful	Every 5 years	Periodic monitoring to detect changes in prevalence or new emerging pathogens, and to monitor trends on contaminant burdens
	Fat content from biopsy		Highly useful	When possible	More research needed, but may have potential to monitor body condition
	Bioelectric Impedance Analysis		n/a	n/a	Requires mass as input. Only where research interest warrants until measurement issues are resolved
Harvested bears	Axillary girth; Skull length and width	H,M	Essential	Annually	Must be newly harvested bears. Can be used to predict body mass
	Condition index assessed by hunters (1-5)		Essential	Annually	Hunters could be provided with plasticized 'score card'. Useful method to monitor body condition when morphometric measurements not available

	Fat thickness at predetermined popjntspoints, and fat content from samples collected at harvest		Highly useful	Annually	Measurement easily taken by hunters
	Contaminants in fat tissue of various organs		Essential	Every 5 years	Samples highly important to monitoring programs
	Stress levels (HCC) from hair samples		Highly useful	When possible	From handled or harvested bear, or from hair traps

Notes for Table 15

Health indices may be most effectively monitored with an international perspective which has already been the case with several contaminant studies (e.g., Norstrom *et al.* 1998, Smithwick *et al.* 2005, Muir *et al.* 2006, Sonne 2010, McKinney *et al.* 2011, "Bear-Health"-program under the International Polar Year http://biologi.no/bearhealth-eng.htm).

Standardized monitoring for diseases and contaminants is necessary to make regional and global comparisons.

Because condition index values may relate directly to the lipid content of adipose tissue, there is a need to further explore this relationship. In addition, there is a need to coordinate fat collection for condition assessment (e.g., linking with other monitoring programs for contaminants).

The significance of variation in hair cortisol levels among bears from different subpopulations is being investigated (e.g., Bechshøft *et al.* 2011; Macbeth *et al.* 2011). This may be an appropriate monitoring method to assess relative stress in handled versus non-handled bears, or to compare general stress levels among subpopulations exposed to different levels of human contact.

Table 16 Body stature metrics

Stature metrics	Description
Skull (zygomatic) width	Maximum head width between the zygomatic arches measured with a set of calipers to the nearest millimeter.
Skull length	Straight-line length from between the upper middle incisors at the gum line to the most posterior dorsal skull process of the sagittal crest measured to the nearest millimeter with a set of calipers.
Straight line body length	Dorsal straight-line distance from the tip of the nose to the caudal end of the last tail vertebra measured to the nearest centimeter with a tape held over the midline of a bear's body. Note the bear should be stretched out in a sternally recumbent positing and the tape should not touch the bears back when taking the measurement.
Axillary girth	The circumference around the chest at the axilla with a small diameter rope (e.g., 0.5 cm) tightened with a tension of about 0.5 kg measured to the nearest centimeter.
Body mass	The mass of bear measured to nearest 100 grams for cubs-of-the year and to the nearest kilogram for bears of all other age classes using a reliable and frequently calibrated scale.

Table 17 Methods and frequencies for monitoring of polar bear stature in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	**Intensity**	**Priority**	**Frequency**	**Comment**
Skull length and width, straight line body length, axillary girth and body mass	H,M	Essential	Ongoing	Measurements from live and harvested bears. No current harvest in any of the subpopulations monitored at low intensity.
Measurements from skeletal material in museum collections where possible	H,M,L	Highly useful	Ongoing	

Table 18
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Table 18 Methods and frequencies for monitoring of human activity in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears. In many cases, community-based monitoring can be an effective approach for monitoring local levels of human activity.

Recommended method	Intensity	Priority	Frequency	Comment
Monitor actual exploratory and development activities (e.g., number of drill or production sites), numbers of ship passages, or tour ship cruises.	H,M,L	Essential	Ongoing, reported annually	Level of all human activities occurring need assessment in order to determine cumulative impacts.
Monitor permit applications: exploratory and development activity, ship passages, research (non-polar bear) permits.	H,M,L	Essential	Ongoing, reported annually	Indicates level of human activity that may occur.
GIS calculations of how much of available habitat is impacted by industrial or other human activities.	H,M,L	Very useful	Reported annually	Quantifies extent of human activities.
Develop a system of recording incidents of bear human interactions resulting from various kinds of human activities in polar bear habitat (cf PBHIMS).	H,M,L	Very useful	Ongoing, reported annually	Quantifies direct impacts on polar bears (cf Table 12)
Study impacts of supplemental feeding.	H,M,L	Helpful	Opportunistic	Significance of one potential impact.

Notes for Table 18

Monitoring levels are the same for all subpopulations because these activities are not necessarily limited by the same constraints that may make detailed polar bear research unlikely in some areas. Many can be assessed by remote sensing and regulatory requirements to file paper work and work plans.

Table 19 Methods and frequencies for monitoring of behavioral change in polar bears in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	Intensity	Priority	Frequency	Comment
Seasonal movements and home range sizes	H,M	Essential	3-5 year sets of observations at 5 year intervals	Quantification of changes, or lack of them, in seasonal movement patterns and home range size will provide critical information on behavior of bears in relation to changes in habitat, ice conditions, and/or prey availability.
Location and time of den entrance and exit	H,M	Essential	3-5 year sets of observations at intervals of 5 years or more	Changes in these parameters will indicate large scale changes in habitat and be influenced by the body condition of females (hunting success and duration of hunting in relation to breakup) over time.
	L	Highly useful	Opportunistic	
Visual observations	H,M,L	Highly useful	Opportunistic	Visual observations of changes in distribution and habitat use, observations of unusual hunting strategies, taking of alternate prey, erratic and anomalous behaviors (e.g., cannibalism, digging through ice) identify significant changes on the part of the bears. Such observations may facilitate design studies to quantitatively address specific questions.
Documentation of problem bear encounters	H,M,L	Highly useful	Opportunistic	Quantification and description of problem bear attacks may facilitate greater understanding of how changes in the environment (particularly ice) influence increases or decreases in this activity.
Occurrence of hybrids	H,M,L	Helpful	Opportunistic	Occurrence of hybrids in a particular area over time may indicate changes in the behaviour of polar and brown bears as a result of environmental change in habitats; will only occur in areas where the ranges of the two species overlap.

Table 20
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Table 20 Methods and frequencies for monitoring of TEK of polar bears in (H)igh-, (M)edium-, and (L)ow-intensity monitored subpopulations of polar bears.

Recommended method	Intensity	Priority	Frequency	Comment
Questionnaires with in-person discussion, semi-direct interviews.	H	Essential	Annually where needed, otherwise at regular intervals as required	Questionnaires need to be user friendly, not too long and well designed, and translated into local language and dialect. Timing post harvest season, during sea ice break-up and freeze-up. Schedule needs to be determined with the communities to be in-sync with knowledge collection.
Questionnaires – mail out, email and/or web-based.	M	Essential	Annually	Timing appropriate for the region in question. Schedule needs to be determined with the communities to be in-sync with knowledge collection.

Notes for Table 20

Note, the level of intensity of TEK monitoring do not parallel those levels identified for scientific monitoring. TEK cannot be monitored at low intensity due to the nature of the data and the often remote locations of communities.