CIRCUMPOLAR
POLAR BEAR MONITORING PLAN

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SOME ABBREVIATIONS

ATV	All Terrain Vehicle
BIA	Bioelectric Impedance Analysis
CAFF	Conservation of Arctic Flora and Fauna
CBM	Community-based Monitoring
CBMP	Circumpolar Biodiversity Monitoring Program
IUCN/SSC	Species Survival Commission of the International Union of the Conservation of Nature
M-R	Mark-Recapture (or Capture/Mark-Recapture)
MRDS	Mark-Recapture Distance Sampling
PBHIMS	Polar Bear-Human Information System
PBSG	Polar Bear Specialist Group of the IUCN Species Survival Commission
PVA	Population Viability Analysis
RSF	Resource Selection Function
TEK	Traditional Ecological Knowledge

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1. INTRODUCTION

Because polar bears live in extreme, remote environments, they are costly to study, and few jurisdictions have devoted 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). Our goal here is to develop a framework for an integrated circumpolar monitoring plan that will help to coordinate monitoring and research with the goal of improving the ability to detect ongoing patterns, predict future trends, and identify the most vulnerable subpopulations.

Polar bears (*Ursus maritimus*) are dependent upon Arctic 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 (PBSG 2010). Arctic sea ice extent is linearly related to global mean temperature, which in turn, is directly related to atmospheric greenhouse gas concentrations (Amstrup et al. 2010). Therefore, without greenhouse gas mitigation, no polar bear populations will be sustainable 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). Similarly, projections of future sea ice change differ among subpopulations and regions (Perovich and Richter-Menge 2009). It is reasonable to hypothesize that polar bears living in historically colder regions of the Arctic might derive transient benefit from a milder climate (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 backdrop for future polar bear monitoring. Habitat loss is not the only threat to the future welfare of polar bears, however. Previously, the greatest single threat to polar bears was considered to be over harvest (Taylor et al. 1987; Larsen and Stirling 2009). Although continuing habitat loss precludes long-term sustainability, many polar bear populations could provide a harvest that is sustainable in the short run-even in the face of continued warming. Therefore, management still must attempt to assure a balance between potential yield and take. Harvest is currently thought to be excessive in some populations, balanced with current yield in some, and its impact is largely unknown in others. In many cases harvest documentation and the population data necessary to assess the impact of harvest both are insufficient to allow managers to provide the desired balance between potential yield and take. 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 critical part of management and therefore is a high priority for any future monitoring.

The global rise in contaminants also is a factor in monitoring the future welfare of polar bears. Although polar bears live in relatively untrammeled 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 are known to vary among regions (e.g. McKinney et al. 2011). More importantly, even where contaminant burdens may be known, the effects of contaminants on polar bear physiology and health are not well understood (Sonne 2010). The potential for contaminants to impact Arctic systems is predicted to increase as climate warming alters global circulation and precipitation patterns (McDonald et al. 2005) and 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 any monitoring plan.

Industrial activities in the Arctic have been increasing and are expected to continue to increase as the world's population demands ever more mineral and hydrocarbon resources. Significant portions of the polar bear's range already are being developed and exploration is proposed for many other areas. With warming induced sea ice decline, previously inaccessible areas will be exposed to development. The direct effects of human activities, the increased potential for negative human-bear encounters, and the potential for increased local pollution are all concerns that must be monitored if we are to understand and manage these impacts on the future for polar bears.

As human populations grow and their distributions change, due to increased access to previously isolated areas, polar bears will face increased risks from a variety of bear-human interactions. New settlements are likely, and expansion of tourist visitations is assured. Although the fact of bear-human interactions can be reasonably measured, we have a long way to go to understand the effect of such interactions. The role added stresses, resulting from a "more crowded" Arctic, may play in the future welfare of polar bears must be considered in future monitoring.

As we are becoming increasingly aware of the coming changes in the Arctic, we also are poignantly aware of our information shortcomings. The current understanding of polar bears and their reliance on sea ice habitats is the result of long-term monitoring that has been conducted in only a few subpopulations, and therefore likely represents an incomplete understanding of the complex ecological ramifications of climate change and other stressors. Sustained long-term monitoring across the polar bear range will be necessary to understand ongoing effects of climate warming and the many other population level stressors about which we are concerned. The circumpolar dimension can be lost if local monitoring efforts do not provide information that can be compared among regions. 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.

The importance of coordinated monitoring was emphasized by the Parties to the 1973 Agreement on the conservation of polar bears at their meeting in Tromsø in 2009. The final report from the meeting states: "The parties 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.

This document represents the first circumpolar monitoring plan for polar bears and is the result of a CAFF/CBMP[1] initiative funded by the US Marine Mammal Commission. A background paper (Vongraven and Peacock 2011) was presented at the 13th biennial meeting of CAFF, Akureyri, Iceland, February 1-3, 2011, and a subsequent workshop was held in Edmonton, Canada, February 19-21, 2011. Invitations to the workshop were extended to experts and managers of all polar bear subpopulation jurisdictions, and to users in Alaska, Canada and Greenland. Twenty-one were able to attend (Vongraven 2011). This monitoring plan is a direct result of the discussions at the Edmonton workshop.

[1] 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.

This document describes the framework of a monitoring regime that hopefully will be implemented across the circumpolar Arctic. Within this framework collection of Traditional Ecological Knowledge (TEK) and Community-based Monitoring (CBM) is integrated with scientific methods. This plan document is a first step in a process, and the level of detail of how this integration between different monitoring tools and cultures will happen will be improved as the process is allowed to continue.

The main elements of the monitoring plan document are:

- A monitoring approach that is based on the four ecoregions (Amstrup *et al.* 2008, 2010) that describe differences in types of ice ecology experienced by polar bears.
- A tiered monitoring approach (using ecoregions and different monitoring intensities)
- Recommended monitoring parameters – background and monitoring schemes
- Specific needs for research that will improve monitoring of the chosen parameters
- Implementation

2. MONITORING PLAN OBJECTIVES

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

- identify existing monitoring techniques and optimal sampling regimes that are likely to succeed in each of the 19 subpopulations, given specific characteristics and logistics of the subpopulations themselves;
- identify new methods, including less-invasive approaches, for conducting directed research and monitoring;
- identify suites of metrics that can provide parallel lines of evidence, albeit with wider confidence limits, of the status of polar bear subpopulations for which intensive monitoring is not possible;
- identify standardized parameters for intensively monitored subpopulations, with a specific focus on identifying factors responsible for determining mechanistic relationships and trends in the subpopulation;
- develop new information that could be used as inputs to population projection models that incorporate response to environmental change; and,
- develop a set of circumpolar indices and indicators to provide regular, consistent and credible reports on the status and trends of individual polar bear subpopulations.

USE OF THE TERMS MONITORING AND RESEARCH

We use the term *monitoring* to mean the methodological and repetitive measurement of biological parameters (e.g., abundance, trend, habitat availability and use, stature, etc.) to describe changes in that parameter (Vongraven and Peacock 2011). In some cases, the term *research* can be used synonymously with *monitoring*. We, however, use the term *research* to specifically refer to studies that are required to fill knowledge gaps, develop and calibrate new techniques and metrics. We also use the term *research* to describe the studies needed to understand the mechanistic causes and ecological ramifications of biological parameters being monitored.

Community-based monitoring (CBM) is a phrase that is often used when describing "the gathering of information by local residents over a period of time" (Gofman 2010). It is an emerging technique that strives to systematically collect and document information collected by local people. This includes, for example, collection of local observations of denning to hiring a local expert to collect data on specific metrics from harvested animals (e.g., Harwood 2000). There are many definitions of Traditional Ecological Knowledge (TEK) (refer to section 5.2) and in many cases CBM includes the use of TEK by local experts. However, separate studies specifically designed to collect TEK are necessary to document the immense knowledge base held by local experts and make that knowledge available.

3. A TIERED MONITORING APPROACH

Monitoring of polar bears is a difficult and resource-demanding task because they generally occur at low densities and live much of the year in an extreme, remote environment that is often accessible to biologists only through elaborate and expensive logistics. To carry out monitoring that will provide valid and precise information about polar bears' population status and well-being, to at least some degree, in all 19 presently acknowledged subpopulations (PBSG 2010) is an enormous and very demanding task, although for some subpopulations, local communities provide a cost-effective opportunity to monitor some parameters using community-based monitoring approaches and/or through the application of TEK. Because the cost of such comprehensive studies 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 relatively high intensity and other subpopulations will be monitored at lower intensity. Subpopulations to be monitored at high intensity will be identified on the basis of existing level of information, accessibility, and perceived challenges and threats. 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.

This tiered monitoring approach is mainly applicable to a few of the suggested monitoring metrics, e.g. subpopulation size and trend, survival rates, and reproductive parameters. Specifically, abundance, reproductive and subpopulation trend assessments fall under this framework. In contrast, for example, habitat monitoring using remote sensing, and, in some cases, methods that use harvest and community-based monitoring, can be applied to subpopulations regardless of the intensity at which they are being monitored.

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, called subpopulations, are recognized throughout the circumpolar Arctic (PBSG 2011). We use the term "subpopulation" according to IUCN terminology (IUCN 2010). In this document we have tried to be consistent in using the term "subpopulation" when it refers directly to polar bear subpopulations, and "population" when it refers to general theory and methodology, e.g. "population dynamics". For more considerations on the use of this term regarding polar bears, see Vongraven and Peacock (2011).

Figure 1 maps out these 19 subpopulations of polar bears. For further descriptions and a current status update see PBSG (2010).

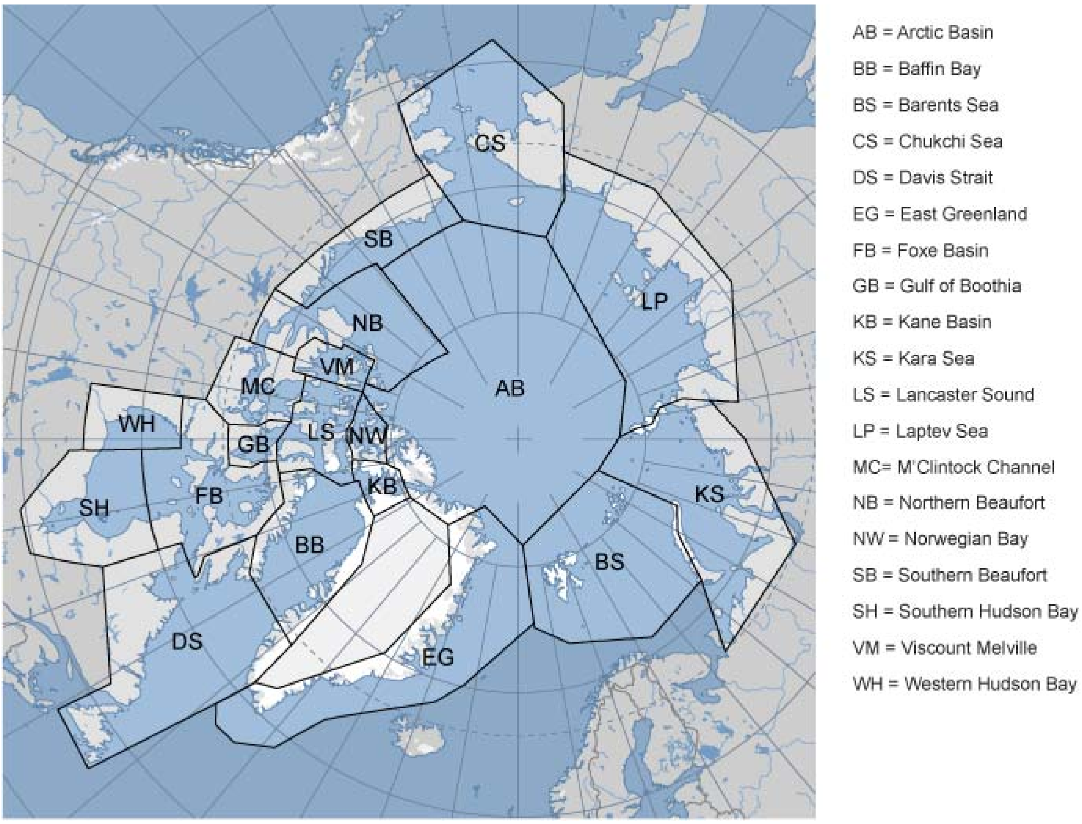

Fig. 1 Polar bear subpopulations (PBSG 2010).

3.2 POLAR BEAR ECOREGIONS

The ecoregion approach has been proposed as a scientific concept describing greater geographic regions (ecoregions) within which polar bears experience ecological similarities (Amstrup *et al.* 2008; fig. 1). These ecoregions were 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, 2010).

We acknowledge within ecoregion habitat variation, potential for change in assignment in the future, and other categorizations of polar bear subpopulations (Thiemann *et al.* 2008). Nevertheless, we accepted the ecoregion approach as a heuristic model for a framework for circumpolar monitoring of polar bears (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.

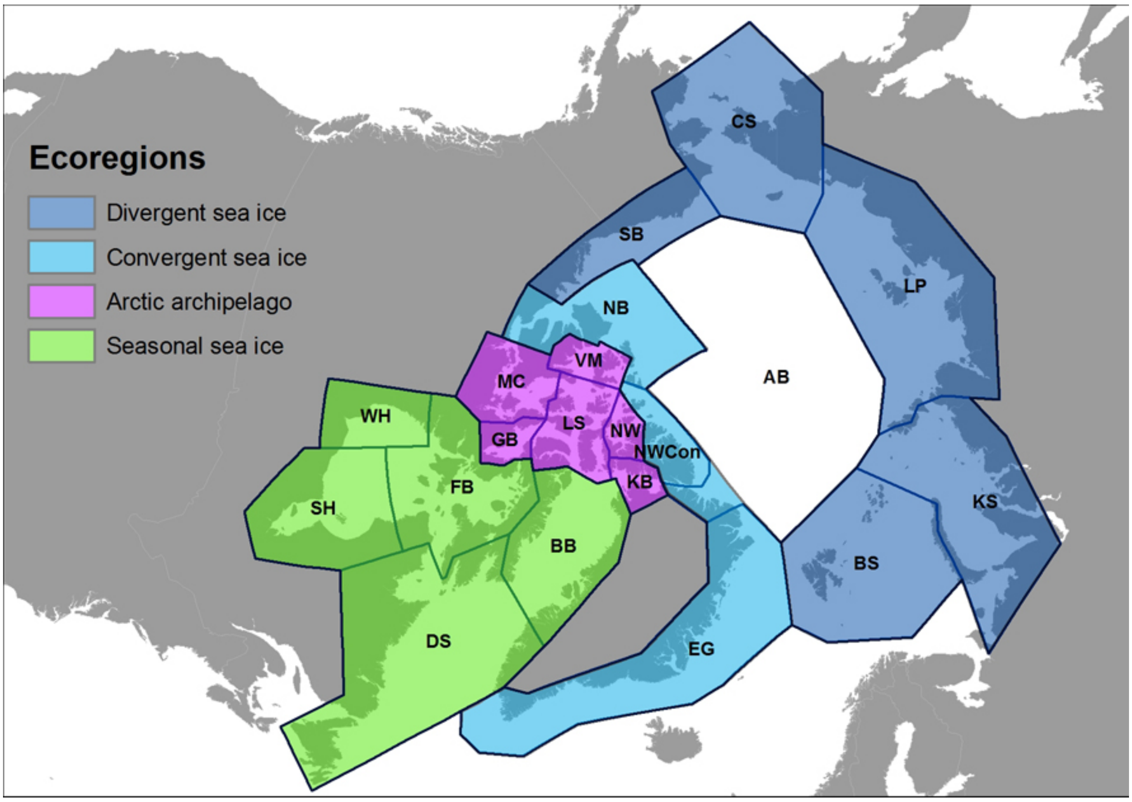

Fig. 2 The 19 polar bear subpopulations categorized according to major sea ice ecoregions . A 20th area (called NWCon for "Norwegian Bay Convergent"– see section 3.5) in the Convergent sea ice ecoregion at the northern coasts of the Queen Elizabeth Islands (Canada) and Greenland is indicated (from Amstrup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

The Arctic Basin (AB) was acknowledged as a separate catch-all subpopulation by the PBSG in 2001 (PBSG 2002). This designation was chosen to account for bears that may reside outside the existing territorial jurisdictions. The AB subpopulation was left out from the analyses made by Amstrup *et al.* (2008), because: 1. The Arctic Basin is characterized by very deep and relatively unproductive waters (polar bears have a preference for sea ice over shallow water - < 300 m - due to more hunting opportunities over more productive waters), 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 monitoring or research in the AB and that the AB may play a different role for polar bears under a scenario of climate warming.

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 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

Note on "ad hoc" sub**population *Norwegian Bay Convergent:***

A Canadian High Arctic polar bear subpopulation entity, or rather *ad hoc* monitoring region, Norwegian Bay Convergent (NWCon), has been added in the Convergent ecoregion. This is mainly due to the realization that this area will probably be an important, possibly one of the most important, future refugia for polar bears. See full argument in section 3.5.

3.3 MONITORING INTENSITIES

There is great variation, among the 19 subpopulations, in accessibility, existing available information, and probability for gathering future information. Ideally therefore, a circumpolar monitoring plan should identify basic and easily collected metrics for each monitoring element that can be reasonably and realistically measured in all or most subpopulations. Such metrics, although basic, must provide sufficient power and resolution to reveal changes in polar bear welfare at the ecoregional or circumpolar level. For subpopulations that are more accessible and/or for which substantial data already exist, the value of monitored metrics have the potential to provide more statistically robust assessments of status and trend. In subpopulations where research access is good and resources are available it is very important to continue research on ecological relationships and causal mechanisms that determine trends.

We recommend three levels of intensity of population-level research and monitoring for the 19 subpopulations of polar bears (high-, medium- and low-intensity – see table 3a & b). These assignments are based on the level of knowledge (e.g. quality of baseline data sets, availability of TEK), accessibility for science-based methods, community-based monitoring, and various current and future conservation threats to each subpopulation of polar bears. Table 3b summarizes the discussion of various threats, accessibility and baseline information upon which assignments were made. While several assessments have provided evidence for climate-warming as a significant threat to polar bears, we also consider 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, community-based monitoring 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).

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 for, and be useable for projecting 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 on-going 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. Note that this categorization does not necessarily reflect a lower severity of threats to the subpopulation.

* see section 3.4
** see Table 3a

Metrics in the medium and low intensity sampling areas must be measured in a way that maximizes their comparability to and compatibility with the more intensely monitored populations within each ecoregion. For example: data derived from community-based monitoring approaches should be collected simultaneously with data derived from more traditional scientific monitoring approaches in medium and high-intensity monitored units allowing for calibration of data derived from CBM in areas where only low-intensity monitoring is possible. This calibration will also maximize the potential value of development of parallel lines of evidence among both intensively and less intensively studied 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 are 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 region which is predicted to be a future refugium for polar bears, under current scenarios of climate warming (Durner *et al.* 2009) – for further argument, see section 3.5.

We recommend that estimates of subpopulation size and assessments of trend for subpopulations monitored at high-intensity should be developed at intervals of about 5 years. However, power analyses of data from subpopulations with long time series of population estimates may help further identify the optimal length of intervals between study efforts (see Priority study #1, section 7.1).

We suggest that subpopulations designated as medium-intensity be monitored in an adaptive framework, i.e., as-needed, based on threats and information needs (section 3.4).

Low-intensity monitoring has been recommended primarily for those subpopulations where research access is difficult and/or prohibitively expensive. However, this designation does not imply that these subpopulations do not have high levels of threats.

We do not advocate the *status quo* for polar bear monitoring, although advocating for high-intensity monitoring based in part on high-quality baseline data may be perceived as such. However, high quality baseline data is very valuable in order to understand ecological changes for polar bears that cannot be ascertained from short-term studies, and thus it is appropriate and valuable to continue these studies. In addition, these populations that have high quality base line data have high research access therefore are feasible populations in which to conduct monitoring. Our medium-level monitoring intensity group should be thought of within an adaptive framework (if information needs are higher, more monitoring will be necessary - Section 3.4) and we also highlight new important research areas for high-intensity monitoring (Lancaster Sound and Norwegian Bay). In this light, our monitoring strategy calls for a change in the *status quo*, which is a non-coordinated effort with no global strategy. The current and future threats to persistence of polar bears require a new paradigm.

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); the *ad hoc* subpopulation Norwegian Bay Convergent (NWCon) has not been added here.

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

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

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, in the future, changes in ecosystems and habitats might be so significant, that existing monitoring schemes will be insufficient to document vital changes within many polar bear subpopulations.

We have thus recommended that the subpopulations designated to medium-intensity monitoring be monitored in an adaptive framework. An adaptive monitoring framework "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). For example, populations, which are not currently showing indications of decline, will become increasingly affected by ice habitat decline (e.g., Davis Strait). In another example, 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 populations should be increased to address emerging or more severe management concerns. In more simplistic terms, this implies that monitoring frequency and intensity will be decided and changed as needed, based on the assessed level of threats, or other factors influencing the well-being of polar bear subpopulations. Assessment of threat levels and monitoring schemes will be undertaken regularly (see section 8.2).

Lastly, in order for this monitoring plan to have long-term utility, we must measure its success. We call for a periodic examination (see Section 8.2 and 8.4), made available to the public and the Parties to the 1973 Agreement on the conservation of polar bears, of evaluating what monitoring has been conducted compared with what the plan recommended. The plan should be refined and revised accordingly, including reassessment of eco-regional and monitoring-intensity designations.

3.5 DESIGNATION OF SUBPOPULATIONS IN HIGH-MEDIUM-LOW

In Table 4 the 19 subpopulations, plus the *ad hoc* monitoring entity called Norwegian Bay Convergent (see text below table), have been placed in a category of monitoring intensity determined as explained above (Section 3.3).

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 3ab 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	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; 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)

Neither of the two defined subpopulations (Northern Beaufort Sea and East Greenland) in the Convergent ecoregion has been identified for high-intensity monitoring. We recommend that a high-intensity program be developed in the region which is a predicted future refugium for polar bears, in the scenario of climate warming (Durner *et al.* 2009). At present this area is occupied by the Norwegian Bay (NW) subpopulation (Figures 1 and 2), but given the predicted changes in sea ice, monitoring in the NW area must also include the northern coasts of the Queen Elizabeth Islands bordering the Arctic Ocean to ensure monitoring of the Convergent sea ice ecoregion. However, this recommendation does not exclude that Northern Beaufort Sea also be considered as a high-intensity monitoring area at some time in the future. This subpopulation has a long-term research history and therefore a comparatively good base-line scientific data base, making it a potential representative of the Convergent sea ice region *sensu* Amstrup *et al.* (2008).

The proposed monitoring unit "Norwegian Bay Convergent" resembles the previously acknowledged subpopulation of Queen Elizabeth, that was "rejected" by the PBSG in 2005 due to lack of data to confirm the boundaries of such a potential subpopulation area (PBSG 2006).

Hence, there is some argument as to whether Northern Beaufort Sea should be chosen as a high-intensity monitoring subpopulation representing the Convergent region, or whether Queen Elizabeth should be reinstated as such. We have chosen to establish a high-intensity monitoring area in the Convergent ecoregion as an extension of the NW subpopulation covering the area of the former Queen Elizabeth subpopulation.

The details and specifics of high-intensity monitoring in the Convergent ecoregion will have to be revisited on a later occasion, e.g. at the workshop suggested for late 2012 (see section 8.4).

The designated high-, medium- and low-intensity subpopulations are shown in Figure 3.

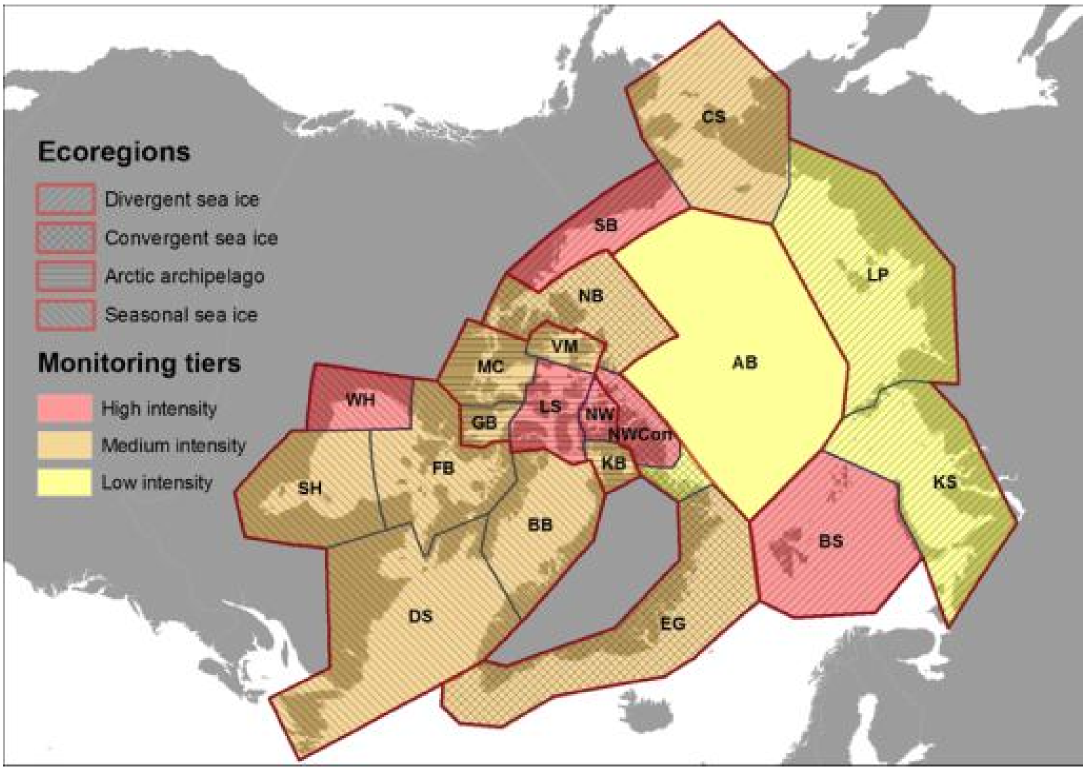

Fig. 3 Polar bear ecoregions and tiered selection of subpopulations to monitor on high and medium intensity, based on various threat and knowledge factors (Ecoregions from Amstrup *et al.* 2008). Note that NWCon (Norwegian Bay Convergent) represents a new designation. Polar bears occurring in this area are currently not considered to represent a separate subpopulation (PBSG 2010) 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 region will be monitored.

4. RECOMMENDED MONITORING PARAMETERS

This section describes what and how to monitor in the so-called high-, medium-, and low-intensity monitoring subpopulations. First, a brief background is given for each parameter, why it should be monitored, how it could be monitored in a standardized manner, and finally how it could or should be monitored related to the different monitoring intensities.

4.1 SUBPOPULATION SIZE AND TREND

Population size is simply the number of animals in the population or subpopulation at any point in time. Population trend is the change over time in the estimated number and indicates whether the population is increasing, decreasing or stable. Population trend is quantitatively expressed as the population growth rate (often designated by the Greek letter Lambda "λ").

WHY MONITOR SUBPOPULATION SIZE AND TREND?

One of the most often asked questions is "how many polar bears are there?" Managers, policy makers, and the general public always have a particular focus on population estimates and attach much importance to them. Ideally, we would like to know the size of each polar bear subpopulation at any point in time. An estimate of subpopulation size is important for estimation of sustainable harvest levels. Unfortunately, population size is a difficult parameter to assess. The logistical difficulties involved in capturing polar bears, inter-annual variations in movements and distribution, and the problem, within many subpopulations, of being unable to sample polar bears throughout their activity areas, can all result in large inter-annual variation in estimates of population size and vital rates, even in the best studied subpopulations.

Because in all populations there are processes of birth, death, emigration and immigration, any estimate of abundance applies only to one point in time. Therefore, the ramification of any size estimate can be fully evaluated only in terms of some indications of trend or λ. That is, is the estimated number of bears in the subpopulation increasing, decreasing or stable?

HOW TO MONITOR SUBPOPULATION SIZE AND TREND

METHODS APPLICABLE IN MORE ACCESSIBLE SUBPOPULATIONS

Currently there are three main quantitative methods for assessing the size of a polar bear subpopulation: Physical mark-recapture (M-R), genetic M-R and aerial surveys. Under some circumstances components of these methods may be combined to provide the best possible measures.

Historically, polar bear subpopulation size has been assessed by the physical M-R method. Physical M-R entails capture efforts that are repeated regularly over (usually 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.* 2005). Physical M-R involves chemical immobilization and handling of individual bears, which can be a drawback in terms of cost, effort and research permitting. It is important to note that merely catching bears and *post hoc* application of mark-recapture methodology is inappropriate. Careful consideration of study area, season and individual and geographic capture heterogeneity must be incorporated in sampling design; without coordination between field efforts and analysis, biases in resulting estimates can be generated. That said, capture and/or harvest recovery heterogeneity can still act to negatively bias estimates of abundance through unequal probability of capture/recovery due to behavior, innate characteristics of individuals, and/or incomplete sampling. Lack of geographic closure, which is ubiquitous in polar bear subpopulations, also compromises the accuracy of abundance estimates. Importantly, using multiple sources for mark and recapture samples (i.e., data collected under different sampling protocols) can work to minimize bias (e.g., Taylor & Lee 1994; Peacock *et al.* 2011b, Taylor *et al.* 2005).

Genetic M-R (or remote M-R), a derivative of the physical M-R method, has been used in other bear species (Woods *et al.* 1999, Kendall *et al.* 2009) and now also been introduced in polar bears on an experimental basis (Peacock *et al.* 2009). In genetic M-R, the "marks" are the genetic identities of individual bears. Therefore, genetic M-R does not require immobilization or handling of individual bears. Genetic M-R can be active or passive. In the "active" method, a bear is chased by a helicopter, similar to the approach in physical M-R. Rather than drugging and capturing the bear, a small hair and skin biopsy is collected by firing a biopsy dart that strikes the animal, bounces out, and falls to the ground where it is subsequently picked up. This approach, therefore, requires chasing the animal as in physical M-R, but avoids the need for drugging the animal. In addition to the DNA code unique to each individual (i.e. the mark); sex also can be determined with this approach. Genetic M-R also can be conducted passively by using hair traps or other methods to collect hair samples from individuals. DNA can be extracted from the roots of individual hairs and, where visitations to such traps are sufficiently predictable, sample sizes large enough to assess numbers may be derived. Because of the effort required to revisit multiple sites, without the use of helicopters that could be used to cover appropriate geography, employing a passive technique to estimate subpopulation sizes would be logistically difficult. Passive genetic sampling may be better suited for answering questions about local activity of polar bears (Herreman & Peacock 2011), or to supplement other mark-recapture efforts.

Line-transect or distance sampling methods provide another way to estimate abundance (Buckland *et al.* 2001). In the case of polar bears, these methods are based upon aerial survey flights, and recently have been used successfully (Aars *et al.* 2009). Aerial surveys can avoid the problem of negative bias from mark-recapture studies employed in study areas that are not representative of demographic populations; aerial surveys produce an abundance estimate for bears present in a specific area at a specific time. 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. The number of bears actually seen and assumptions regarding sightability are used to estimate how many bears were in the sampled area at the time of survey. If the whole subpopulation area is not sampled, information derived from the locations of radio-collared bears and other information related to relative densities in different parts of the study area, can allow researchers to extrapolate the number of bears in the sampled area to the whole area of interest. Line transect/distance sampling methods can be combined with mark-recapture methods to take advantage of marked animals in the subpopulation or by using multiple platforms for observations. Such mark-recapture-distance sampling may provide greater accuracy and precision than more standard distance sampling methods while still minimizing animal handling. Aars *et al.* (2009) provide a current example of the processes by which aerial counts are converted to estimated numbers of polar bears. Whereas an aerial survey may provide an estimate of subpopulation size, such surveys must be replicated over time to estimate trend.

Physical mark-recapture is still regarded as the most reliable method for estimating subpopulation size for polar bears, when appropriately designed and implemented. Importantly, data from physical M-R provides estimates of the vital rates of reproduction and survival and therefore evidence of trend, as well as estimates of abundance. In M-R studies, estimates of vital rates depend only on recaptures of previously marked animals, while estimates of subpopulation size depend on ratios of marked to unmarked animals (Amstrup *et al.* 2005). This means that estimates of vital rates are subject to fewer biases than estimates of abundance and may provide indications of subpopulation trend even before accurate abundance estimates are available.

The first way of assessing trend is the comparison over time of a series of estimates or indicators of abundance (Regehr *et al.* 2007; Stirling *et al.* 2011). This "comparison over time" approach also is possible with physical and genetic M-R and aerial surveys. The second way of assessing trend is projection of the subpopulation growth rate based upon estimates of vital rates – reproduction and survival (Taylor *et al.* 2002; Hunter *et al.* 2010). Such projections, if constructed for the observed period, provide a valuable "cross-checking" against the change in numbers recorded by comparing temporal changes in estimates of subpopulation size. Projections also can be made for the future. In this case, the future trend is forecast based upon observed estimates of vital rates (Taylor *et al.* 2002) or anticipated future changes in the vital rates based on relationships between vital rates and environmental variables, and predictions of how the environment will change (e.g., from global climate models) (Hunter *et al.* 2010).

Aerial survey approaches (e.g., line transects), like M-R, provide estimates of abundance at the time of the survey. A principal shortcoming of these survey methods, especially when applied to large mobile animals like polar bears, is that they cannot account for animals that were not in the survey area at the time of sampling. When all bears are available to survey, such as on-land or on ice that can be covered given logistical and safety considerations, aerial surveys can directly estimate the whole subpopulation. However, with polar bears, occupied areas often are out of reach of the survey effort. Mark-recapture, because it provides estimates derived over time, has the ability to estimate the whole subpopulation even though all members may not have been in the sampling area at the time of any one sampling event. If all subpopulation members have some significant probability of being in the sampling area, mark-recapture theoretically can account for them. Line-transect or distance sampling survey methods require animals be within the survey area not just a probability they could have been there. For this reason, a distance-sampling estimate of abundance for a particular point in time would not always be expected to match a mark-recapture estimate derived for the same time. Radio-telemetry records and other information about the distribution of animals within the subpopulation in question, may be incorporated in aerial survey abundance estimation exercises. .

METHODS APPLICABLE IN LESS ACCESSIBLE SUBPOPULATIONS

For many of the currently identified polar bear subpopulations, it may be prohibitively expensive to conduct either M-R or aerial survey assessments. Even if an abundance estimate could be derived from a one-time survey, the trend and productivity of the subpopulation would be unknown. In some of these areas, estimates of abundance may be possible from multiple-source M-R methods. Such estimates would be based upon collection of identity data from a combination of passively and actively collected genetic material. Hair samples, for example, could be collected through community based monitoring programs and then analysed with modern molecular genetics methods. Studies that solely depend on remote-marking, however, and where little other information is available, may have larger bias and unless large and consistent sample sizes can be assured, will have lower precision.

Realistically, estimates of abundance will likely not be possible over much of the circumpolar range of the polar bear. Even if abundance cannot be estimated, however, there may be an opportunity to develop indices to trends in abundance. In areas where polar bears are harvested, systematic monitoring of the sex and age breakdown of the harvest can provide information on subpopulation structure, reproduction and survival. This information, in life-table kinds of analyses (Skalski *et al.* 2005), may provide an index to trend in the subpopulation. Visual observations from hunters (if standardized, properly recorded, and calibrated) along with community-based observations made by snowmobile, ATV, boat or dog-team could provide information on changes in distribution. If such changes are evaluated along with information on condition of harvested animals and the composition of the harvest; they might be capable of providing an index to subpopulation trend in some circumstances. In areas where denning is common, systematic community based surveys of denning could be an index to trend in productivity in the subpopulation (e.g., Jonkel *et al.* 1978).

An essential requirement for using these kinds of observations as indices of trend is that they be calibrated. Changed frequencies of sightings, for example, might reflect altered distributions rather than altered numbers (e.g. Born *et al.* 2011). Almost all long-lived animals respond to reduced availability of food resources by expanding their movements in search of alternate feeding areas. Therefore, changes detected on the ground need to be evaluated in relation to all other available sources of information. In the more remote polar bear subpopulation areas, there will not be much other information. So an additional requirement for interpreting these observations will be to compare them to trends in the same observations collected where more intensive monitoring is occurring. If trends in the harvest, changes in community based observations, and changes observed by hunters are recorded systematically in the same areas where higher intensity monitoring also is occurring, it may be possible to establish relationships between some of the high and low intensity techniques. Such relationships, if they exist, may then be extrapolated, with caution, to areas where only indices are available. Such calibration can elevate confidence in indices monitored elsewhere.

FREQUENCY OF MONITORING

Figure 3 illustrates the decline of subpopulation size over time in western Hudson Bay. This is the best and most consistently monitored subpopulation of polar bears in the world. With continuous high-intensity subpopulation monitoring a steady and statistically significant declining trend is obvious despite the inter-annual variation among estimates. Would the trend have been so obvious however, if we only had access to the estimates derived every 10 years? Because of the long term monitoring in western Hudson Bay, many other indicators of the trend are available. We know that there have been declines in stature, physical condition, and survival, and we also know that those things are linked to the period of ice absence in the Bay (Stirling *et al.* 1999, Regehr *et al.* 2007). Having that information, even without the estimates of numbers would suggest things are not going well in that subpopulation. Interpretation of the estimated trend in numbers is made clear in the light of these other indicators. If we had only estimates of numbers (e.g. from an aerial survey, or periodic physical and/or genetic captures) and only for selected years (say from 1990-1995 and 2000-2005), changes in abundance could be documented if periodic assessments were well designed and of high enough sample size.

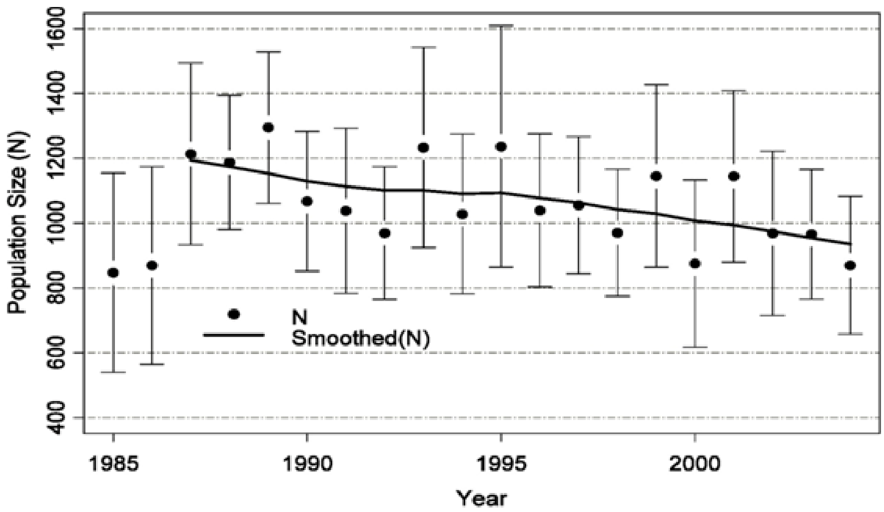

Fig. 3 Subpopulation size estimates from long term monitoring of polar bears in western Hudson Bay, Canada (from Regehr *et al.* 2007). Note that annual variation in the estimates would make interpretations regarding size and trend difficult if only a few years were available. The long term declining trend, however, is clear when all years in the sample are considered.

The uncertainties in estimates of subpopulation size and trend mean that more frequent monitoring will always be more informative than less frequent monitoring. However, even with continuous, annual monitoring often confidence intervals can be sufficiently wide that it has not been possible to quantify statistical support for actual change in population size (Regehr *et al.* 2006). This means that wherever possible, estimates of subpopulation size and trend should be interpreted in light of other monitoring elements such as quantified changes in stature, physical condition, cub production, and changes in habitat quality and availability.

Intensive monitoring, however, is not possible or practical throughout most of the range of the polar bear. Therefore, an important research component of future monitoring must be to use the data collected from subpopulations where long-term continuous data are available, to evaluate the costs and benefits of intensive monitoring done at intervals versus that done continuously (see Priority study #1, section 7.1). Another important research component is to understand how indices from life-table kinds of analyses can contribute to understanding trend. Such research will necessitate comparisons made in areas where high intensity monitoring data also are available. Regardless of the frequency of intensive monitoring (e.g. physical M-R); if lower intensity monitoring is to be applied reliably throughout polar bear range it must be standardized and applied systematically and continuously. Only in this way will we have any hope of documenting, or even detecting, global trends. This means that in subpopulations that are monitored with high intensity (reference subpopulations), less intensive methods also must be applied to aid extrapolation of trend information from reference subpopulations to others in each ecoregion.

Finally, we must recognize that priorities will be set and efforts allocated according to the level of risk faced by each subpopulations. Priorities also will be set according to the anticipated understanding and benefits that knowledge about each subpopulation may bring.

TABULAR MONITORING SCHEMES

Table 5 Methods and frequencies for monitoring of subpopulation abundance in high-, medium-, and low-intensity monitored subpopulations of polar bears (M-R = Mark-Recapture, MRDS = Aerial survey involving Mark-Recapture Distance Sampling, M = Methods, F = Frequency).

SUBPOPULATION SIZE "N"		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	Physical M-R	Physical M-R: Conducted by helicopter over multi-years this provides maximum information on subpopulation status and trends.
	Genetic M-R	Genetic M-R: Using biopsy darts, hairtraps etc. this method can provide estimates of status and trend, but do not allow assessment of animal condition.
	Multiple source M-R	Multiple source M-R: Combination of identities derived from physical, genetic and harvest identity data.
	MRDS	MRDS: Aerial surveys provide estimates of abundance with reduced or no handling of bears.
	CBM	CBM: High intensity methods are accompanied by lower intensity methods, which may be accomplished with CBM. Accomplishing these in parallel with higher intensity methods will allow calibration of lower intensity methods in subpopulation areas that may only receive low-intensity monitoring.
F	Annually or at least every 5 years[2]	"Every 5 years" marks the maximum time interval between updated estimates.
Medium-intensity monitoring		
M	Physical M-R Genetic M-R MRDS CBM	Same as high-intensity monitoring subpopulations.
F	Every 5 years or less frequent	The inventory interval should be based upon assessed level of threat, the needed power/level of confidence to make decisions, and the ability to extrapolate from higher intensity monitoring areas to lower intensity areas.

[2] See priority study #1

Low-intensity monitoring		
M	Standardized visual observations, land-based hair samples, harvest monitoring (from CBM)	Due to cost and relative accessibility, precise quantitative methods, based upon helicopter sampling, may never or only rarely be possible, and estimates of N simply may not be possible. Lower intensity methods may be the only sources of information from these subpopulations. Because these lower intensity methods are standardized they may provide an index to subpopulation size in regions where high intensity sampling is not possible.
F	Annually or as frequently as possible.	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 Methods and frequencies for monitoring of trend in subpopulation abundance in high-, medium-, and low-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. Abbreviations: PVA = Population Viability Analysis, M = Methods. F = Frequency.

Subpopulation trend or growth rate (λ)		
	Recommended methods	**Comments**
High-intensity monitoring		
M	Repeated measurements of subpopulation size from M-R or distance sampling; PVA from M-R data. + low-intensity methods	Estimation of λ based upon assessments of birth and survival rates that are projected forward in time. Changes in sex and age composition and animal condition, observed during mark-recapture studies, can provide an index to subpopulation trend, and changes in vital rates (births and deaths) estimated from mark-recapture can provide ongoing trend assessment.
F	Subpopulation size estimates must be available at least every 5 years to provide useful assessment of subpopulation trend.	
Medium-intensity monitoring		
M	Repeated measurements of N from M-R or distance sampling; PVA from M-R data. + low-intensity methods	Same as high-intensity monitoring subpopulations
F	Ideally trend estimate at least every 5 years.	The inventory interval should be based upon assessed level of threat, the needed power/level of confidence to make decisions, and the ability to extrapolate from higher intensity monitoring areas to lower intensity areas.
Low-intensity monitoring		
M	- Visual observations or track counts from snow machine, ATV, boat or dog-team; - In combination with possible but infrequent aerial survey; - Repeated visual observations at known concentration sites, genetic material (e.g. hair) gathered at corrals day beds or dens, and repeated den surveys.	These methods, some of which can be accomplished with CBM, will take advantage of the calibration accomplished by conducting them simultaneously with high intensity methods in high and medium intensity areas.
F	Annually or as frequently as possible.	High frequency to compensate for the potential for bias and imprecision in these indices, and to maximize the ability for calibration.

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.

4.2 REPRODUCTION

Reproduction in polar bears is inherently variable and as a k-selected species, all ursids are noted to have low reproductive rates as a result of late maturation, small litter sizes, and long mother-offspring association (Bunnell and Tait 1981).

WHY MONITOR REPRODUCTION?

Reproduction is one of the best understood demographic parameters in most polar bear subpopulations (e.g., Lønø 1970; DeMaster and Stirling 1983; Larsen 1985; Larsen 1986; Watts and Hansen 1987; Taylor *et al.* 1987; Ramsay and Stirling 1988; Derocher *et al.* 1992; Derocher and Stirling 1994; Rode *et al.* 2010). In all subpopulations where some assessment has been undertaken, elements of reproduction are monitored to varying degrees. Some subpopulations have long-time series and others have episodic data collection. A major concern with monitoring reproduction over the shorter periods often associated with population estimation for management is that reproductive rates may reflect short-term or transient dynamics. For example, a 3 year population inventory may include 3 good years of reproductive output, 3 bad years, or a mix of both (cf. Priority study #1, section 7.1). The net result is that when the results from short term studies are used for for population projections modeling it may not represent the longer term, and are of limited utility for population monitoring unless they are carried out at a sufficiently high frequency (e.g., more frequently than the 15 year inventory cycle currently envisioned for parts of Canada).

HOW TO MONITOR REPRODUCTION

There is a suite of parameters that can be monitored in polar bear subpopulations (Table 7), 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 the status of a subpopulation (i.e., monitoring utility).

Table 7 Reproductive parameters for monitoring of polar bear subpopulations and a qualitative assessment of their monitoring potential (ability to collect the data) and monitoring utility (ability to detect significant population changes).

Parameter	**Monitoring potential**	**Monitoring utility**	**Monitoring metrics**
Age of first reproduction	high	low	Age class when first companied with cubs-of-the year
Mating ecology	low	low	n.a.
Pregnancy rates	low	low	# pregnant/# available to breed
Litter size	high	low	cubs/litter
Interbirth interval	high	high	Years
Litter production rate	high	high	# cubs/female/year
Den abundance	high	low	# of dens in a defined area
Reproductive success	high	high	cubs weaned
Reproductive senescence	low	low	Age after which no cubs are produced
Density dependence	low	high	changes in reproductive rates in relation to subpopulation size
Infanticide	low	low	% of cubs by age class

Age of first reproduction in polar bears can be defined as the age of cub production or the age of first mating with the former being 1 year later. The age of first cub production varies both between subpopulations and over time within a subpopulation (Ramsay and Stirling 1988). While age of first reproduction is often determined in population studies, it has a relatively slow response time (i.e. it changes slowly in response to environmental perturbations), difficulties in age determination in some populations may limit its utility, and it has little influence on population growth rates. Measurement of this parameter can come from capture studies (i.e., noting the first age that females are accompanied by cubs) or by following individual adult females from 4 years of age onward. In harvested subpopulations an estimate of age at 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, which are usually assumed to be in sufficient abundance for the purpose of reproduction in most populations.

Mating ecology, here broadly considered as the behavioral aspects of breeding, has limited potential as a monitoring parameter given that is it difficult to collect and has low statistical power. However, it can be studied by use of genetic methods (e.g., Zeyl *et al.* 2009). Nonetheless, monitoring of males paired with breeding females may be of some use for assessing effects of male harvest in that a trend to younger males paired with adult females could indicate excessive removal of mature males (Molnar *et al.* 2008b). Such changes would likely be difficult to detect.

Den counts can be used to provide insight into a subpopulation's status although it must be used in conjunction with other data because denning areas can shift (Derocher *et al.* 2004; Fischbach *et al.* 2007). Therefore, an increase or decrease in den abundance could result from a redistribution of pregnant females. Further, an increase in the abundance of dens in an area can occur for very different reasons. For example, high cub mortality could reduce the reproductive interval resulting in more females denning. In contrast, a subpopulation increase could result in a similar increase in den numbers.

Litter size is a common and easily collected parameter in all polar bear subpopulation studies. Changes in litter size have been used to estimate survival (DeMaster and Stirling

1983) although monitoring cub survival through repeated observations of satellite telemetry equipped females is now more common and more accurate. Litter size, however, is relatively unimportant in determining population growth rate (or sustainable harvest) relative to adult female survival although it still ranks relatively highly when compared to other population parameters (Taylor *et al.* 1987). A major concern for the utility of using litter size as a monitoring parameter stems from its sensitivity to the date of collection (Derocher 1999). Partial litter loss results in a reduction in mean litter size and variation in the date of observation, between years or between populations, renders comparisons difficult. A modeling analysis of litter size suggests that the observed litter size is relatively insensitive to even major change in cub production because some females will continue to produce cubs although the overall cub production rate can decrease dramatically (Molnar *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).

Interbirth interval is a complex population parameter and is measured by following the reproductive success of individuals. The normal interbirth interval for successful reproduction is 3 years (measured as the time between successive litters). In the Western Hudson Bay subpopulation, a 2 year interbirth interval was observed in the 1970s and 1980s, and the survival of the yearling cubs there was comparable to that of cubs weaned at two years of age in the High Arctic, although that pattern is now uncommon (Ramsay and Stirling 1988; Derocher and Stirling 1995; Stirling *et al.* 1999). If individual adult females are followed by satellite telemetry for a period of 2 years or more, it is possible to assess cub survival and reproductive interval (e.g. Wiig 1998). The difficulty is that a large number of bears (e.g., > 30) would need to be followed to provide sufficient insight into this parameter for most populations. Interbirth interval is largely determined by cub survival. If cubs die before weaning, females often have shorter reproductive intervals. Because shorter reproductive intervals have been associated with early weaning in the Western Hudson Bay subpopulation, to be useful for monitoring, a change in interbirth interval should also assess cub survival.

Litter production rate is a derived parameter that integrates a population age structure and the number of cubs produced per female per year. This parameter is a standard monitoring component of polar bear subpopulation dynamics studies and requires a large random (or non-selective) sample of the adult females. Litter production rate is a standard parameter in demographic projection models. 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 cause for concern as it implies lower rates of recruitment into the population. Monitoring pregnancy rates (Derocher *et al.* 1992) can be used to gain additional insight into the reproductive dynamics of a subpopulation if individuals are handled after the mating season or if non-invasive methods (e.g., scats) can be developed.

Reproductive success is closely linked to interbirth interval. Adult females that successfully wean their cubs, usually at 2.5 years of age, are deemed to have been successful, resulting in the recruitment of new independent 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 which may be possible using genetic methods. As an integrative parameter, reproductive success can yield significant insight into population status and trend although the information required to monitor this parameter will preclude its use in all but the most intensively studied subpopulations.

Reproductive senescence is a relatively unimportant parameter for population monitoring, although it might be related to the estimation of generation time according to the IUCN Redlist criteria (IUCN 2010). There is debate about whether or not adult female polar bears decline in reproductive output beyond 20 years of age (Ramsay and Stirling 1988; Derocher and Stirling 1994) but because so few females are in a population at this age, their relative contribution to the population is small.

Infanticide has been observed in many polar bear 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 rarity 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.

Modeling of polar bear reproduction has been used widely as a management tool in several different subpopulations (Taylor *et al.* 1987, 2005, 2006). Such a modeling approach is a reasonable means of estimating population trend when two conditions are met: 1) the reproductive rates being used are unbiased and 2) the conditions under which the reproductive rates were collected are similar to those for the period of the population projection. Under rapidly changing sea ice conditions, unless mechanisms of population change are understood, projection models incorporating reproductive rates beyond a few years are likely to give spurious results (Molnar *et al.* 2010). Incorporation of changing ice conditions may provide some insights into population trend (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 may be used to detect short-term population trend.

RECOMMENDATIONS FOR MONITORING REPRODUCTION

The most informative studies on the nature and 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 inventory form used in Canada (ca. 3 years) may give adequate insight on status for less intensively monitored subpopulations.

Given the large amount of documented ecological variation in Arctic ecosystems, reproductive rates collected over short periods can be influenced by transient or short-term population dynamics. Because of this, reproductive rates can be used to derive a current rate of population growth, as long as there is no inappropriate projection of that rate into the future, unless projected ecological conditions that are tied to the reproductive rates are incorporated in the modeling. To adequately monitor polar bear reproduction, it is necessary to incorporate a series of metrics that can be assessed in overview with associated observations to assess population status. The recommended suite of parameters, when taken as a whole, can provide meaningful insight into population status. Because reproductive parameters in concert with survival rates determine population growth rate, adequate population monitoring for the more intensively studied subpopulations will optimally rely on a combination of methods for estimating both reproduction and survival, including mark and recapture methods.

The recommended suite of monitoring parameters will vary for each subpopulation with the intensity of monitoring. For intensively monitored subpopulations, age of first reproduction, litter size, litter production rate, interbirth interval, and reproductive success provide valuable information. For less intensively monitored subpopulations, the same suite of parameters can be monitored, but interpretations made using those data will be less robust. Monitoring that relies on aerial survey alone will provide less information in comparison to populations monitored at high-intensity. Such less invasive studies cannot provide age-structure data nor the tracking of individuals and thus for monitoring purposes.

TABULAR MONITORING SCHEME

Table 8 Methods and frequencies for monitoring of reproduction in high-, medium-, and low-intensity monitored subpopulations of polar bears.

REPRODUCTION		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- M-R estimates of litter size, litter production rates, age at first reproduction, interbirth interval, age of weaning, sex-ratio at birth. - Telemetry monitoring of den occupancy (light-sensing ear tags); Infrared monitoring of denning areas. - Visual observations of cubs per female in spring. - CBM (e.g. monitoring of den distribution, reports of litter sizes of observed bears. - Reproductive tract analysis of harvested bears.	Cross-calibration between methods.
F	Frequency and intensity will depend on assessed level of threat. Adjust interval depending on rate of change and other threats.	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Ongoing.	
Low-intensity monitoring		
M	- Visual observations of cubs per female in spring. - CBM (e.g. monitoring of den distribution, reports of litter sizes of observed bears. - Reproductive tract analysis of harvested bears.	
F	Annually or as frequently as possible.	High frequency to compensate for the potential for bias and imprecision in these indices, and to maximize ability for calibration.

Notes for Table 8

The interval is the time between estimates, not the time between beginning or ending of field efforts.

The inventory interval concept should be reassessed based upon the needed power/level of confidence to make decisions, and the ability to extrapolate from higher intensity monitoring areas to lower intensity areas.

A study is needed to assess the relative value of annual mark-recapture versus capture samples taken at intervals of 3 or 5 or more years. Such a study could be conducted by selecting clusters of years from continuously studied subpopulations (see Priority study #1, section 7.1).

Monitoring could also benefit from carrying out a power analysis that compares information from hunter kills in the same years as mark-recapture studies to assess whether trend can be determined from monitoring hunter kills for those subpopulations that experience harvest.

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.

4.3 SURVIVAL

Survival is a life history trait that is critically important for population monitoring and one that can be directly affected by harvest, human-bear interactions, environmental variation, pollution, and oil spills, and climate change. Survival rates of ursids are generally high (Bunnell and Tait 1981) but vary substantially across different life stages (Amstrup and Durner 1995).

WHY MONITOR SURVIVAL?

Given the importance of adult survival for determining population trend, monitoring of survival in a population should be a priority in subpopulations where data allow.

HOW TO MONITOR SURVIVAL

There are two means by which survival rates of polar bear can be monitored: radio telemetry and mark-recapture methods. Both methods have been applied to monitoring survival and have provided estimates (Amstrup and Durner 1995; Derocher and Stirling 1996; Regehr *et al.* 2007, 2010; Taylor *et al.* 2005). Change in litter size has also been used to estimate survival (DeMaster and Stirling 1983) although this method has seen limited use.

Age classes used for monitoring survival usually fall into the following: cubs (den emergence to 1 year of age), yearling (1-2 years of age), subadult (2-4 years of age), and adult survival (often age-specific where sufficient data exists). There is abundant information to support both age- and sex-specific survival rates and most detailed studies provide such estimates. There are a variety of mortality factors that vary with both age and sex. It is useful to postulate the major causes of mortality in a monitoring study because the ability to detect change will be influenced by the cause of mortality. For example, harvest mortality may vary little from year to year in areas with a harvest quota but mortality linked to sea ice condition may show substantial interannual variation.

Linking survival to sea ice conditions (e.g., Regehr *et al.* 2007) provides a powerful approach to population monitoring. Less invasive methods, such as aerial surveys to estimate abundance cannot provide insight into survival rates. In these cases, survival estimates could be ascertained using satellite telemetry (e.g., known-fates analysis). Given the expense of collecting survival data, it is recommended that this parameter be considered for the more intensively monitored subpopulations.

RECOMMENDATIONS FOR MONITORING SURVIVAL

In intensively monitored subpopulations, survival rate should be monitored across all age- and sex-classes. Optimal monitoring methods will include mark and recapture analyses and satellite telemetry studies. Aerial surveys cannot provide survival *per se*, although repeated surveys of sufficient precision can provide information on population trend, which is the ultimate goal of estimating survival. Genetic mark-recapture studies can provide estimates of survival, similar to those based on physical mark-recapture. Physical mark-recapture studies, which are accompanied with age determinations from known-age bears or analysis of cementum growth layers in teeth, theoretically can provide age-specific survival rates. However, in practice, survival estimates are provided for age-classes due to sample size (Regher *et al.* 2007, Taylor *et al.* 2005). It is likely that age-classes can be assigned from remote observation (e.g., biopsy-based mark-recapture) given use of experienced observers. Short-term studies will usually provide biased estimates of survival given the nature of long-lived species.

However, in some cases, trend (which incorporates both survival and reproduction) can be studied in place of evaluating survival and reproduction separately. This is especially needed in those populations where mark-recapture estimates of survival are not attainable. Further, indices of survival can be ascertained from age-specific analysis of harvested polar bears. It must be also noted, that even if survival can theoretically be estimated through mark and recapture techniques, resulting estimates can be biased (if assumptions of the models are not upheld) and even small biases would have compounded effects when calculating population growth rate. Small bias in survival can have meaningful conservation implications for a long-lived species like polar bears characterized by survival rates near one. Therefore, much care must be taken when proposing to produce actual survival estimates. In these cases, multiple-parallel lines of evidence, which may be weaker individually (e.g., body condition, abundance over time, change in age at harvest), for assessing trend, without actual estimates of survival, should be employed.

TABULAR MONITORING SCHEME

Table 9 Methods and frequencies for monitoring of survival in high-, medium-, and low-intensity monitored subpopulations of polar bears.

SURVIVAL		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- M-R survival of marks. - Documentation of whole litter and individual cub losses for tagged reproductive females. - Annual monitoring of litter and cohort survival via radio-telemetry. - Tabulate cubs, yearlings, and two-year olds per adult, from capture data. - Tabulate cubs, yearlings, and two-year-olds per adult, from CBM for comparison with mark-recapture data. - Estimate age structure from teeth collected by harvest or from captured animals. - Evaluation of cohort strength or weakness from age structure of capture and harvest. samples - Life table type analyses.	
F	Frequency and intensity will depend on assessed level of threat. Adjust interval depending on rate of change and other threats.	

Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Ongoing.	
Low-intensity monitoring .		
M	- Tabulate cubs, yearlings, and two-year-olds per adult, from visual observations including CBM. Proportion of family groups observed. - Age categories of bears observed. - Estimate age structure from teeth collected in harvest and life table type analyses. - Examination of missing cohorts in harvest.	
F	Annually or as frequently as possible.	To maximize ability for validation and minimize potential for bias and imprecision in indices.

Notes for Table 9

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.

4.4 HABITAT AND ECOSYSTEM CHANGE

Broad categories of polar bear habitat include 1) sea ice hunting habitat, 2) sea ice denning habitat, 3) land used during the summer ice minimum or open water period in seasonal ice zone, and 3) terrestrial denning habitat.

Polar bears only occur in regions of the northern hemisphere where sea ice is a dominant feature in the environment. In 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. In some subpopulations, however, some or all polar bears may spend the entire summer and early autumn ice-free periods on land. While sea ice is the most important habitat because it allows polar bears to hunt ice-dependent seals, periods of time spent on land may also be important because of the impact of periods of food deprivation on polar bear energetics. In most of their range, polar bears use land for maternal denning. In the Beaufort Sea much of the subpopulation historically used sea ice as a substrate for denning. There is some evidence that polar bears in the Svalbard area may den on sea ice 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). Ultimately, however, it will be the presence of suitable sea ice during critical stages of polar bear life history that will allow polar bear subpopulations to persist.

Sea ice is a ubiquitous feature in the Arctic and its composition, and temporal and spatial extent determines the distribution and trend of polar bear subpopulations. Polar bears do not use all sea ice equally; rather they respond to variations in concentration, ice age (thickness), floe size, water depth beneath the ice, and the proximity of sea ice edges and land fast ice. The distribution of sea ice relative to ocean depth is important in many regions of polar bear range as bears show their greatest selection for sea 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 in areas where the sea ice melts completely, or almost completely. The areas selected by polar bears appear to primarily be those that are adjacent to where the last sea ice melts in early summer.

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 areas, such as western and southern Hudson Bay, polar bears den on land and dig dens in frozen peat banks (Stirling *et al.* 1977; Richardson *et al.* 2005).

WHY MONITOR POLAR BEAR HABITAT AND ECOSYSTEM CHANGE?

Arctic sea ice is the most critical habitat for the survival of polar bear subpopulations. The distribution and timing of ice relative to critical phases of polar bear life history has been linked to population status and trend (Hunter *et al.* 2010; Regehr *et al.* 2010; Stirling *et al.* 1999). Polar bear in western Hudson Bay have been shown to depart sea ice shortly after the average concentration of ice drops below 50% (Stirling *et al.* 1997). 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 in that region (Regehr *et al.* 2007). In the southern Beaufort Sea, 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 polar bear subpopulation growth. Absence of or reduced suitability of sea ice of the continental shelf leads to increased nutritional stress and poorer body condition and survival of some age/sex categories of polar bears (Rode *et al.* 2010). We may assume, based on these prior studies, that sea ice habitat may be a useful proxy of polar bear subpopulation status and distribution when other monitoring data, such as capture-recapture or distance sampling, are not available.

The availability of sea ice habitat is linearly related to global temperature (Amstrup *et al.* 2010). Hence, as temperatures rise there will be less and less polar bear habitat as currently understood (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 welfare is uncertain and probably not linear (Molnar *et al.* 2010). Regardless of the uncertainties in the rate at which polar bears may decline as their habitat declines, if habitat availability declines, so will polar bears. This knowledge along with the understandings of polar bear-sea ice relationships developed in intensively studied areas provides great ability to extrapolate across regions with similar patterns of ice change.

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 may 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.* 2008a), hence increased opportunities for shipping through the Northwest Passage and northern Russia may also increase the opportunity for the introduction of exotics. Relatively few harmful alien species have been reported within the range of the polar bear (Molnar *et al.* 2008a). In much of the Arctic, however, including the Canadian archipelago, northern Greenland and northern Asia, there is no data to assess the potential impacts of non-native species on polar bear habitat (Molnar *et al.* 2008a). In rare cases the increase of an uncommon prey species may benefit polar bears. This may be the situation in Baffin Bay and Davis Strait, where decreasing sea ice concentration has led to an increase in hooded (*Cystophora cristata*) and harp seals (*Pagophilus groenlandicus*; Stirling and Parkinson 2006). Both of these seals are prey for polar bears and their increase in these regions has likely had a positive effect on the polar bear subpopulations of Baffin Bay and Davis Strait (Stirling and Parkinson 2006).

Knowledge of the distribution of maternal den habitat has significant management potential to protect polar bears in dens. It is important to monitor and document changes in sea ice habitat and patterns of ice breakup because changes can have a significant effect on the distribution of maternal dens (Fischbach *et al.* 2007).

HOW TO MONITOR POLAR BEAR HABITAT AND ECOSYSTEM CHANGE

Physical features in the environment (i.e. sea ice extent and concentration and ocean depth) may provide useful metrics for monitoring polar bear habitat when other data and modeling tools are not available. Satellite-borne passive microwave (PMW) daily estimates of sea ice extent and concentration have been available since 1979 to users free of charge. 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 relatively fine-grained (i.e., AMSR-E since 2002; 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 not affected by daylight or cloud cover; hence these are a robust and consistent source of sea ice data. Ocean depth data are available for most of the range of polar bears (International Bathymetric Chart of the Arctic Ocean; Jakobsson *et al.* 2000). Because the spatial and temporal distribution of sea ice is critical for polar bear survival, these data (PMW and ocean depth) may be a useful first step for monitoring polar bear sea ice habitat.

Sufficient snow accumulation is necessary for successful polar bear maternal denning (Durner *et al.* 2003) and ringed seal reproduction (Kelly *et al.* 2010). Snow may be an important driver for the distribution of polar bear age and sex categories (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 distribution of accumulated snow plays 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). Several data sources are available for mapping snow cover, including MODIS/Aqua snow over estimates (NSIDC; Hall *et al.* 2007) and SSM/I-SSMIS EASE-Grids (NSIDC; Nolin *et al.* 1998). 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. These data may have their greatest utility in estimating maternal den habitat suitability and the distribution of ringed seals, but the value of satellite-derived snow distribution data for monitoring polar bear habitat has yet to be tested.

Standardized methods of developing habitat models (resource selection functions, or RSFs) for polar bears have been developed for several subpopulations (Mauritzen *et al.* 2003; Ferguson *et al.* 2000; Durner *et al.* 2004, 2006) and within a large part of polar bear range (Durner *et al.* 2009). 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. 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). Polar bears occur in four primary ecoregions (Amstrup *et al.* 2008); hence ecoregion-specific RSFs should be explored. While a specific RSF has allowed predictions and projections of polar bear subpopulation distribution in the Divergent and Convergent ecoregions (Durner *et al.* 2009) other RSFs may be necessary for estimating polar bear subpopulation distribution within the Archipelago and in the Seasonal Ice ecoregions. Ice modeling developed specifically for these regions would be necessary.

A RSF, with its covariates, may be thought of as simply 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 distribution of a subpopulation (Durner *et al.* 2009). Applying the RSF to available hemispheric 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. Several medium to high scientific access subpopulations already have RSFs that may be used for habitat monitoring (Durner *et al.* 2009). Habitat monitoring may be done for subpopulations with low scientific access potential by reasonable extrapolation of RSF from well-studied subpopulations. Ongoing research in the Seasonal 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 polar bear range.

Protocols for identifying non-indigenous species in the Arctic have not been developed. Stable isotope (Bentzen *et al.* 2007) and fatty acid analysis (Iverson *et al.* 2006) polar bear and prey tissues can provide information of 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 are intensively monitored or receive medium-intensive 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 anecdotal observations by researchers and subsistence-dependent residents of coastal communities.

Knowledge of the distribution of maternal den habitat is built upon observations of polar bear maternal dens through direct on-ground sighting by local residents and visitors, 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). The distribution of denning habitat 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 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 (Fischbach *et al.* 2007).

Finally, habitat availability and change have been linked to polar bear demography and/or condition in two subpopulations. However, in other populations, where habitat has declined, there have not been concomitant documented changes in population size or survival (Stirling *et al.* 2011, Obbard *et al.* 2007). This is likely the result of complex interacting factors including increase in prey (Stirling & Parkinson 2006), lower rates of change in ice habitat (Obbard *et al.* 2007) or declining harvest rates. Further, lack of detection of links between ice habitat and demography may simply be a result of lack of statistical power. Nonetheless, quantitative links between habitat and demographic parameters are complex and need to be refined. Without better understood links to demography/productivity, the interpretation of metrics of ice decline will be difficult.

TABULAR MONITORING SCHEME

Table 10 Methods and frequencies for monitoring of habitat and ecosystem change in high-, medium-, and low-intensity monitored subpopulations of polar bears.

Habitat and ecosystem change		
	Recommended methods	**Comments**
High-intensity monitoring		
M	- 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. - Use satellite imagery to measure snow accumulation and persistence. - Map optimal habitat with resource selection functions (RSF) derived from telemetry, observational (e.g. from aerial surveys) and satellite environmental data. - 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). - Document invasive or unusual species occurrence through scientific and CBM observations. - Survey denning distribution and changes in coastal habitats. Determine the amount of denning habitat impacted by industrial or other human activities through scientific and CBM observations.	
F	Yearly or as frequently as possible.	
Medium-intensity monitoring		
M	- 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. - Use satellite imagery to measure snow accumulation and persistence. - Map optimal habitat with resource selection functions (RSF) derived from telemetry, observational (e.g. from aerial surveys) and satellite environmental data. Alternatively, delineate optimal habitat through extrapolation of previously created RSFs or from RSFs developed in other regions. - 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). - Document invasive or unusual species occurrence through scientific and CBM observations. - Survey denning distribution and changes in coastal habitats. Determine the amount of denning habitat impacted by industrial or other human activities through scientific and CBM observations.	As for high-intensity, except that RSFs could be extrapolated from RSFs previously created or from RSFs developed in other regions.
F	Yearly or as frequently as possible.	

Low-intensity monitoring		
M	- 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. - Use satellite imagery to measure snow accumulation and persistence. - Delineate optimal habitat through extrapolation of previously created RSFs or from RSFs developed in other regions. - 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) that may be available despite inability to collect detailed scientific data on bears. - Document invasive or unusual species occurrence through CBM observations. - Determine denning distribution and changes in coastal habitats through CBM.	As for high-intensity, except that RSFs will be extrapolated from RSFs previously created or from RSFs developed in other regions, and monitoring of denning and coastal habitats through CBM.
F	Yearly or as frequently as possible.	

Notes for Table 10
Caution should be used when extrapolating movement data and RSFs from a high risk subpopulation to all other subpopulations in the ecoregion.

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 and mortality associated with research. Legal harvest is most often set at annual limits, which are set by governments, co-management boards, local communities and/or treaties. In some regions, harvest may be legal, but the levels are un-regulated. 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 on the Conservation of Polar Bears (1973) and respective national legislation (see Table 3a for an overview of what subpopulations are currently legally harvested). For many, but not all, subpopulations in these countries, harvest levels are based on scientific assessments of the status of the subpopulations, while some subpopulations are harvested based solely on considerations involving TEK and subsistence needs. In some regions, unmonitored harvest or lack of information on subpopulation status prevents a quantitative assessment. Consequently, harvest levels may not be sustainable in some subpopulations. In most regions, legal harvest activities are closely monitored (Table 11). There is a wealth of information on the effects of harvest on polar bear populations (e.g., Taylor *et al.* 1987; Taylor *et al.* 2009), and in particular on the the ramifications of sex-selective harvest (Taylor *et al.* 2008; Molnar *et al.* 2009); similar harvest-risk assessment studies should continue as the effects of harvest will interact with those of climate change.

Table 11 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[6]
East Greenland	Can be improved; sampling strategy to be developed[2]	Sustainability of harvest is unknown as subpopulation is considered data deficient[5]
Foxe Basin	Can be improved[4]	Sustainability of harvest is unknown as subpopulation is considered data deficient[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[7]
Kara Sea	Not applicable	Poaching level unknown
Lancaster Sound	High	Subpopulation is considered to be declining due to sex-ratio and level of harvest[5]
Laptev Sea	Not applicable	Poaching level unknown
M'Clintock Channel	High	Low[5]
Northern Beaufort Sea	High	Low[8]
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 can be improved in the U.S.	
Southern Hudson Bay	Can be improved[4]	Low[5]
Viscount Melville	High	Sustainability of harvest is unknown as subpopulation is considered data deficient[5]
Western Hudson Bay	High	Harvest mortality is in addition to the negative natural population growth rate [7,9]

[1] High quality of harvest data and sampling in Canada, [2] Catch reporting has been improved in Greenland since 2006 quota were introduced, [3] PBSG 2006, [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 (specifically sampling Davis Strait), [5] PBSG 2010, [6] Peacock *et al.* in prep., [7] Taylor *et al.* 2009, [8] Stirling *et al.* 2011, [9] Regehr *et al.* 2007.

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. A shared, regulated harvest level has been determined by the bi-lateral international commission and will be implemented by the United States in 2013; Russia is currently determining when the legal harvest will be reinstated in Chukotka.

In 1973, the Agreement on the conservation of polar bears restricted the harvest of polar bears to local people. Accordingly, most polar bears are harvested by Indigenous people for nutritional and cultural subsistence. There are also commercial interests associated with the harvest of polar bears. In its national ratification of the 1973 Agreement, Canada allowed for a "token" number of bears to be harvested for sport. Sport hunting of polar bears in Canada is guided by

Inuit hunters, and these hunts form part of the quota assigned to a community. 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, commercial 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.

WHY HUMAN-CAUSED MORTALITY SHOULD BE MONITORED

Compared to the 1960s and 1970s, polar bear harvest management is vastly improved. Several subpopulations have experienced demographic recovery due to harvest regulations (Amstrup *et al.* 1986; Derocher 2005; Peacock *et al.* in prep.). 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 (PBSG 2010). This figure includes defense kills that occur throughout the polar bears' range. Poaching, or illegal hunting of polar bears, is not thought to be a major concern generally although the extent of illegal hunting in eastern Russia has been reported to be up to almost 300 bears per year (Kochnev 2004) and is a serious concern.

Harvest monitoring is important for the quantification, and mitigation, of the effect of human-caused mortality on polar bears. Harvest is a concern in some polar bear subpopulations because of the level of harvest, and also where there is little or no information on the size or status of the subpopulation. In some areas, the monitoring of polar bear harvest has been inconsistent, and therefore its effect on subpopulation is unknown. In addition, subpopulation inventory programs occur relatively infrequently such that if the harvest rate is above the sustainable level, the subpopulation may be severely reduced before the next inventory is conducted and a decline in subpopulation size may be detected. As threats such as pollution, climate change, tourism, and development increase, 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 throughout the circumpolar Arctic. In some regions, notably in Nunavut and the Northwest Territories of Canada, harvest is well monitored, and includes extensive sampling and measurements of harvested bears. In other regions, harvest sampling and/or data collection should be improved or developed.

HOW HUMAN-CAUSED MORTALITY SHOULD BE MONITORED

Table 12 outlines the data and samples that should be collected from harvested polar bears, and Table 13 outlines the methods to collect these data and samples. Such data should be obtained annually from all subpopulations, where polar bears are harvested, whether these populations are recommended for high-, medium- or low-intensity monitoring. Where medium- or low-intensity scientific monitoring is recommended for the subpopulation, harvest data and samples are especially important, as they may constitute the majority of, or only, information from the subpopulation. In some cases, harvest data or samples may be developed and used as indices for the general status of a subpopulation (e.g., indices for health, stature, trend), in addition to information to specifically describe the harvest. Analysis of samples and/or harvest data, to better understand the ecology and the status of polar bear subpopulations, should be improved throughout the circumpolar Arctic (see Priority study #2, section 7.2). Community-based monitoring can be an effective means to collect harvest information and data.

Table 12 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, but may also be used for evaluating population status and for ecological research. Adapted and updated from Vongraven and Peacock (2011: Tables 2 and 3).

Metric or sample	Description
Number	Annual total number of human-caused mortalities for each subpopulation.
Type of human-caused mortality	Regulated (legal), illegal, defense, sport or research kill.
Sex and sex-ratio	Sex of harvested bear. Baculum and/or tissue sample for genetic analysis can be required for proof of sex. 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.
Field class	Adult, subadult, dependent cub (cub-of-the year, yearling or two-year old) and reproductive status (encumbered or unencumbered adult female).
Lower premolar tooth	Analysis of cementum growth layers for age.
Age-structure of harvest	Age-structure of the harvest is important for assessment of population growth, past and current influences of harvest, and to understand selectivity of harvest.
Lip tattoo or ear-tag number	Individual identity number used in scientific research. These data are used in mark-recapture population modeling and distribution analysis.
Skull morphometrics	Skull length, zygomatic breadth.
Body condition	1-5 index, axillary girth measured by rope, fat thickness at predetermined point.
Fat sample	Fatty-acid diet analysis, analysis of lipophilic contaminants.
Tissue sample	Genetic individual identification, genetic sex identification, stable-isotope diet analysis.
Hair sample	Stable-isotope diet analysis, contaminant analysis, cortisol analysis.
Location of harvest	Latitude/longitude and written description.
Mode of conveyance	Boat, ATV, dog sled, snow machine, on foot.
Distance travelled	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.
Hours/days actively hunting	Time spent searching for harvested bear (including records of additional bears observed). This information is useful only when a catch-per-unit-effort study is carefully designed.
Polar bear parts traded commercially	Number and sources of hides, skulls, claws in domestic and international trades. This information is important to understand influence of commercial trade on level of harvest.

TABULAR MONITORING SCHEME

Table 13 Methods and frequencies for monitoring of human-caused mortality in polar bears in high-, medium-, and low-intensity monitored subpopulations of polar bears.

HUMAN-CAUSED MORTALITY		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- Harvest records through government and/or CBM. - Harvest sampling through government and/or CBM. - In subpopulations where physical and/or genetic marks are deployed during research operations, individual identity (e.g., ear tag number) should be collected in the harvest. These data are used in mark-recapture population modeling and distribution analysis. - Human-bear conflicts. - Retrospective CBM to establish past harvest. - CBM from hunters to establish catch-per-unit effort, distribution and indices surveys. - Influence of economic activities (fur trade, trophy hunts, etc.), and traditional cultural uses of polar bears on harvest patterns.	See Tables 12 and 14
F	Yearly or as frequently as possible.	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	See Tables 12 and 14
F	Yearly or as frequently as possible	
Low-intensity monitoring		
M	Same as for high-intensity monitoring.	See Tables 12 and 14
F	Yearly or as frequently as possible.	

Notes to Table 13

Important to use existing harvest material (see Priority study #2, section 7.2), and to improve collection harvest material where possible.

4.6 HUMAN-BEAR CONFLICT

Human–bear conflict has been variously defined (Schirokauer and Boyd 1998; Smith *et al.* 2005; Wilder *et al.* 2007; WSPA 2009; Hopkins *et al.* 2010). 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). Such conflict situations compromise human safety and can result in property damage. And while the majority of these situations do not result in human injury or fatality, a much larger proportion results in the bear's death. Trends in reports of conflicts may not necessarily indicate trends in population abundance (e.g., Howe *et al.* 2010), yet monitoring of human–polar bear conflict will be 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).

WHY HUMAN-BEAR CONFLICT SHOULD BE MONITORED

As polar bear distribution changes and bears spend extended periods of time on land during open water seasons the potential for human–bear conflict increases. When the parties to the *Agreement on the Conservation of Polar Bears* (Canada, Greenland, Norway, Russia, and the United States of America [Range States]) last met in Tromsø, Norway in March 2009 they 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 status and trends for polar bear subpopulations. They further agreed on the need to strengthen monitoring throughout the range of polar bears, and to coordinate and harmonize national monitoring efforts. The Range States tasked the U.S.A. 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.

HOW HUMAN-BEAR CONFLICT SHOULD BE MONITORED

To address this emerging issue, the Polar Bear-Human Information Management System (PBHIMS) has been developed to standardize the collection of human–polar bear 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.

In order to provide for continuous monitoring of human–polar bear conflict data across the necessary range of scales (i.e., local community to range-wide) it is necessary that a uniform system be adopted by the polar bear Range States. When the Range States adopt such a system (i.e., PBHIMS), then a range-wide meta-analysis could be conducted to provide insight regarding the trend and occurrence of human–polar bear interactions. The main purpose of such an analysis would be to 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 parties 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.

TABULAR MONITORING SCHEME

Table 14 Methods and frequencies for monitoring of human-bear conflict in high-, medium-, and low-intensity monitored subpopulations of polar bears (PBHIMS = Polar Bear Human Information Management System).

Human-bear conflict		
	Recommended methods	**Comments**
High-intensity monitoring		
M	- Documentation of conflicts (cf PBHIMS). - Organize and analyze historic polar bear-human conflict data from archives and then maintain up-to-date records. - Investigate historic and current patterns of polar bear-human conflicts to address specific bear management and conservation issues. - Monitoring at village, industrial site, vessel, and tourism levels.	
F	Continuous monitoring and recording. Yearly compilation, analysis and interpretation of current data no less frequently than yearly.	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Continuous monitoring and recording. Yearly compilation, analysis, and interpretation of current data. Begin compilation of archival data for analysis in 2–3 years.	
Low-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Continuous monitoring and recording. Compilation, analysis, and interpretation of current and archival data as frequently as possible.	

Notes on Table 14

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.

4.7 DISTRIBUTION

The distribution of polar bears may be viewed at three spatial levels: 1) the global range; 2) ecoregion-specific; and 3) regional subpopulation distribution. A circumpolar monitoring plan should consider these different spatial levels because ecoregions or subpopulations are affected by different physical, biological and management factors Also, level of scientific information and TEK on polar bear distribution varies and is limited for some subpopulations.

Sea ice is an essential habitat feature for polar bear subpopulations as it provides the substrate necessary for bears to capture ice-dependent seals. The presence of sea ice during critical stages of polar bear life history allows polar bears to survive in the Arctic. Sea ice extent undergoes large seasonal fluctuations; 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). Seasonal ice ecoregions undergo complete ice melt and polar bears there must necessarily spend the entire summer and early autumn on land (Stirling *et al.* 1999). The annual variability of regional sea ice and the distribution of seals influence the distribution of polar bears (Ferguson *et al.* 1999; Gleason and Rode 2009). Apparently, there may be changes in subpopulation distribution as a result of increased temporal and spatial extent of open water during summer and autumn (Stirling and Parkinson 2006; Schliebe *et al.* 2008).

WHY POLAR BEAR DISTRIBUTION SHOULD BE MONITORED

An understanding of polar bear distribution is necessary information for addressing management issues (e.g., Amstrup *et al.* 2005b; USFWS 2010). Effective surveys of subpopulation size may depend on estimates 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/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. Such changes driven by reduced habitat availability or altered habitat character will lead ultimately to altered population welfare. Consistent records of changing distribution can inform management, regarding anticipated changes in the impacts of direct human removals (Peacock *et al.* 2011a), 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 will be necessary to mitigate the impacts of climate change habitat loss (Amstrup *et al.* 2010). It is also important to understand distribution of polar bears within populations for the better design of aerial survey and mark-recapture studies.

HOW DISTRIBUTION COULD BE MONITORED

Satellite radio-telemetry is a resource intensive technique that has been effective in the identification of, and in estimating the distribution and degree of discreteness of polar bear subpopulations (Bethke *et al.* 1996; Mauritzen *et al.* 2002; Amstrup *et al.* 2004). Counts from aerial transects may also provide estimates of changes in subpopulation distribution (Gleason and Rode 2009).

Identification of optimal sea ice habitat may be a useful proxy of polar bear distribution when other monitoring data, such as radio-telemetry or distance sampling, are not possible. Sea ice habitat has been shown to be a driver of polar bear distribution (Durner *et al.* 2009). Resource selection functions (RSF) 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 changes in sea ice extent and composition over time. While this has allowed predictions of polar bear subpopulation distribution in the Divergent and Convergent ecoregions (Amstrup *et al.* 2008), other RSFs may be necessary for estimating polar bear subpopulation distribution within the Archipelago and in the Seasonal Ice ecoregions. Estimating subpopulation distribution in ecoregions with low scientific access potential may be possible by reasonable extrapolation of RSFs from well-studied ecoregions.

Distribution of polar bears can also be studied through spatially-explicit mark-recapture (physical or genetic), aerial surveys and the returns of tagged animals in the harvest (Taylor and Lee 1995).

TABULAR MONITORING SCHEME

Table 15 Methods and frequencies for monitoring of polar bear distribution in high-, medium-, and low-intensity monitored subpopulations of polar bears.

DISTRIBUTION		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- Radio-telemetry, tag recovery, visual survey, genetic survey, CBM, aerial/ground/CBM den observations. - Systematic observations from ship traffic (tourism, industry, research) in the Arctic. - Estimate distribution with resource selection functions (RSF).	Does molecular genetics have the resolution to detect distribution change in the time frame needed within a high- intensity monitoring regime?
F	Frequency and intensity will depend on assessed level of threat. Adjust interval depending on rate of change and other threats.	
Medium-intensity monitoring		
M	Same as high-intensity monitoring.	
F	Ongoing	
Low-intensity monitoring		
M	- Tag recovery, visual survey, genetic survey, CBM, ground/CBM den observations. - Systematic observations from ship traffic (tourism, industry, research) in the Arctic. - Predict distribution through extrapolation of previously created RSFs or from RSFs developed in other regions.	
F	Annually or as frequently as possible.	To maximize ability for calibration.

4.8 PREY DISTRIBUTION AND ABUNDANCE

Polar bears primarily depend on the most ice-adapted seals (ringed and, to a lesser degree, bearded seals) for their survival in most parts of their circumpolar range. Stirling and Øritsland (1995) showed that in several areas of the Canadian Arctic, there is a significant relationship between estimates of the total numbers of bears and ringed seals over large geographic areas. Stirling (2002) reviewed how changes in reproduction of ringed seals in the Beaufort Sea resulted in marked and immediate responses in the reproduction and cub survival in polar bears. In some polar bear subpopulations, other marine mammal species such as harp seals, hooded seals, walruses, harbor seals, and sometimes belugas and narwhals can also be important and their relative importance in the diet may change over time (Thiemann *et al.* 2008).

WHY PREY DISTRIBUTION AND ABUNDANCE SHOULD BE MONITORED

As the climate continues to warm, there will be significant changes in the patterns of breakup and freeze-up of sea ice, and the extent and duration of periods of open water when most marine mammals are not accessible to polar bears. Monitoring changes in abundance of prey species and their relative importance to polar bears will be of significant importance to understanding, and possibly predicting, changes in the survival, reproductive success, and population size of individual bear populations. Population size of ringed seals and the proportion of ringed seals in polar bear diets in different polar bear subpopulations will be among the most important ecological factors to monitor into the future. In some areas, there are already data that can be used to compare the present, or future, to the past.

HOW PREY DISTRIBUTION AND ABUNDANCE SHOULD BE MONITORED

Several different kinds of studies have laid down quantifiable approaches to assessing the distribution and abundance of polar bear prey species, their reproductive productivity, and their importance to the diet of polar bears. The following methods will be helpful in different areas and with differing degrees of potential resolution because of both the huge size of the home ranges of most polar bears and the financial and logistic limitations to how widely most methods can be applied.

1) *Repeating quantitative aerial surveys on the distribution and abundance of seals undertaken in the past.* A number of quantitative surveys for ringed seals in particular have been conducted in past years (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 may provide broad but relatively course scale comparisons of ringed seal distribution and abundance over large geographic areas. Use of helicopter belly-camera 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 where some reasonable baseline surveys have been conducted in the past, and where polar bear subpopulations are already 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 the previous surveys. In future, it will be useful to designate areas where new and possibly better designed broadly based regional scale surveys may be appropriate.

2) S*pecific monitoring of indices of ringed seal reproduction and numbers in more specific areas.* Smith and Stirling (1978) demonstrated the feasibility of quantitative assessment of ringed seal reproduction between years. The method is applicable and repeatable but is labor intensive and requires well-trained dogs and probably mainly of benefit over a relatively local area. 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).

Collection and recording of species taken by polar bears that are encountered during the course of intensive polar bear studies will reflect changes in diet. Although it may be difficult to quantify, diet changes must reflect changes in prey availability, and may be an early indicator of changes in prey distribution and abundance. Similarly, in areas where local people hunt marine mammals, changes in composition of their takes will reflect these changes. Recording the species and sex and age composition of human takes would accompany collecting tissues from these harvested animals.

3) *Community-based monitoring of ringed seal reproduction and condition.* In settlements where ringed seals are harvested for local use, sampling of the harvest has provided information on condition and reproductive success (Harwood *et al.* 2000). This information has been demonstrated to provide direct and dynamic information on the reproductive success of the seals, which in turn has a direct effect on the bears (e.g., Stirling 2002, 2005).

4) *Indirect monitoring of diet.* In recent years, stable isotopes have been effectively used to study polar bear diet (e.g., Bentzen *et al.* 2007; Hobson *et al.*, 2007; Cherry *et al.* 2010). While useful, this method provides information more related to the tropic level of the prey, rather than the individual prey species. The 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 and harvest), the species being consumed by polar bears can be identified as well as their relative proportion in the diet (e.g. Iverson *et al.*, 2006; Thiemann *et al.* 2007a, 2008, 2011). Done at intervals of time, this technique is one of the most potentially useful methods available for monitoring possible changes in the abundance and accessibility of prey species to polar bears (Thiemann *et al.* 2008). To be effective, this method requires building up a region-specific reference set of fat specimens from all available prey species (Thiemann *et al.* 2007 a,b). Diet can also be inferred from morphological and molecular analyses of faeces samples (Iversen 2011). The information can be used to analyze spatial and temporal change in diet composition.

Sampling of ringed seal harvests during the open water period, and collection of fat samples from bears killed by Inuit hunters represents the most cost-effective method of obtaining relevant specimens but there is still considerable specialized laboratory follow-up required. The most important areas for continuing to collect fat samples, for 2-3 years at a time, at intervals of five years or so between collections, would be those subpopulations where polar bears are known to 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, or Svalbard). Such sampling would probably be appropriate for both the high and medium intensity monitoring subpopulations. Fat sampling for QFASA analyses in low frequency areas probably doesn't need to be done more frequently than 10 year intervals unless something changes that results in concern being upgraded.

TABULAR MONITORING SCHEME

Table 16 Methods and frequencies for monitoring of polar bear prey distribution and abundance in high-, medium-, and low-intensity monitored subpopulations of polar bears.

PREY DISTRIBUTION AND ABUNDANCE		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- Stable isotopes and fatty acid analyses of samples. - Prey surveys. - CBM-Hunter questionnaires. - Collect and analyze faeces samples. - Record observations of capture of alternate prey while conducting field work. - Collect specimens of prey found killed by polar bears for tabulation of species, age, sex, condition, degree of utilization and scavenging. - 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.	Fat samples from harvested or captured animals, or those sampled by biopsy darting.
F	Frequency and intensity will depend on assessed level of threat and scale of research undertaken. Adjust interval depending on rate of change and other threats.	
Medium-intensity monitoring		
M	- Stable isotopes and fatty acid analyses of samples. - Prey surveys. - CBM-Hunter questionnaires. - Collect and analyze faeces samples. - 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.	Fat samples from harvest or captured animals, or biopsy darting.
F	Frequency and intensity will depend on assessed level of threat and scale of research undertaken. Adjust interval depending on rate of change and other threats.	
Low-intensity monitoring		
M	- Prey surveys. - CBM questionnaires. - Changes in fast ice break-up etc. in relation to availability or abundance of prey, movements or travel of polar bears.	No harvest occurs in any of the low-intensity subpopulations.
F	Annual or as frequent as possible.	To maximize ability for calibration.

Notes to Table 16

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

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.

WHY MONITOR POLAR BEAR HEALTH?

For many years the health of animal populations has been assessed with the tools of population dynamics: estimations of trends in abundance, mortality, and reproductive rates. However, for species such as bears that have 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. As a consequence, efforts to link environmental stress with the health of populations remain speculative, lacking in convincing supportive data. 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.

HOW TO MONITOR POLAR BEAR HEALTH

One way to examine animal health is to evaluate body condition. Body condition indices can be estimated in a variety of ways if animals are physically handled including subjective fatness ratings, various length to weight ratios, and bioelectrical impedance to measure body composition (Stirling *et al.* 1999; Cattet *et al.* 2002; Robbins *et al.* 2004; Cattet and Obbard 2005; Stirling *et al.* 2008b), and condition indices have been used to assess the status of several polar bear subpopulations (Derocher and Stirling 1998; Stirling *et al.* 1999; Obbard *et al.* 2006; Rode *et al.* 2010). 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. However, different approaches that do not entail handling animals may be desired. Information on body condition can also be obtained from darted or harvested animals, or observations (e.g. from aerial surveys).

To date, the measurement of environmental stress in animal populations 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 grizzly bears (*Ursus arctos;* Chow *et al.* 2010), and has been effectively measured in polar bears (Chow *et al.* 2011).

Another novel approach is the use of cortisol (the primary stress hormone associated with the hypothalamic-pituitary-adrenal axis) in hair as a sensitive, reliable, and non-invasive measure of long term stress. Hair cortisol concentration (HCC) has recently been established as a biomarker of long-term stress in humans and domestic animals, and has been recently validated for polar bears (Bechshøft *et al.* 2011). Broad application of this technique may provide insight into potential linkages between the environment and population performance in a variety of wild species facing ecological change.

Other techniques are directed toward assessment of the cellular stress response, a homeostasis-restoring process that has evolved in all living organisms that is triggered within hours after perturbation, and persists until recovery (Bechert and Southern 2002). An example of this is heat shock proteins (Hsps), a family of proteins that are crucial for allowing cells to cope with stress (Feder 1999). Heat shock proteins are induced when long-term endogenous or exogenous stressors affect the protein machinery; they are not affected by short-term stress such as capture and handling. From the perspective of health monitoring, cellular stress is evident before biological function is altered, therefore detection of cellular stress offers the potential to 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 changing levels reflect a persistent change or simply inter-annual variation. Also, it will be important to test whether these indicators of "stress" are related to subsequent physical changes. If levels of these compounds change but are not associated with any detectable physical parameter, what does that mean? Similarly, as with physical measurements, changes in circulating levels of these compounds must be linked to a source of the stress to be really useful. Finally, correlations between these blood-borne indicators of stress and hair cortisol concentration (HCC) should be tested to see if there are consistent responses in line with the things all three are hypothesized to indicate. Nonetheless, there seems great potential here at relatively little extra cost to harvest monitoring and capture-recapture programs.

Once developed and verified, physiological indicators of chronic stress could be valuable tools to monitor status of the various subpopulations. Such samples could be obtained from hunter harvested animals or from a biopsy marking effort.

Multiple studies of polar bears indicate negative relationships between exposure to contaminants and health parameters. However, these are all of a correlative nature and do not represent true cause-and-effects and no effects on reproduction or survival have been demonstrated. Therefore, information from controlled studies of farmed Norwegian Arctic foxes (*Vulpes lagopus*) and housed East and West Greenland sledge dogs (*Canis familiaris*) have been included as supportive weight of evidence in the clarification of contaminant exposure and health effects in polar bears. Several studies have indicated that hormone and vitamin concentrations, liver, kidney and thyroid gland morphology as well as reproductive and immune systems of polar bears are likely to be influenced by contaminant exposure. Furthermore, exclusively based on polar bear contaminant studies, bone density reduction and neurochemical disruption and DNA hypomethylation of the brain stem seemed to 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.

TABULAR MONITORING SCHEME

Table 17 Methods and frequencies for monitoring of polar bear health in high-, medium-, and low-intensity monitored subpopulations of polar bears.

POLAR BEAR HEALTH		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	Captured Bears: • Mass and straight-line body length→Body Condition Index • Axillary girth and zygomatic width→can be used to predict mass • Bioelectric Impedance Analysis - BIA (requires mass as an input) • Condition scale 1-5 (1 vs. 2 scale for aerial observations) • Pathogens and contaminants in blood/feces; • Fat content from biopsy • Stress levels (blood parameters: CBG and/or Hsps, and HCC from hair) Harvested bears: • Axillary girth of newly harvested bears. • Skull length and width (with girth can predict mass). • Condition index assessed by hunters (1-5) (Stirling *et al.* 2008b). • Fat thickness at predetermined point(s), and fat content from samples collected at harvest. • Contaminants in fat tissue or various organs. • Stress levels (HCC) - from hair samples from handled and harvested bears, or from hair traps.	
F	Ongoing	
Medium-intensity monitoring		
M	Same as high-intensity monitoring.	
F	Ongoing	
Low-intensity monitoring		
M		Currently no harvest in any low-intensity subpopulation.
F	Ongoing	

Notes for Table 17

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., Macbeth *et al.* 2011; Bechshøft *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.

4.10 STATURE

Stature is used here as a broad term to describe any measurable aspect of the physical size, mass or condition of a polar bear.

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) and other large vertebrates (e.g. roe deer, Kjellander *et al.* 2006) and ice-dependent marine mammals (Hammill and Stenson 2011) indicate that density can play an important role in limiting populations. However, because polar bears are not territorial and typically occur at very low densities on the sea ice it is likely that density-independent factors (e.g. changes in the availability of prey in relation to sea ice distribution) will have the greatest influence on any observed changes in polar bear stature.

Monitoring reductions in polar bear body size (e.g. skull length/width and body length) can provide an indication of nutritional stress during early development 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 ultimate adult size. If they encounter a mixture of bad and better years as they are growing up, they may be able to survive, but will not be able achieve the growth rates and ultimate sizes they could have had conditions consistently been better. Because a symptom of global warming is more erratic climate and weather fluctuations, one of the early effects could be reduced stature of current adults compared to previous times.

Body stature has been related to reproductive success for bear species and other large mammals (Noyce *et al.* 1994; Hilderbrand *et al. 1*999; Clutton-Brock *et al.* 1988) Both Atkinson *et al.* (1996) and Derocher (2005) have 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 (i.e. skull length/width and body length) 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 (Rode *et al.* 2010). The body condition of bears can be estimated using combinations of morphometric measurements and estimated weights (e.g., the Quetelet Index; Ganong 1991 or the body condition index; Cattet *et al.* 2002) which can provide a measure of energetic reserves available to an animal for reproduction and survival. 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 1994) that are less likely to survive (Derocher and Stirling 1996). In summary measuring the stature of polar bears provides insight into both historic and current shifts in the availability of energetic resources in addition to providing potential valuable insight into future subpopulation demographics.

HOW TO MONITOR POLAR BEAR STATURE

In table 18 below a standard set of metrics to monitor spatial and temporal variation in polar bear stature is described.

Table 18 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 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.
Quetelet Index	Body mass/(straight line length)^2
Body Condition Index	Require that both body mass and straight line length be known (see Cattett *et al.* 2002 for equations).

Monitoring polar stature should be a mandatory component of all research programs that involve research handling of polar bears. All of the measurements with the exception of body mass can be obtained with a tape measure, small diameter nylon rope and a set of calipers. Weighing polar bears, although time consuming, can provide valuable information on the condition of animals. Thus the importance of weighing captured bears, or a sample of captured bears, must be weighed against 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 a sufficient length of rope to measure both of these metrics. Hunters would simply 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 then put it in their harvest collection kit. A similar process could be followed for measuring the axillary girth. Skulls and bacula should be collected from harvested bears where possible to get detailed measurements of skeletal growth.

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

TABULAR MONITORING SCHEME

Table 19 Methods and frequencies for monitoring of polar bear stature in high-, medium-, and low-intensity monitored subpopulations of polar bears.

STATURE		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	Measurements from live bears and harvested bears: skull length and weight, body length, girth, body condition. Measurements from skeletal material in museum collections.	
F	Ongoing	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Ongoing	
Low-intensity monitoring		
M	No available measurements from harvested bears. Measurements from skeletal material in museum collections.	No current harvest in any low-intensity subpopulation.
F	Ongoing	

4.11 HUMAN ACTIVITY

Such activity includes mineral exploration and development, tourism (polar bear and non-polar bear), scientific research (non-polar bear), shipping, and infrastructure development to support these.

WHY MONITOR HUMAN ACTIVITY?

Historically, the remoteness of the Arctic marine environment probably provided adequate protection for both polar bears and their habitat. 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). This increase in human activity and the number of people either visiting or working in areas inhabited by polar bears increases 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 are less understood (Vongraven and Peacock 2011). Polar bears are often attracted by the smells and sounds 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).

Andersen and Aars (2008) reported that polar bears appear to be disturbed by snowmachines and often showed avoidance behavior. The effects of increased ship traffic, pollution from human activity, and noise on polar bears and their prey are unknown. Ice-breaking vessels and industrial noise have been shown to increase abandonment of subnivean seal structures on sea ice, and consequently may have negative impacts on ringed seal breeding (Kelly *et al.* 1988). All such data can 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).

Although chronic human disturbance may result in polar bears abandoning preferred habitats, previous research suggests that females tolerate human activity within relatively close proximity to den sites (Amstrup 1993). There are reasons to believe that some impacts can be controlled with good management. However, combined effects of several negative factors acting simultaneously (e.g., climatic stress, pollution, and disturbance) can be difficult to predict and constitute a problem that needs increased attention from both scientists and managers. The cumulative impact of chronic human disturbance, whether from industry or tourism, from infrastructure, or noise, is unknown, but could potentially be long-term and 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 likely vary across the Arctic, it is important to begin collecting baseline data on an ongoing basis for all subpopulations.

HOW TO MONITOR HUMAN ACTIVITY

Many of the human activities that occur within polar bear habitat typically require proponents to submit applications and to be issued with permits. Therefore, much of the monitoring can likely be done through regulatory requirements and reporting schedules that become conditions of this process. National contact points will need to be established to collect and collate these data on an annual basis.

1. *Permit applications* – All proposed exploratory or development activity, ship passages, tourism, and non-polar bear research (for polar bear research, see section 4.13) should be recorded and subsequently reported to document the interest in the various types of activities, frequency, intensity, timing, and areas of interest. 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 be occurring in key areas important to polar bears or at particularly sensitive times of the year.

2. *Activity that actually occurs* – In addition to knowing what activities are planned, it is equally important to document the details of the various types of activities, frequency, intensity, timing, observations of bears, and location of activities that actually occur within polar bear habitat. This is particularly important if permit applications are broader in scope. For example, if a tour company applies to bring five tours to an area over a defined period of time, it would be important to capture after the tours are over how many days they were in area, how many tourists were involved, how many bears did they see, etc.

3. *GIS applications and remote sensing* – Through the use of these technologies and the information collected above, spatial and temporal analysis could be undertaken to identify particular areas that might be of concern with respect to human activity and disturbance. These types of analysis may also refine additional monitoring needs and/or specific research questions that need to be answered.

4. *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.

TABULAR MONITORING SCHEME

Table 20 Methods and frequencies for monitoring levels of human activity in high-, medium-, and low-intensity monitored subpopulations of polar bears.

HUMAN ACTIVITY		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- Monitor permit applications: exploratory and development activity, ship passages, research (non-polar bear) permits. - Monitor actual exploratory and development activities (e.g. number of drill or production sites), numbers of ship passages, or tour ship cruises. - GIS calculations of how much of available habitat is impacted by industrial or other human activities. - Develop a system of recording incidents of bear human interactions resulting from various kinds of human activities in polar bear habitat. - Study impacts of supplemental feeding.	
F	Ongoing	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Ongoing	
Low-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Ongoing	

Notes for Table 20

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.

4.12 BEHAVIORAL CHANGE[3]

There are at least two circumstances where recording of behavior (using the term broadly) might be useful, and 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, at different time periods, can provide insight into the ways in which change, if it is occurring, could be manifested. Data on relative hunting success could be useful as input for energetics models. Qualitative documentation of certain kinds of specific behavior, recorded on an opportunistic basis, would be extremely valuable, for example expert-opinion models (Amstrup *et al.* 2008), provided the recording is done consistently and reliably.

WHY MONITOR CHANGES IN POLAR BEAR BEHAVIOR?

Potentially, the most insightful behavioral comparisons could be made using quantified activity budgets and hunting success rates. For areas such as Radstock Bay in the Canadian High Arctic, and the western coast of Hudson Bay there has been some quantitative documentation of activity budgets. At Radstock Bay, activity budgets, and hunting success of bears of different ages and sex classes, and with different ages of cubs, have been quantified in several different 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 open water season has been quantified at Cape Churchill and some other points near the coast (Latour 1981; Lunn and Stirling 1985).

Probably the most important documentation of behavior, which might indicate the overall health of a polar bear subpopulation, relates to bear-human events and intraspecific mortality events. Systematic documentation of the number of problem bears that occur in settlements, and individual-specific information on the age and body condition of animals killed as problem bears (see section 4.6) is probably 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 extremely relevant to testing of hypotheses related to whether the subpopulation being 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.

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

[3] This section overlaps to some extent with section 4.6 Human-bear conflict.

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 entirely on the reliability of the database over time. Bears killed because they threatened human life or property may be given a normal hunting tag, but the reason for their death still 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/novel behavior and intraspecific polar bear mortality: Observations of cannibalism, swimming and drowning, infanticide, have been made in subpopulations where we think food stress and body condition are becoming an issue. Systematic recording of these behaviors plus other irregular or novel behaviors, such as unusual hunting strategies (e.g. digging through ice), taking 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 directly related to its completeness. The value also depends on available information on observer effort.

Quantitative energy budgets: At this point, considering quantitative energy budgets is probably more of a research approach than one that might be useful for monitoring. An initial test of its potential usefulness might be considered in western Hudson Bay because there are some data from the past and we know it is being fairly severely affected now. The only place where past data exists is Radstock Bay in the Canadian High Arctic.

TABULAR MONITORING SCHEME

Table 21 Methods and frequencies for monitoring of behavioral change in polar bears in high-, medium-, and low-intensity monitored subpopulations of polar bears.

BEHAVIORAL CHANGE		
	RECOMMENDED METHODS	**COMMENTS**
High-intensity monitoring		
M	- Systematic documentation of human-bear conflicts (see section 4.6). - Systematic documentation by scientists and CBM (e.g. , cannibalism, digging through ice, infanticide, drowning). - Observations, facilitated by radio-telemetry and other intensive monitoring and study, of swimming, unusual hunting strategies, taking of alternate prey, erratic and anomalous behaviors. - Changes in movements and home range sizes. - Changes in denning chronology, timing of appearance on land. - Visual observations, CBM of possible observations of changes in distribution and habitat uses or other aspects of natural history. - Occurrence of hybrids.	
F	Ongoing	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Ongoing	

Low-intensity monitoring		
M	- Visual observations, CBM, changes in distribution and habitat uses, observations of unusual hunting strategies, taking of alternate prey, erratic and anomalous behaviors (e.g. cannibalism, digging through ice). - Changes in denning chronology, timing and location of appearance on land. - Occurrence of hybrids.	No facilitation from radio-telemetry studies.
F	Ongoing	

4.13 EFFECTS OF MONITORING POLAR BEARS ON POLAR BEARS

Monitoring polar bears can involve immobilizing polar bears to collect samples, mark 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).

WHY MONITOR POLAR BEAR MONITORING AND RESEARCH?

Concerns about the impacts of polar bear monitoring have been raised by both members of northern communities, management agencies, and scientists (Dyck *et al.* 2007; Cattet *et al.* 2008). Specifically, concerns about the lethal and sub-lethal effects of handling on polar bears, the number of bears being handled, the impacts of wearing a collar or other devices (e.g., impact on bears 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 bears that have been drugged). Whether or not the capture of polar bears has a measurable impact at the individual or subpopulation level, the capture of polar bears and/or the volume of research, is considered not appropriate by a constituency of the northern public (Inuit Tapiriit Kanatami 2009). Further, as polar bear subpopulations are becoming increasingly stressed, the relative 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. Many Inuit consider chemical immobilization of bears unacceptable as they claim that the immobilization drug changes the taste of the meat and fat (Henri & Peacock 2011). Further, permanent dye applied to bears in some populations (the southern Beaufort Sea) to avoid recapture of the same bear the same season renders the hide of the bear unusable.

Impacts of polar bear research vary depending on the method. It is difficult to imagine thataerial surveys could have effects on the subpopulation level. Although flying at low altitude obviously disturbs individual bears, there are no studies that document the presence or absence of effects on the subpopulation level. 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 usually requires approval by a wildlife/animal care committee and adherence to best practices following techniques that minimize potential impacts. Impacts of wearing a collar on the energetics and survival of an individual bear seem to be insignificant (Messier 2000), however determining the impacts would be difficult and require a study specifically design for this purpose. Analysis of existing data may yield additional insight. There is now an increased use of electronic release mechanisms for collars.

Monitoring polar bears has obvious 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. The effects relative to information needs must be judged by management/co-management authorities, affected communities.

To date, there is little or no 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). 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.

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
- Number and types of radio telemetry devices deployed annually
- Type of treatment (and medicamentation) 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 annually (i.e., bear has been handled before)
- Average number of times the recaptured bears have been handled in their lifetime (with maximum and minimum)
- Number of sightings of marked bears during polar bear research annually
- 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 as of Dec 31
- 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. An international group (e.g., CAFF, IUCN/PBSG or designates of the Range States) could provide the infrastructure (most effectively, web-based) for reporting these parameters.

TABULAR MONITORING SCHEME

Table 22 Methods and frequencies for monitoring of polar bear research in high-, medium-, and low-intensity monitored polar bear subpopulations of polar bears.

Polar bear research		
	Recommended methods	**Comments**
High-intensity monitoring		
M	Level and intensity of research by subpopulation as listed above.	
F	Annually	
Medium-intensity monitoring		
M	Same as for high-intensity monitoring.	
F	Annually	
Low-intensity monitoring		
M	Same as for high-intensity monitoring (if research occurs).	
F	Annually (if research occurs).	

5. LOCAL KNOWLEDGE AND INVOLVEMENT

It is an integral part of this effort to coordinate monitoring efforts around the circumpolar Arctic employing both scientific approaches and locally acquired knowledge (e.g. Traditional Ecological Knowledge and Local Knowledge) and the monitoring of relevant parameters using community-based monitoring approaches. This collaborative approach, using both scientific and local, traditional, approaches is an ongoing challenge, however, good examples of such collaborative approaches do exist in many parts of the Arctic (e.g. Beluga monitoring and research in the Western Canadian Arctic). In order to achieve a solid understanding of the circumpolar status and trends in polar bears and their habitat, a successful collaborative effort, utilizing scientific and community-based approaches alongside the application of TEK is crucial.

For a number of the parameters and subpopulations identified in this monitoring plan, community-based monitoring and the application of TEK has been identified as a core approach. To successfully, implement such a collaborative approach, establishing productive and trusting relationships with communities is vital. The following sections not only describe community-based monitoring and Traditional Ecological Knowledge in the context of polar bear monitoring but also identify elements that make these collaborations successful.

5.1 COMMUNITY-BASED MONITORING (CBM)

Community-based monitoring (CBM) is a phrase that is often used when describing "the gathering of information by local residents over a period of time" (Gofman 2010). It is an emerging technique that strives to systematically collect and document either scientific information and/or traditional ecological knowledge (see Section 5.2) through local people (e.g., Harwood 2000) in order to obtain the best available basis for managing the resource in question. CBM requires a careful fostering of relationships between communities and researchers. It also requires long-term planning that establishes trust between the proponents and participants of CBM. If a CBM project is to be part of a larger monitoring effort, the details of the CBM component need to be conceptualized in tandem with the larger project.

Potential parameters for CBM in the context of polar bear monitoring could include hunter specimen return programs, locations of denning sites, health and local abundance of bears harvested and observed, local ice conditions, local abundance and distribution of key prey species, and observations of behavioral changes (see Section 4). For polar bear monitoring, CBM has the potential advantage of providing cost-effective monitoring by people who live within polar bear habitat. CBM has been used successfully to monitor bowhead whale (*Balaena mysticetus*) numbers on in the southern Beaufort Sea of the USA (George *et al.* 2004), ringed seals (*Phoca hispida*) in Amundsen Gulf, Canada (Harwood *et al.* 2000) and is being used to monitor marine mammal health and movements in the Hudson Bay region of Canada (Ferguson *et al.* 2010). Specifically, with respect to polar bears, CBM has been used extensively in the harvest sampling and monitoring in Nunavut and the Northwest Territories in Canada and in Greenland; information provided by these data have been used in abundance monitoring (e.g., Taylor *et al.* 2005) and other ecological studies on polar bears (e.g., Thiemann *et al.* 2008).

In most regions where polar bears occur the species is regarded by the indigenous peoples as iconic, often symbolic of traditional culture and practices, in addition to being a practical source of food, clothing, and income. Across the circumpolar Arctic, the input of local communities in polar bear monitoring and management has varied. In Greenland consultation and dialogue with local communities is an integrated part of the process leading to the determination of the size of regional quotas for the take of polar bear. In Canada, polar bears have become political focal points, and in some communities the management regimes may be viewed as not supportive of traditional harvesting practices. Up until recently, most management decisions in Canada have been based upon science, in accordance with Article II of the Agreement on the conservation of polar bears (see PBSG 2006). Efforts have been made to ensure the contributions of local knowledge and direct participation through CBM and direct participation in management such as is the case with the Inuvialuit-Inupiat Agreement for management of polar bears in the Southern Beaufort Sea (Brower *et al.* 2002). Wildlife co-management boards, Institutions of Public Governance that are derived from legislated Land Claim Agreements have been established in Canada to ensure greater emphasis on local and regional participation on decisions that affect harvesting. Many of these Land Claim Agreements require to some degree that CBM be integrated into management decisions (references needed). Through these processes, many northern communities in Canada are now undertaking their own CBM in order to obtain the data that in their view is necessary to ensure sustainable harvesting (references needed). Many of the organizations have also published research guidelines that recommend best practices for conducting research in northern communities (for example the Yukon North Slope Research Guide: http://www.wmacns.ca/conservation/ltrmp/researchguide/) that can be of substantial use for all proponents of CBM.

In Greenland, CBM involving that polar bear hunters routinely take various tissue samples from their kill has been practiced since the mid-1980s. This successful cooperation between scientists from Greenland and Denmark and the local hunting communities is especially taking place in the polar bear hunting areas in NW and Central East Greenland. The sampling by the hunters, and its local organization, has been instrumental for e.g. long-term studies of pollution in polar bears (cf. Sonne 2010), analyses of the catch composition (e.g. Born 1995a,b, Rosing-Asvid 2002) and reproduction (Rosing-Asvid *et al.* 2002).

Extensive consultation with a community and its hunters is a prerequisite for a CBM project. Establishment of a relationship between all the participants in a particular project, whether it be with an organization or individuals in a community, aids in essential communication and understanding of both the project and its implications. If there is widespread opposition to any element of the project, then the community concerns must be taken into account and the study design changed accordingly. Prior consultation about potential joint projects, combining CBM and science, is important because it is beneficial if the community needs to fully understand the objectives and potential benefits of a project.

Once a community has indicated support for a CBM project, the proponents of the project need to allocate sufficient time and resources to training the participants and communicating the rationale for the methodology. It is also important to be flexible, and to understand that participants often have other priorities than the project, as long as flexibility does not compromise chosen methodologies. Frequently there is a high degree of turnover among participants, and CBM proponents need to be prepared for this. It is recommended that a core group of participants be established who 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. While the best CBM projects employ quantifiable methods that allow for meaningful comparisons to other data, it is also important to relate these methods and data back to the community in a way that is easily understood by community members.

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). Common to all terms and definitions is that the knowledge is specific to geographic place, society, culture, individuals, has accumulated over time and is dynamic. There is some similarity to ecological science in that it is based on an accumulation of observations but, historically at least, the observations, hypotheses, and validation tests were not recorded in written form instead transmitted orally.

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.

The challenge of using TEK to monitor polar bears is dealing with its often qualitative and narrative format requiring use of social science methodologies (Huntington 2000) and its geographic specificity which can limit regional or broader applications (Gagnon & Berteaux 2009; Krupnik & Ray 2007; Wohling 2009). However, there have been recent innovations in the use of TEK, for example: TEK has been used to parameterize a population simulation model for harvesting the New Zealand pigeon (Lyver et al. 2009), to model habitat use and distribution of fish (Mackinson 2001), and to detect population trends and changing habitat use of arctic birds (Gilchrist et al. 2005). In some instances, TEK has been tested and compared with science and found to be robust (Anadon et al. 2009; Lyver & Gunn 2004; Wong 2010). There is agreement that combining science and TEK is important and beneficial for advancing understanding and management of wildlife (Berkes et al. 2007; Krupnik & Ray 2007; Moller et al. 2004), including polar bears (Peacock et al. 2011).

TEK of polar bears has included distribution, movements, travel routes, habitat use, population, cub production, denning, behaviour, hunting methods and success, tracking, health, and prey species. This research has occurred in Greenland since 1983 (Born et al. 2011), Canada (Dowsley 2005; Harington 1968; Keith 2005; Kotierk 2009b; Maraj 2011; Sahanatien et al. 2011; Slavik 2010; Urquhart & Schweinsburg 1984; Van de Velde 1971; Van de Velde et al. 2003; Wong 2010), Alaska (Kalxdorff 1997), and Russia (http://belyemedvedi.ru/index.html) (Kochnev et al. 2003; Zdor 2007). The TEK was collected using the semi-directed interview method and/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 (Anon 2005, 2008; McDonald et al. 1997; Sang et al. 2004). While many of these studies collected TEK about observations of changes in polar bear ecology, behaviour, populations and sea ice habitat, most studies were not designed for monitoring of population size or trend. 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 (see section 5.1).

As an example, the Arctic Borderlands Knowledge Co-operative (http://www.taiga.net/coop/) began collecting TEK in 1996 using standardized questionnaires, with the goal of wildlife monitoring in arctic Canada and Alaska (Anon 2005). The TEK on caribou was analyzed and some trends were observed, it was not possible to attribute causal factors but new questions arose about caribou ecology and harvest management (Russell et al. 2008).

Sea ice and climate research has made considerable progress in collecting and reporting on TEK and using TEK for monitoring (Gearheard et al. 2011; Krupnik et al. 2010; Laidler & Elee 2008; Pulsifer et al. 2011; Weatherhead et al. 2010). Inter-disciplinary teamwork, developing a strong relationship with communities, principle investigator continuity, common researcher and community objectives, and strong community interest and knowledge of sea ice and climate (the research topics) are emergent themes.

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 (Peacock et al. 2011). Some jurisdictions require the use of TEK for management of polar bears and have a policy framework for monitoring (Anon 2004).

TEK has been used where scientific information is lacking for regions where little is known about polar bears 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 in duration. People holding TEK on are on the ground and sea ice year round and for generations.

TEK is an avenue for discovering new information, to elucidate existing questions and formulate hypotheses (Gagnon & Berteaux 2009; Huntington 2000). Conceptual models are the bases for TEK but it can take time and intellectual openness for people from outside that culture to realize and comprehend the models (Gearheard et al. 2010; Laidler 2006; Mackinson 2001). As such, TEK can improve the quality of scientific research and monitoring. Collection of TEK is also a mechanism for involving harvesters and communities (e.g., CBM) in polar bear conservation and developing support for polar bear conservation (Berkes 2002; Kofinas et al. 2002). However, the primary purpose of TEK collection should be to collect reliable information to help make more informed wildlife management decisions (Gilchrist & Mallory 2007).

MONITORING POLAR BEARS USING TEK

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.

To facilitate trend analysis a standardized questionnaire or survey method should be used but one that allows participants to elaborate as in a semi-directed interview. Each questionnaire or interview should include spatial information options.

It is essential that individuals collecting TEK are knowledgeable about the subject to allow informed interactions with the participants particularly when semi-directed interviews methods are used. The ability to speak the local language (e.g. Inuktitut, Cree) is essential, and if not, the interviewer must use an experienced interpreter; someone that knows wildlife, habitat, hunting, and sea ice terminology All materials should be translated all materials into the local language and appropriate dialect. In arctic North America it has been found that TEK collection is best done in-person, rather than sending out a questionnaire, 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.

RECOMMENDATIONS FOR MONITORING POLAR BEARS USING TEK

It is vital to move quickly to develop TEK baselines as youth in some regions of the Arctic are increasingly less knowledgeable of the environment and wildlife in comparison to elders. It is important to collect the knowledge of elders that were born and lived in coastal camps in close proximity to polar bears. These interviews will extend the time series to pre-harvest management times and the strong effects of climate change on sea ice habitat.

Because TEK is also limited by environmental and physiographic conditions (e.g. travel on land and sea ice, season and available light) the limitations of TEK for monitoring in a particular project must be identified prior to the start of the study. For example, hunters may hunt in the fall while bears are accessible on land or in spring when bears are on the sea ice. Sometimes TEK can be limited by lack of spatial and temporal information to qualify or quantify local observations (Peacock et al. 2011). Further, TEK is by definition retrospective and local, and does not include predictive tools to extrapolate over space and into the future; yet such models have been useful for managers to act pro-actively (Amstrup et al. 2008; Taylor et al. 1987). Polar bear managers and scientists must work with communities to determine what aspects of polar bear ecology can be monitored using TEK. People recognized the limitations of their knowledge (Grenier 1998; Laidler 2006; Sahanatien 2011).

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. Polar bear management and legislative restrictions have changed the type or 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 allow understanding of the variability across a subpopulation and to provide opportunity for inter-community collaboration (Dowsley 2009). Medium intensity monitoring is appropriate for subpopulations with communities that are amenable to non-personal collection of TEK. Low intensity monitoring is not possible in light of the effort and expense required to collect and analyze TEK; no monitoring or low intensity monitoring will necessarily occur where there are no communities or traditional-use areas.

TABULAR MONITORING SCHEME

Table 23 Methods and frequencies for monitoring TEK of polar bears. Note, the level of intensity of TEK monitoring do not parallel those levels identified for scientific monitoring

Traditional ecological knowledge		
	Recommended methods	**Comments**
High-intensity monitoring		
M	-Questionnaires with in-person discussion -Semi-directed interviews	Questionnaires need to be user friendly, not too long and well designed. Translated into local language and dialect.
F	-Annually, post harvest season, during break-up and/or freeze-up	Schedule needs to be determined with the communities to be in-sync with knowledge collection.
Medium-intensity monitoring		
M	-Questionnaires – mail out, email and/or web-based	Mail out, email or web-based questionnaires need to be user friendly, not too long and well designed. Translated into local language and dialect. If email or web-based consider the quality of local internet and ease of access.
F	-Annually based on appropriate timing for that region	Schedule needs to be determined with the communities to be in-sync with knowledge collection.
Low-intensity monitoring		
M	N/A	Low intensity is not possible based on the nature of the data and locations of communities.
F	N/A	

6. KNOWLEDGE GAPS

Some information needs for the conservation and management of polar bears supersede what can be ascertained from monitoring efforts. 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 either baseline or more sophisticated ecological research. In Table 24 below there is an overview of the most important knowledge gaps that will improve monitoring of the chosen parameters if they were sufficiently addressed.

Table 24 Main research needs to enhance monitoring of polar bears.

Monitoring topics	Knowledge gaps	Suggested approach	Comments
Population size and trend	Effect of incomplete sampling on estimates	Simulation studies to quantify bias in estimates caused by unequal capture availability	In many areas, studies include only part of the subpopulation range. This results in variation in availability of each individual for capture which can bias estimates. The extent of such bias is yet to be established.
	Understanding optimal sampling strategies and frequencies	Resampling/simulation studies based on existing databases.	
	Understanding cost/benefit relationships between high frequency capture recapture and alternate less intensive methods	Parallel investigations using proven methodologies along side alternatives (e.g. various aerial survey approaches, genetic sampling, single season mark-resight)	
	Quantitative evaluation of status and trend information available from harvest data.	Comparative assessment of harvest data and various ways of analyzing it to subpopulation information gained from intensive sampling.	
	Influence of fasting periods of different durations on reproduction, demographic characteristics, and, consequently, population size and trend.	Documentation of energetic requirements from captive and field studies to improve data base and modeling of effects similar to earlier work by Molnar.	Several populations may be approaching the point where large scale negative effects are likely to occur as a result of extended periods of open water. An improved ability to forecast consequences will emphasize the need to develop strategies for responding.
	Understand the capabilities vital rates monitoring in bears to indicate trends in numbers.	Evaluate available simulation modeling and determine its applicability to polar bears.	Assessing trends with vital rates rather than measured changes in numbers depends on many assumptions as well as on precise and unbiased assessments of rates. The degree to which we have or could acquire such assessments needs to be evaluated with simulation studies.
Reproductive rates	Mechanisms affecting litter production and size	Nutritional/energetics studies and simulation	
		Changes in distribution and frequency of denning, Comparisons of corpora and luteal scar counts versus cub production rates	
	Reproductive plasticity	Studies of controls on timing of implantation and parturition (light sensing ear tags, implanted birth monitors)	
Survival rates	Mechanisms affecting recruitment of young	Studies of timing of mortalities (after den emergence, summer ice free period, winter)	
		Understanding partial versus whole litter losses	
		Understanding nutritional versus mechanical (e.g. forced long swims) issues.	
	Comparisons of marking studies to visual observations	Comparing assessments of trend via C/R versus counts of young per adult in several different populations.	Such parameters are likely to vary between populations so comparative studies could be quite important

Habitat and ecosystem change	Habitat use	Expansion of data for RSF modeling throughout the Arctic and enhancement of RSF methodologies to take advantage of latest methods and imagery.	
	Changing habitat	Assessment of productivity changes,	
		Assessment of snow accumulation WRT ringed seal reproduction	
	Altered prey structures	Studies of changing prey availability, aerial surveys, harvest monitoring,	
	Altered prey utilization	Refinements of methods (Stable isotope, fatty acid analysis) necessary to evaluate changes in diet and variations in individual-specific predation strategies.	
	Telemetry/energetics studies	Improvement of methods for understanding movements and habitat use by bears to refine energetics models and quantify polar bear dietary plasticity	
	High Arctic information void	Basic high intensity research is necessary in High Arctic areas to provide the basis for measuring changes that are yet to come to these areas.	
Human-caused mortality	Refine assessment methods	Studies to compare M-R approaches to CBM approaches.	
	How to quantify unintentional human caused mortalities	Understanding cumulative effects of industrial development, tourism, northern field camps etc.	
Sublethal human impacts	Separating the fact of a disturbance from the effect of that disturbance	Improving methods for understanding impacts of human disturbances (energetics, food deprivation,	
Distribution changes	How is distribution changing as habitat changes	Telemetry studies in representative areas of each ecoregion to understand differences in responses to changing sea ice patterns.	
	Energy impact of altered movements and distribution	Energetics studies and simulation studies.	
	Understanding potential for supplemental feeding	Quantitative assessment of costs and benefits of feeding polar bears during ice free season, to aid persistence or simply to divert them from areas we don't want them.	Necessary to prepare us for a topic that will come up as polar bears face more protracted periods of ice absence over greater portions of their range.
Prey Distribution and Abundance	Assessing the relative population sizes and accessibility by species in different areas over time.	Quantitative monitoring using fatty acid analysis, aerial surveys of population size of prey species, sampling of prey killed by polar bears.	With climate warming, both access and species structure are likely to change significantly in several areas, some within the next 10-20 years.
Population Condition Metrics	Appreciation of relationships between various body metrics and animal health	Quantitative studies of changes in stature versus changes in mass and how these relate to reproduction and survival.	
	Assessments of stress	Quantify relationships, if any, between various cortisol measurements and physical well-being.	
Behavioral Change	How are polar bear behaviors changing as a result of habitat changes	Telemetry studies and collaborative work in communities to establish methods to quantitatively monitor changes.	To date, we have mainly anecdotal observations of changes in behaviors. We need to determine how to quantify these things so that they can become part of a monitoring scheme.
Effects of polar bear monitoring on polar bears	Is (and how is) monitoring affecting the polar bears being studied.	Quantitative comparisons of body stature and condition, and cub production and survival between marked and unmarked bears. Comparisons in movements between bears that are radiocollared versus those that are fitted with ear-tag or glue-on tags.	Any time we study animals, we have a chance of altering the natural state of things. We need to assess as well as possible whether such alterations we might be causing may bias our findings.
Technological Development	Employ advances in technology to create new methods and to understand polar bears	Development of less-invasive satellite tags, high-resolution imagery, use of telomeres for genetic aging, metric of condition from fat samples, etc.	

7. PRIORITY STUDIES

There are two projects/activities that need to be given higher priority than the other research needs described in the previous section. The first one is vital to find optimal sampling schemes and the other because it will utilize a large collection of polar bear samples that will provide a significant amount of relevant information on harvested polar bear subpopulations.

7.1 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, which could be used for such an analysis, i.e. Western Hudson Bay. Such an analysis could be conducted by selecting out 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 the needed information to scale sampling effort accordingly. Even though a high number of marks in the population is generally considered a good thing for long-term population monitoring, a cost-benefit analysis could provide guidance on sample size requirements for particular desired confidence level.

Such a power analysis should be initiated as soon as possible. Endorsement should be sought among the Parties to the 1973 Agreement on the conservation of polar bears at their meeting in Iqaluit, Oct 24-26 2011, after which funding partners should be found to complete such a study in 2012.

A related aspect that could be analyzed from existing data bases 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 good enough 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, collected over many years, but not always from the entire area. An evaluation of the value of surveys of partial samples could be evaluated.

7.2 STUDY #2: ANALYSES OF EXISTING SAMPLES FROM 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 and the majority of these have age, sex, date of harvest, and location data collected. The effort dedicated to the collection of harvest data suggests that this is important information for the management and monitoring of polar bear subpopulations. Redoubling and coordinating efforts to collect and analyze harvest data is necessary due to the known impacts of harvest on polar bears (e.g., Taylor *et al.* 1987; McLoughlin *et al.* 2005; Molnar *et al.* 2008b).To date, harvest samples have been valuable in contributing to the estimates of population size and survival (e.g., Taylor *et al.* 2005, 2008, 2009), distribution (Taylor & Lee 1994), population structure (e.g., Paetkau *et al.* 1999; Crompton *et al.* 2008), foraging ecology (Thiemann *et al.* 2006) and basic zoology (Dyck *et al.* 2004). Further, much of what we know about contaminant accumulation and variation diet has been derived from harvest samples (e.g., Verreault *et al.* 2005; Thiemann *et al.* 2006).We call for more systematic analysis of polar bear harvest data and samples.

We know that large mammal populations with high/excess harvest levels tend to show a shift towards younger mean ages. In other situations, such as low recruitment, a shift towards older animals can reflect demographic changes in a population. Given that male polar bears are more vulnerable to harvest, because of management regulations, a shift in the harvest sex composition may indicated shifts in hunter behavior or changes in subpopulation composition. Given that many harvested subpopulations are monitored at a 15-20 year interval, harvest data may provide insights into subpopulation status..

Given the length of the data series, the breadth of area of collection, and the consistency of methodology, the harvest data provides a meaningful and substantive source of monitoring data. Methodology for analysis of harvest data for detecting change in polar bear subpopulations is only partly developed (Taylor *et al.* 2008b).

Use of harvest data for subpopulation monitoring falls into 2 broad classes: analysis of existing data and collection of new data. Potential areas for harvest data analyses fall into 5 main areas:

1) temporal patterns of age structure
2) temporal patterns of sex composition of harvest
3) spatial patterns of harvest over time
4) standardization and collection of body condition information from hunters
5) observations on the distribution of polar bears from hunters

Analysis of teeth collected from harvested bears may provide new opportunities to monitor subpopulation status. However, it is of vital importance to better understand the reasons for uncertainty in the precision of age determination based on teeth sections between geographic areas (see Christensen-Dahlsgaard *et al.* 2010). Recently developed methods providing for preliminary analysis of life history traits in polar bears (Medill *et al.* 2009; Medill *et al.* 2010) could be applied to harvested bears, although they are relatively labor-intensive.

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 (e.g., 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. For example, a fat sample collected from harvested bears could be analyzed for body condition (Thiemann *et* *al.* 2006, 2008; Stirling *et al.* 2008b) and compared to hunter assessments, or a more systematic collection of observations of females with cubs..

8. IMPLEMENTATION

We have chosen to suggest a monitoring plan that describes an "ideal" situation, where we focus on what should be done based on existing best knowledge of polar bear habitat, biology and ecology. This has been developed collaboratively by experts from all jurisdictions.

The implementation of all the parts of this monitoring plan will depend on the positive involvement of all jurisdictions, including federal, regional and local levels. This plan outlines a suggested framework and does not indicate that there are any financial commitments or legal requirements for jurisdictions to adhere to the entire suggested monitoring plan. However, we hope there will be wide acceptance followed by implementation of some or all of the recommended monitoring activities.

Adherence to this monitoring plan will no doubt represent a challenge for some jurisdictions and management authorities for a variety of reasons. Thus, although jurisdictions might have a desire to comply with this plan, or they might already have similar plans, there will be obvious challenges for some jurisdictions to find the capacity and resources necessary to be able to carry out the suggested monitoring scheme. As such, an effort was made to identify representative subpopulations for each sea-ice ecoregion to help focus research and monitoring efforts as efficiently as possible with consequent lower monitoring intensities suggested for other subpopulations.

8.1 RESPONSIBLE JURISDICTIONS

Of the 19 acknowledged subpopulations, 12 are exclusively within the jurisdiction of a single Arctic country, while the rest are shared between two countries (see figure 4). Within Canada, jurisdiction is primarily at provincial/territorial level (see figure 5), of which Nunavut has shared or exclusive jurisdiction over 13 subpopulations, where we find 2/3 of the world's polar bears. This rather complex picture, where subpopulations are so unevenly shared between jurisdictions, emphasizes the need for extensive bilateral, regional and circumpolar consultations to discuss and agree on suggested long-term monitoring schemes. This plan attempts to assist in that process.

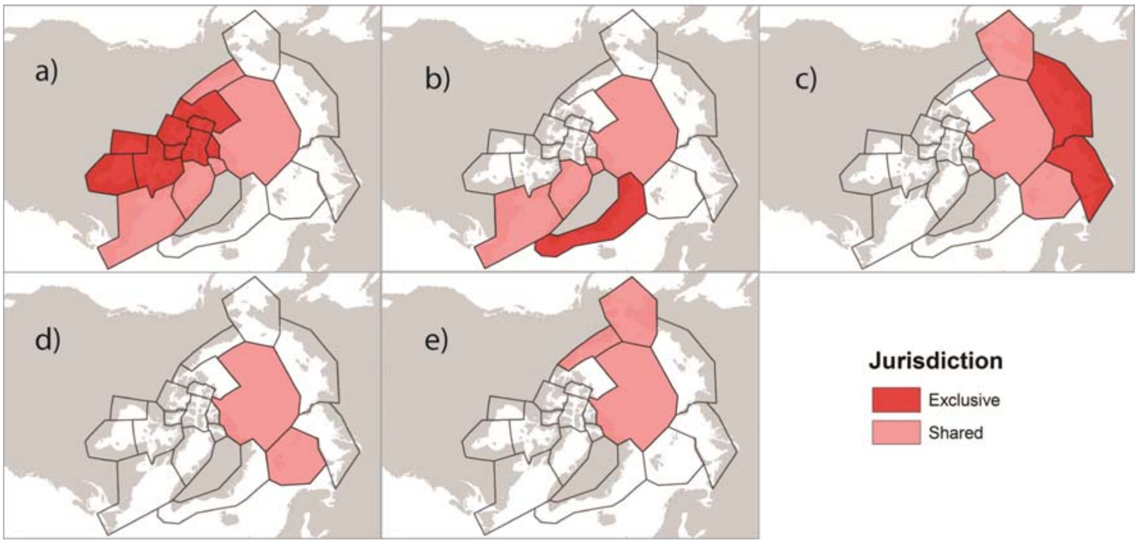

Fig. 4 Federal exclusive and shared jurisdictions over the 19 polar bear subpopulations, a) Canada, b) Greenland, c) Russia, d) Norway, and e) USA.

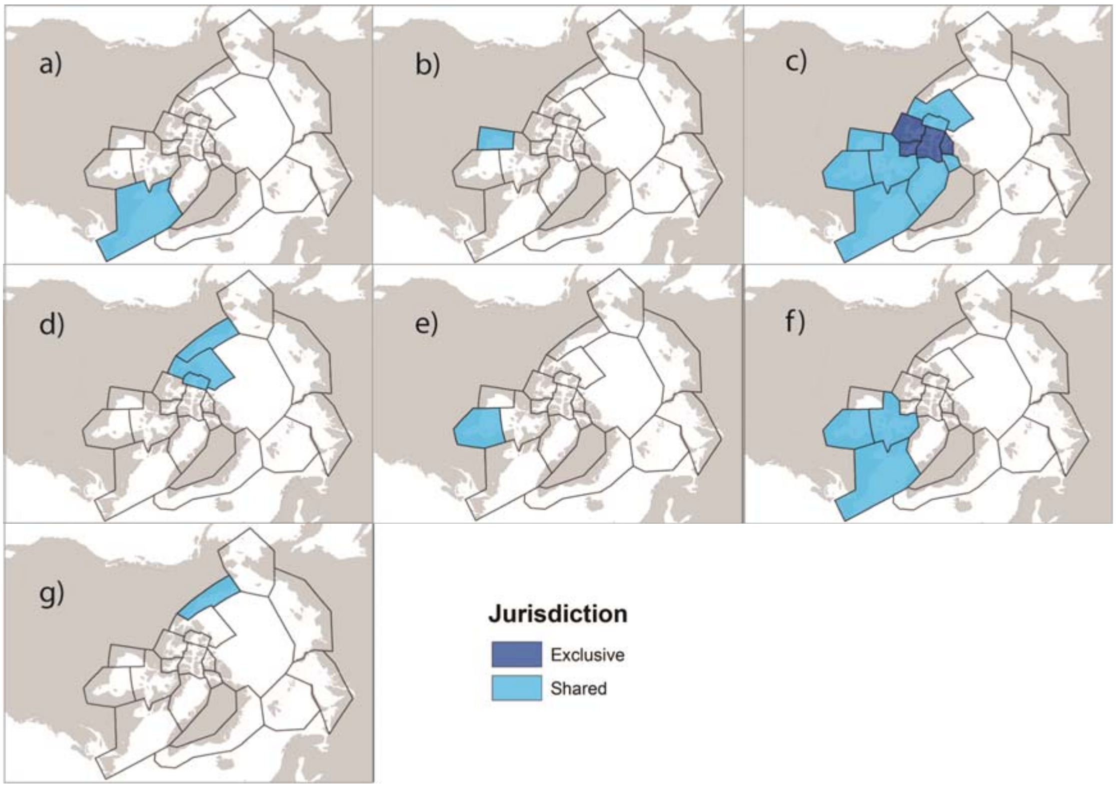

Fig. 5 Canadian internal territorial jurisdictions over the "Canadian" polar bear subpopulations, a) Newfoundland and Labrador, b) Manitoba, c) Nunavut, d) NWT, e) Ontario, f) Quebec, and g) Yukon. The circumpolar catch-all subpopulation Arctic Basin has been left out.

8.2 REGULAR ASSESSMENTS

The status of the 19 subpopulations of polar bears is reviewed regularly (at approximately 4 year intervals) at the meetings of the IUCN/Polar Bear Specialist Group. The reports and deliberations of the last meeting, held in 2009 in Copenhagen, and the status review from that meeting, are published in the proceedings from the meeting (PBSG 2010).

As this plan describes a coordinated and differentiated long-term effort to monitor essential population parameters in a circumpolar, regional perspective, there is a need to do a regular independent assessment of the status and trends of all the polar bear subpopulations (see Table 25). This should be done by an expert group commissioned by CAFF, and advised by the PBSG[4], and should consist of polar bear experts from as many jurisdictions as possible. A five year assessment period, with regular updates of key indicators, in line with the CAFF/CBMP's Arctic Marine Biodiversity Monitoring Plan (Gill *et al.* 2011), is suggested. It is however suggested that a first meeting/workshop be held in late 2012, to focus and sharpen the monitoring plan further, hopefully with the support of priority studies well executed (section 7.1).

It is suggested that CAFF commits to fund 1) priority studies and 2) assessment workshops.

8.3 THE ROLE OF THE PBSG

The IUCN/Polar Bear Specialist Group was initiated concurrently with the negotiations that were undertaken for the "Agreement on the Conservation of Polar Bears". The agreement was signed in 1973, and the Parties met again in 1981 after the five year trial period as prescribed in the Agreement, and unanimously concluded that the agreement should continue in perpetuity. The next time the Parties officially met was in Tromsø in 2009, and in the 28 years between 1981 and 2009, the PBSG responded to all matters pertaining to the Agreement and advised their governments accordingly. In 2009, at their 15th meeting in Copenhagen, the PBSG accepted an invitation from the Parties to provide scientific advice to the Parties as requested.

The PBSG has 25 members, three appointed by each of the five polar bear nations, and ten appointed by the Chair. To qualify for membership, individuals must be "actively involved in research and/or management of polar bears" (PBSG 2009).

The membership of the PBSG represents the leading authorities in polar bear research and, through government appointed members, all federal jurisdictions are represented. Through the members' collective experience and competence in polar bear monitoring, research and management, the PBSG is the authoritative scientific source for information on the world's polar bears and will be an essential advisor in the implementation and execution of this plan.

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[4] There is no formal relationship between CAFF and PBSG; CAFF is an Arctic Council working group, and PBSG is a specialist group under the Species Survival Commission of the IUCN. The PBSG is an independent advisory body on matters pertaining to polar bear behavior and ecology.

8.4 PROCESS TIMELINE

Table 25 Timeline for the circumpolar monitoring plan 2011-2014.

Item #	Action	Deadline	Comments
1	Presentation at Iqaluit Meeting of the Parties of the 1973 Agreement	October 24-26, 2011	Dependent on acceptance and endorsement by CAFF Board prior to this meeting.
2	Consultations between range states, jurisdictions, CAFF	Continuous	Process should be advised and facilitated by PBSG
3	Priority study 1: Power analysis	Fall 2012	Needs funding
4	Priority study 2: Analyses of harvest samples	Initiated in 2012?	Needs Canadian domestic concerted effort
5	Monitoring workshop	Fall 2012	To further focus monitoring, and to include power analysis
6	First assessment	2013 (every 5 years)	
7	Parameter review	2013 (every 3-5 years)	Parameter revision in line with ongoing power analysis

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