PREAMBLE

On 22 December 2010 the Parties of the 1973 Agreement on the Conservation of Polar Bear asked the IUCN/SCC Polar Bear Specialist Group (PBSG) to:

"…prepare a draft science chapter of the Action Plan (i.e. Key Research Elements),…".

The present report represents the response of the PBSG to this request.

Further information on the identified threats to polar bears is given in Vongraven and Peacock (2011, Chapter 4) and PBSG (2010a, pages: 60-61).

RANGE-WIDE CONSERVATION STRATEGY AND ACTION PLAN

KEY RESEARCH ELEMENTS

IUCN/SSC Polar Bear Specialist Group

Contents

Introduction

Although the continued and increasing loss and fragmentation of sea ice constitutes the most important threat to polar bear conservation, other stressors include over-harvest, contaminants, resource exploration and development, shipping, and tourism. Effective management and conservation of polar bears will require an integrated pan-Arctic research and monitoring plan that will improve the ability to detect ongoing patterns and predict future trends, identify the most vulnerable subpopulations, and provide decision-makers and management authorities with independent advice based on the best available scientific knowledge.

In 2010 a process to develop a pan-Arctic monitoring plan for polar bears was initiated under the umbrella of the Conservation of Arctic Flora and Fauna (CAFF) working group of the Arctic Council. To facilitate this process a background paper was developed to provide a comprehensive review of elements to consider for effective monitoring and research of polar bears (Vongraven and Peacock 2011).

To further enhance the development of a pan-Arctic monitoring plan for polar bears, a workshop was held in Edmonton, Canada, 19-21 February 2011 that was attended by 21 polar bear experts representing science, management and user-groups. Fourteen members of the PBSG, representing all five polar bear Range States were among participants. The workshop resulted in detailed recommendations and subsequently, a pan-Arctic monitoring plan for polar bears (Vongraven et al. 2011 in prep.).

The PBSG was inspired by the parallel process of CAFF and recognized both the process and output as directly relevant to the Range States initiative. The PBSG has drawn extensively from the CAFF background paper and subsequent monitoring plan.

Although in this chapter we use "monitor and/or monitoring" to mean **i)** observe and check the progress or quality of (something) over a period of time, or **ii)** maintain regular surveillance over (http://www.thefreedictionary.com/monitoring), we consider a distinction between monitoring and research as being semantic and arbitrary (PBSG 2010b). Effective monitoring must have basis in research and the PBSG identifies several research needs and scientific studies necessary for effective monitoring.

Monitoring of animal populations in its most strict sense implies precise, methodical and repetitive measurements of biological parameters, or metrics, which enable the accurate description of any rate of change in the monitored parameter. Such a definition of monitoring describes an ideal situation. The remote nature of the Arctic, along with the occurrence of polar bears at low densities over a wide range means that effective monitoring of polar bears will require considerable planning, and it will be expensive. Monitoring at a level that provides adequate information for science-based management, will depend on collaboration among jurisdictions, input from scientists and users, and methods that allow extrapolation from well-known populations to those that are more difficult to access and less well-known.

We recommend that considerations be given to the intensity by which various populations should be monitored. The PBSG´s identification of various key monitoring/research elements applies to all subpopulations but it also emphasizes the importance of continued intensive monitoring of subpopulations for which good baseline data or a long time series of data exists. This is particularly so for three subpopulations (Fig. 1): Western Hudson Bay (WH); Southern Beaufort Sea (SB); and, the Barents Sea (BS). Subpopulations with good baseline data and a continuous time series of data have already provided, and will continue to provide, invaluable information on basic polar bear population dynamics and responses to global warming. This information enhances the ability to understand population dynamics in other subpopulations of polar bears and to predict what may happen to them in the future.

We suggest several ideal metrics that have been and can be applied in more accessible areas as well as a variety of other monitoring metrics that can provide monitoring throughout the polar bear's circumpolar range.

We recognize that Traditional Ecological Knowledge (TEK) (e.g. Dowsley and Wenzel 2008, Born et al. 2011) and Community-Based Monitoring (CBM) may be valuable tools for obtaining additional information on polar bear ecology (Dowsley 2009). Thus, this chapter has a section suggesting elements where TEK/CBM may complement scientific monitoring/research. However, the PBSG believes elaborating on TEK/CBM elements that may be used for monitoring polar bears is better addressed by those with more in-depth knowledge of and experience in TEK/CBM and its integration in effective monitoring and management programs.

We remain convinced that trends in abundance, and trends in vital rates (reproduction and survival) are the most important parameters to monitor in light of the rapid deterioration of polar bear habitat due to global warming. These must be key elements of any action plan for polar bears. It is especially important to obtain population estimates at regular intervals for polar bear subpopulations where good baseline data on abundance already exist. However, we also recommend that other subpopulations (*e.g.* Northern Beaufort Sea, NB; Norwegian Bay, NW; Lancaster Sound, LS; Fig. 1) that are expected to experience significant changes in the future and have existing background data should be monitored intensively in the future.

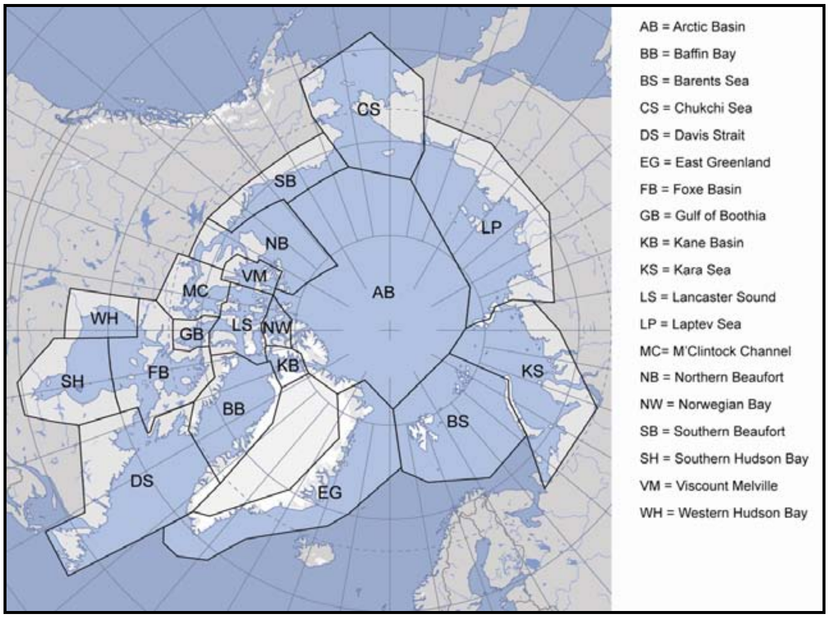

Fig. 1. Distribution of polar bear subpopulations throughout the circumpolar Arctic (PBSG 2010a).

Population size and trend

Population size is 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. Knowledge of population size and trend is necessary for establishing sustainable levels of harvest. Knowledge of the trend provides insights into the overall vigor of the population and its ability to withstand various perturbations.

There are three methods currently available for assessing the population size of polar bears:

1. Physical mark-recapture (M-R)
2. Genetic M-R
3. Aerial survey

The three techniques vary not only in the approach and logistics, but also in the extent that each has been applied to polar bears, the length of time each takes to produce an estimate of abundance, the extent to which the methods have been reviewed by the scientific community, and, the additional information that can be collected.

Physical Mark-Recapture

Physical M-R involves the chemical immobilization, handling, and marking of individual bears. It has been the most common method used to estimate abundance and vital rates for polar bears since the 1960s (Amstrup et al. 2001). The mark consists of a permanent tattoo and ear tags. During subsequent capture sessions or through the harvesting by hunters, some of the same individuals are encountered again and their identities verified from the mark. Based on the ratio of marked animals in relation to unmarked animals, among all animals captured or harvested, the total number of animals in the population can be estimated. During each capture event, physical measurements can be made (*e.g.* length and girth for estimation on individual growth and physical condition), and samples taken for individual age estimation, pollution, disease, etc. These allow for long-term studies in animal condition and for the estimation of age-specific survival and reproductive rates.

Genetic Mark-Recapture

Genetic M-R is a modification of physical M-R, and these two methods rely on similar field logistics. However, in contrast to physical M-R, genetic M-R does not include the immobilization or handling of individual bears. After the bear is pursued by a helicopter, similar to that in approach and duration as the physical M-R, 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. The collected tissue contains a DNA code unique to each individual (*i.e.* the "mark"); gender can also be determined. Since animals are not handled, genetic M-R does not allow for the collection of samples other than the skin biopsy. Therefore, other important information such as growth, body condition, age, survival, reproduction, pollution and disease are not obtained.

Genetic M-R has not previously been used to estimate the abundance of any polar bear subpopulation, although the method has been used successfully in other species of bears (*e.g.* Woods et al. 1999; Kendall et al. 2009). Recent testing of field methods in Foxe Basin (polar bears; Peacock et al. 2009) and in the western Canadian Arctic (grizzly bears; A. Derocher pers. comm. 2010) and the genotyping of polar bear biopsies in Foxe Basin and Southern Beaufort Sea (L. Peacock pers. comm. 2010) suggest that genetic M-R may be a viable means of assessing the size of polar bear subpopulations.

Aerial Survey

Aerial surveys have been used successfully to estimate abundance of polar bears in the Barents Sea (Aars et al. 2009) and ongoing research in Foxe Basin suggests that the technique will result in an abundance estimate with adequate precision (Peacock et al. 2009; S. Stapleton unpublished data).

During aerial surveys, transects are flown over polar bear habitat to detect polar bears from the air along predefined transect lines. In this manner, "samples" of polar bear density (bear/square unit) are taken. The distance from each polar bear to the track line is determined by measurements from the air and used to create a "probability of detection"-function and calculate the area from the track line covered by the survey. The line-transect methodology can include double observer teams which allow for estimation of observer efficiency. Multiple observers also can provide a "capture-recapture" component to surveys, and lead to improved precision. Data on movement and habitat choice can be obtained prior and during the surveys from polar bears fitted with satellite transmitters. This information can be used to optimally design a survey (create strata for areas where bears occur at different densities) and can be used for correcting estimates of abundance to include areas that were not covered during the survey due to inclement weather or other factors (Aars et al. 2009).

Of the three methods, physical M-R is still considered the best method for estimating size of polar bear subpopulations. Importantly, mark-recapture data can provide evidence of trend, as well as estimates of abundance, because the vital rates of reproduction and survival are assessed by M-R along with estimates of population size. Estimates of vital rates obtained from M-R can be used to project population growth rate. Therefore, mark-recapture can provide a series of estimates of population size and two ways of assessing trend. The first way of assessing trend is the comparison over time of a series of estimates of abundance (e.g. Regehr et al. 2007). The second way of assessing trend is projection of the population growth rate based upon estimates of vital rates (Taylor et al. 2002). Such projections can be constructed for the observed period. In that case, the observed change in numbers over time can provide a "cross-checking" of the projection for the same period based upon vital rates. Projections also can be made for the future. In this case, the future trend is forecast based upon observed estimates of vital rates or anticipated changes in vital rates (Hunter et al. 2010).

In establishing any research or monitoring program, it is critical to evaluate the costs and benefits of the methods. In the case of genetic versus physical mark-recapture, planners must be aware of the trade-offs. For example, the collection of DNA with biopsy darts is likely to be nearly as expensive as physically capturing bears; yet it provides far less information because animals are not available for measuring and condition assessment, and their individual age cannot be determined. Such considerations are especially critical when concerned about detecting changes that result from habitat deterioration. Physical examination can provide information on changes in weight, stature, pollution and disease that can provide evidence of problems well before these might be picked up through the monitoring of population trend. It is critical in any research and monitoring program that data is collected in a way that provides maximum comparability with data collected in the past and that such comparability is not unnecessarily sacrificed by altering methods.

It is especially important to obtain population estimates at regular intervals for subpopulations for which good baseline data on abundance already exist. Currently, these subpopulations are Western Hudson Bay and Southern Beaufort Sea for which estimates of abundance and vital rates have been obtained via physical M-R (Amstrup et al. 1986; Regehr et al. 2006, 2007) and the Barents Sea, where aerial surveys have been used to estimate abundance (Aars et al. 2009). For Western Hudson Bay, a series of abundance estimates and associated estimates of vital parameters are available that go back to 1987.

The necessary frequency for abundance estimates should be determined on a case-specific basis depending on observed and expected rate of population decrease due to reduction in sea ice. For subpopulations which already have experienced documented decreases in abundance (*e.g.* Western Hudson Bay, Southern Beaufort Sea) and are likely to experience significant changes in the future, it is recommended to conduct abundance surveys at short intervals. Power analyses of existing abundance data may be used to further specify survey frequency in various subpopulations.

The uncertainties in estimates of population size and trend mean that more frequent monitoring will always be more informative than less frequent monitoring. Abundance can then be interpreted as the average of estimates made over several years rather than the estimate for just one year. It also means that wherever possible, estimates of population size and trend should be interpreted in conjunction with other monitoring elements like observed changes in stature, physical condition, cub production, and changes in habitat quality and availability.

There is no substitute, in terms of accuracy and precision of population demographic parameters, for continuous long-term monitoring of subpopulations. Intensive monitoring, however, is not possible or practical throughout the range of the polar bear. Therefore, an important research component of future monitoring must be to use the data collected from populations where long-term continuous data are available to evaluate the costs and benefits of intensive monitoring done at intervals versus that done continuously. Another important research component is to understand how indices of trend from life-table types of analyses can contribute to an overall understanding of trend. Such research will necessitate comparisons made in areas where high intensity monitoring is also available. Regardless of the frequency of intensive monitoring, lower intensity monitoring that can be applied over much of polar bear range must be standardized and used systematically and continuously in order to adequately document global trends.

Priorities must also be set and effort allocated according to the level of risk that each subpopulation faces and according to the anticipated understanding that knowledge about each subpopulation can bring. Presently polar bear subpopulations in the Seasonal Ice (*i.e.* Baffin Bay, Davis Strait, Foxe Basin, Hudson Bay, and James Bay) and Divergent Ice (*i.e.* Barents, Chukchi, Kara, Laptev, and Southern Beaufort Seas) eco-regions (Amstrup et al. 2008) are experiencing major declines in the spatial and temporal availability of sea ice habitats (Stirling et al. 1999; Durner et al. 2009).

For populations where bears are harvested but abundance estimates do not yet exist (*e.g.* East Greenland), base-line information on abundance must be obtained.

Recommended research elements for obtaining information on abundance and trends in abundance are listed in Table 1. Which method to use will be subpopulation specific and based on, amongst other considerations, logistics and accessibility. However, for populations where previous abundance data exist, and in the case of Western Hudson Bay and Southern Beaufort Sea where there are long data series based on physical M-R, it is recommended that future population studies use the same method to maximize compatibility and comparability with previous studies.

Tab. 1. Recommended research elements for monitoring of polar bear population size and trend.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Population size	• Physical mark-recapture (M-R). • Genetic M-R. • Aerial survey.	Physical M-R: Conducted over multi-years and provides maximum information on population status and trends. Genetic M-R: Conducted over multi-years. Using biopsy darts, hair traps, samples from killed bears etc. it can provide estimates of status and trend, but does not allow assessment of animal condition and health. Aerial survey (distance-sampling method, Buckland et al. 2001): Can provide estimates of abundance without handling bears.
Population trend	• Repeated measurements of population size from M-R or aerial surveys. • Modeling from physical M-R data.	Modeling: Estimation of birth and survival rates that are projected forward in time. Changes in sex and age composition and animal condition, observed during physical M-R studies, can provide an index to population trend, and changes in vital rates (births and deaths) estimated from M-R can provide ongoing trend assessment.

Realistically, estimates of abundance may not be possible over much of polar bear range. Where abundance cannot be estimated, however, there is opportunity to develop indices to ongoing trends in abundance. In areas where polar bears are harvested, systematic monitoring of the sex and age composition of the harvest can provide additional information on reproduction and survival. This information, in life-table types of analyses (Skalski et al. 2005), can provide an index of trend in the population. Visual observations from hunters (if standardized and validated) along with community-based observations 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 could provide information on demographic changes in the population additional to the information from the science-based monitoring. In areas where denning is common, systematic community-based surveys of denning could be an index of trend in the population (see section: Traditional Ecological Knowledge and Community Based Monitoring).

Reproduction

All species of bears have low reproductive rates due to late maturation, small litter size, and long mother-offspring association (Bunnell and Tait 1981). Reproduction is one of the best understood demographic parameters in most polar bear subpopulations (*e.g.* Lønø 1970; DeMaster and Stirling 1983; Larsen 1985, 1986; Watts and Hansen 1987; Ramsay and Stirling 1988; Derocher et al. 1992; Derocher and Stirling 1994; Rosing-Asvid et al. 2002; Rode et al. 2010). In all subpopulations where some assessment has been undertaken, elements of reproduction are investigated to varying degrees. Trends in polar bear reproduction can only be effectively evaluated with multi-year efforts. Shorter-term studies will reflect short-term dynamics in both the biotic and abiotic systems (*e.g.* inter-annual changes in weather and sea ice), and may mask long-term trends. For example, a three year population inventory may include three good years of reproductive output, three bad years, or a combination of both, but would not provide any reliable indication of trend in the population. Therefore, the most comprehensive information on polar bear reproduction comes from the most intensively studied subpopulations with long time series (*ca.* >10 years).

Recommended research elements for monitoring of polar bear reproduction are listed in Table 2.

Tab. 2. Recommended research elements for monitoring of polar bear reproduction.

Essential monitoring/Research parameter	Recommended research elements	Comments
Reproduction	• Estimates of litter production rates, age at first reproduction, mating interval, age of weaning, sex-ratio at birth from physical M-R. • Frequency of maternity denning based on telemetry studies. • Infrared monitoring of denning areas. • Visual observations of cubs per female in spring. • Analyses of reproductive organs of harvested bears.	Cross-validation between methods will improve results.

Survival

Survival rates of bears are generally high (Bunnell and Tait 1981) but vary substantially across life stages (Amstrup and Durner 1995).

There are two means by which survival rates of polar bear can be monitored: telemetry and physical mark-recapture methods. Both methods have been used with studies of polar bears and provide estimates (Amstrup and Durner 1995; Derocher and Stirling 1996; Taylor et al. 2002, 2005, 2008, 2009; Regehr et al. 2007, 2010). 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 (5+ years of age; often age-specific where sufficient data exists). There is abundant information to support variation in survival rates among sex and age classes, and most detailed studies provide such estimates. There are a number 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 natural mortality linked to sea ice condition may show substantial annual variation.

Monitoring of survival in all subpopulations should be a priority because it is easer to assess than other metrics, may be less biased, and can provide an early indication of a potential problem. Linking survival to sea ice conditions (*e.g.* Regehr et al. 2007) provides a powerful approach to population monitoring, and can highlight which sex and age groups are first to be in trouble. Historically, it has been shown that survival of adult females is most critical to population welfare. However, polar bears are long-lived animals and adults may carry sufficient body mass to survive considerable reductions in foraging opportunity that result from a more variable and declining habitat base. Young animals, however, are less resilient to such habitat changes. Also, females may retain sufficient body mass to survive, but will be unable to nurse young or ultimately even to get pregnant. Therefore, survival of young may be one of the first parameters that show effects of a declining habitat base.

In intensively monitored subpopulations, survival rate is the parameter of utmost importance and should be monitored across all age- and sex-classes. Optimal monitoring methods will include mark and recapture analyses and satellite telemetry studies. Survival cannot be determined from aerial survey methods. In addition, short-term studies are less likely to provide robust estimates of survival given the large and/or intensive sampling required to produce accurate and precise estimates of survival.

Research elements that are recommended for studies of survival are listed in Table 3.

Tab. 3. Recommended research elements for monitoring of polar bear survival.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Survival	• Survival rate based on physical M-R studies. • Documentation of cub losses for tagged animals. • Following cohorts via radio-telemetry. • Estimate age structure from teeth collected by harvest and from captured animals. • Examination of missing cohorts in capture and harvest. • Life table type analyses.	

Habitat change

Over much of their range, polar bears remain with sea ice throughout the year, hence their range 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 on land. While sea ice is the most important habitat because it allows polar bears to hunt ice-dependent seals, land habitat may also be important in terms of its relative impact on polar bear energetics during periods of food inaccessibility. In most of their range, polar bears use land for maternal denning, although in the Beaufort Sea some of the population use the sea ice as a substrate for denning. Ultimately, however, it is the presence of sea ice during critical stages of polar bear life history that allows polar bears to survive in the Arctic.

Satellite imagery from passive microwave, visible and infrared sensors can provide reliable estimates of circumpolar sea ice extent and concentration and are readily available to government and academic researchers (e.g. http://nsidc.org/data/seaice/index.html). Many of these data sources also provide historical data that allow for the assessment of changes in the availability and distribution of preferred polar bear habitat over space and time. These data sources in conjunction with satellite telemetry data from studies of polar bears can also provide a means for developing detailed habitat models.

Polar bears do not use all sea ice equally; rather they respond to variations in concentration, ice age (thickness), floe size, and the proximity of sea ice edges and land fast ice. 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 where marine productivity is relatively high. Sea ice habitat has been shown to be a driver of polar bear distribution (Durner et al. 2009), body condition (Rode et al. 2010), survival (Rode et al. 2010), and population trend (Amstrup et al. 2008; Regehr et al. 2006; Hunter et al. 2010). Therefore, sea ice habitat may be a useful proxy of polar bear population status and distribution.

Polar bears may use land at any time of year but do so most often in regions with extensive summer sea ice melt. Little is known of the land habitats selected by polar bears, although some habitats are selected to allow bears to conserve energy (Clark et al. 1997) and in places like Western Hudson Bay, adult females select specific habitat for maternal denning (Richardson et al. 2005).

Maternal denning occurs wherever there is snow on a stable substrate, either land or sea ice, that has suitable depth for digging a den and will persist during the period necessary for den tenure. Knowledge of the distribution of maternal den habitat has significant management potential to protect denning polar bears. Changes in sea ice habitat necessary for maternal denning can alert managers to changes in maternal den distribution (Fischbach et al. 2007).

Recommended research elements for monitoring of habitat and ecosystem change are listed in Table 4.

Tab. 4. Recommended research elements for monitoring of polar bear habitat change.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Habitat and ecosystem change	• 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.* 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 occurrence of invasive or unusual species. • 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.	

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 incidental mortality. Legal harvest is most often set at annual limits. In some regions, although harvest may be legal, 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.

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, but also in areas where information on the size or status of the subpopulation is insufficient to determine the sustainability of the harvest (PBSG 2010a).

Recommended research elements for monitoring of human-caused mortality in polar bears are listed in Table 5.

Tab. 5. Recommended research elements for monitoring of human-caused mortality of polar bears.

Essential monitoring/Research parameter	Recommended research elements	Comments
Human-caused mortality	• Detailed documentation of harvest (catch records/reporting), defense kills, illegal kills, and incidental mortality. • Assessment of impact of human-caused mortality on populations. • Collection of identity information to be used in mark-recapture estimation of survival. • Investigate economic importance of trade, harvest, trophy hunting and illegal kills.	

Human-bear conflicts

As bears spend extended periods of time on land, during open water seasons, the potential for human–bear conflict will likely increase in the future. The expansion of human populations and human activity, *i.e.* industrial development, tourism and other commercial activities, increases the potential for human-bear conflicts. Also, polar bear distribution changes and a continued increase in the number of nutritionally stressed bears on land due to retreating sea ice, have the potential to increase the number of conflicts between polar bears and humans (Vongraven and Peacock 2011 and references therein).

The Range States have already agreed on the need to develop comprehensive strategies to manage such conflicts. As human-bear interactions have the potential to increase direct human-caused mortality, it is important to monitor and mitigate the trend in human-bear conflicts, defense kills and distribution of bears in areas of human activity.

To address this emerging issue, the Polar Bear-Human Information Management System (PBHIMS, http://216.197.125.77/bhims/index.cfm?action=dsp&topic=home&item=home) 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.

Recommended research elements for monitoring of human-polar bear conflicts are listed in Table 6.

Tab. 6. Recommended research elements for monitoring of human-polar bear conflicts.

Essential monitoring/Research parameter	Recommended research elements	Comments
Human-bear conflicts	• Documentation and analysis of human-bear conflicts from all sources. • Documentation of trends in human activity within polar bear range.	*cf.* PBHIMS. Investigate historic and current patterns of polar bear-human conflicts to address specific bear management and conservation issues.

Distribution

The distribution of polar bears may be viewed at three spatial levels: 1) the overall world population; 2) eco-region-specific; and 3) regional subpopulation distribution. A range-wide monitoring program should consider these different spatial levels because eco-regions or subpopulations are affected by different physical, biological, and management factors.

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). Evidence suggests that 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).

An understanding of polar bear distribution is necessary for addressing management issues (*e.g.* Amstrup et al. 2005; USFWS 2010). Effective surveys of population size may depend on estimates of subpopulation distribution (*e.g.* Taylor et al. 2001; 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). Management, however, will continue to focus on the impacts of direct human removals (Peacock et al. 2011) and increased commerce in the Arctic (*e.g.* mineral extraction, Gautier et al. 2009) as means to mitigate the impacts of climate change habitat loss (Amstrup et al. 2010).

Satellite radio-telemetry is a relatively resource intensive technique that has been effective in the identification of, and in describing the distribution and degree of discreetness of polar bear subpopulations (Bethke et al. 1996; Taylor et al. 2001; Mauritzen et al. 2003; Amstrup et al. 2004). The ability of jurisdictions to conduct satellite telemetry to the degree required for estimating subpopulation delineation has been limited to only several of the 19 polar bear subpopulations and, in many of these areas, data are now a decade old. This is problematic because polar bear habitat has changed during the last 20 years (Durner et al. 2009) and there is evidence that animal distribution also may be changing (Gleason and Rode 2009).

Identification of optimal sea ice habitat through remote sensing and extrapolation from other regions with good data may be a useful proxy of polar bear distribution where other monitoring data, such as radio-telemetry or aerial surveys, are not possible to collect. Sea ice habitat has been shown to be a driver of polar bear distribution (Durner et al. 2009). Resource selection functions (RSF) are a standard 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 estimate the distribution of polar bears in subpopulations that cannot be accessed by scientific research. 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 process has allowed predictions of polar bear population distribution in the Divergent and Convergent eco-regions (Amstrup et al. 2008), development of new RSFs will be necessary for evaluating changes in polar bear distribution within the Archipelago (Canadian High Arctic) and Seasonal Ice eco-regions (Baffin Bay, Davis Strait, Foxe Basin, Hudson Bay, James Bay). Estimating polar bear distribution in eco-regions with low scientific access potential may be possible by reasonable extrapolation of RSFs from well-studied eco-regions.

Recommended research elements for monitoring of polar bear distribution are listed in Table 7.

Tab. 7. Recommended research elements for monitoring of polar bear distribution.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Distribution	• Radio-telemetry, tag recovery, systematic aerial and ship-based visual survey, genetic survey. • Estimate distribution in unsurveyed areas with resource selection functions (RSF). • Incidental observations by field-teams, ship crews, etc.	

Feeding ecology and change in prey distribution and abundance

Over most of their circumpolar range, polar bears depend for their survival on the most ice-adapted of seals: primarily ringed and bearded seals. It has been shown that changes in reproduction of ringed seals in an area resulted in a marked and immediate response in the reproduction and cub survival of polar bears (Stirling 2002) and, in some areas, there is a significant relationship between population estimates of polar bears and ringed seals (Stirling and Øritsland 1995).

Abundance estimates for ringed and bearded seals are largely lacking, and reliably monitoring changes in their abundance is not practical and may not be possible in most areas. Monitoring an index of abundance of seals and the proportion of various seal species in polar bear diets in different polar bear populations could likely provide a mechanistic index of polar bear population health. The relative contribution to polar bear diets of different prey can be studied with stable isotope and fatty acid methods. Changes in dietary composition, which undoubtedly reflect changes in prey availability and possibly abundance, and their links to survival, reproductive success, and population size will be important areas to monitor. Understanding these links will be key to understanding and potentially predicting changes in population welfare that occur due to warming induced changes in sea ice.

Recommended research elements for monitoring of changes in polar bear feeding ecology and change in distribution and abundance of polar bear prey are listed in Table 8.

Tab. 8. Recommended research elements for monitoring of polar bear feeding ecology and change in prey distribution and abundance.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Feeding ecology and change in prey distribution and abundance	• Systematic surveys of prey distribution and abundance. • Stable isotopes and fatty acid analyses of samples of polar bears and prey. • Record observations of capture of alternate prey while conducting field work. • Analysis of fecal samples of polar bears. • Collect specimens of prey found killed by polar bears for tabulation of species, age, sex, condition, and degree of use and scavenging.	Fat samples from all harvested or captured animals, or those sampled by biopsy darting.

Health and pollution

One way to examine animal health is to evaluate body condition. 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 polar bear health. Body condition indices can be estimated in a variety of ways if animals are physically handled (Stirling et al. 1999; Cattet et al. 2002; Cattet and Obbard 2005; Stirling et al. 2008).

The health of polar bears may also be assessed by new methods. Until recently, the measurement of environmental stress to which animal populations are exposed has been problematic. 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). Recently, however, improved techniques for detecting long-term stress have been developed (Alexander and Irvine 1998; Iwama et al. 1999; Southern et al. 2002). One example successful in polar bears is the measurement of corticosteroid-binding globulin (Chow et al. 2011).

Cellular stress responses that restore homeostasis within hours of a perturbation, and persists until recovery (Bechert and Southern 2002) may also be useful in monitoring long term stress to which animals are exposed. An example of this is heat shock proteins; a family of proteins that are crucial for allowing cells to cope with stress (Feder 1999). 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.

Another new approach that does not involve physical handling of the bear 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 has been recently validated for polar bears (Beschøft et al. 2011). If linkages between the environment and population performance can be 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 scientific studies of polar bears indicate negative relationships between exposure to contaminants (*e.g.* PCB) and health parameters. However, these studies have been correlative in nature. However, information from experimental studies of farmed Arctic foxes and East and West Greenland sledge dogs 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 (*cf.* review in Sonne 2010).

Global warming is expected to increase the emissions of volatile contaminants such as PCBs resulting in increased exposure of wildlife and humans affecting health and biodiversity including the Arctic (AMAP 1998; Macdonald et al. 2003; AMAP 2004, 2005; McKinney et al. 2009; Noyes et al. 2009; Letcher et al. 2010; Sonne 2010; UNEP at http://chm.pops.int/default.aspx). In addition a number of examples in relation to mercury being affected by changes in ecological processes have recently been summarized (Stern et al. in press; Braune et al. in press). Also the increased use of DDT for fighting malaria in Africa is supposed to increase the emissions and thereby the transport to the Arctic (Macdonald et al. 2003; AMAP 2004; Noyes et al. 2009; UNEP at http://chm.pops.int/default.aspx and http://chm.pops.int/Convention/Media/Pressreleases/UNFCCCCOP16ClimateChangeCancun7Dec2010/tabid/1269/language/en-US/Default.aspx. Further to this, it is speculated that decreased availability of prey and starvation will induce metabolization of stored fat which in turn results in release of accumulated fat-soluble contaminants usually at the time prior to or during breeding season when the animals are most vulnerable (Letcher et al. 2010; Sonne 2010). The energetic stress is therefore thought to increase the health risk from endocrine disruption of stress and metabolizing hormones such as cortisol and thyroid affecting individual health, survival, immunity and reproductive performance as (Thomas and Hindsdill 1978; Shope 1992; Svensson et al. 1998; Tryphonas and Feeley 2001; Jenssen 2006; Burek et al. 2008; Jensen et al. 2010; Letcher et al. 2010; Mills et al. 2010; Sonne 2010).

Continued studies of the synergistic effects on polar bears of decrease in sea ice, food deprivation, starving and pollution are needed.

Research elements recommended for monitoring of health in polar bears are listed in Table 9.

Tab. 9. Recommended research elements for monitoring of polar bear health.

Essential monitoring/Research parameter	**Recommended research elements**	**Comments**
Health	• Systematic collection of body metric data for estimation of body condition. • Pathogens and contaminants in blood/tissues/feces. • Parasites. • Cell fat content. • Fat layer thickness (from harvested bears). • Stress levels (from blood and tissue chemistry). • Relevant tissue (*e.g.* adipose, muscle, liver, and kidney) for monitoring contaminant loads (from harvested bears). • Relevant tissue (*e.g.* brain, thyroidea, sexual organs, liver, and kidney) for histology and biomarker studies relating to effects of contaminants (from harvested bears). • Studies of stable isotopes and fatty acids to study changes in feeding behavior.	All elements, except fat layer thickness, can and should be collected from captured and harvested bears. Archived material (*e.g.* museum collections) should also be utilized.

Stature

Monitoring polar bear stature should be a mandatory component of all research programs. Herein stature is used as a broad term to describe any measurable aspect of the physical size, mass or condition of a polar bear.

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, which may in turn have long term fitness consequences. Both Atkinson et al. (1996) and Derocher (2005) have documented reductions in body length in polar bears but to date these changes in stature have not been related to changing population 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 have been shown to influence survival and reproduction in bears (Rode et al. 2010). Measuring changes in the physical stature 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 trends in the availability of energetic resources in addition to providing potential valuable insight into future population demographics.

Research elements for monitoring of polar bears stature are listed in Table 10.

Tab. 10. Recommended research elements for monitoring of polar bear stature.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Stature	• Measurements from live-captured bears and harvested bears (*e.g.* skull length and width, body length, girth, energy content). • Utilization of archived material (from museum collections, etc.) shall be included for studies of trends.	

Human activity

As the Arctic becomes more accessible, due to technical developments and less sea ice, human activities within polar bear habitat are likely to increase for a variety of reasons (PBSG 2010a; Vongraven and Peacock 2011). Tourism is increasing rapidly, and resource exploration introduces humans and infrastructure in the remote areas of the Arctic. This increase in human activity and the number of people in areas inhabited by polar bears increases the probability for disturbance and human-bear encounters.

Although chronic disturbance from human activity 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.

Recommended research elements for monitoring of human activities as relevant to polar bears are listed in Table 11.

Tab. 11. Recommended research elements for monitoring of human activity as relevant to polar bears.

Essential monitoring/Research parameter	**Recommended research elements**	**Comments**
Human activity	• 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. • Study impacts of supplemental feeding.	GIS analyses have been conducted re: the Northern Sea Route (Brude et al. 1998).

Behavioral change

Changes in observed behaviors can be an outcome of reductions in the spatial and temporal availability of habitats and diminished foraging opportunity it causes. In some polar bear populations, observations of infanticide, cannibalism, starvation, and other unusual behaviors, suggestive of a food-stressed polar bear population, already have been recorded (*e.g.* Lunn and Stenhouse 1985; Derocher and Wiig 1999; Amstrup et al. 2006; Monnett and Gleason 2006; Stirling et al. 2008). Changes in the number and distribution of problem bears that occur in settlements, is another behavioral clue habitats are changing in ways that reduce nutritional welfare of bears (Regehr et al. 2007). These changes are likely to be linked to changes in age and body condition, and changes in metabolic state (Cherry et al. 2009) of animals killed as problem bears when they enter communities or industrial development sites. Although we must always be careful when assigning causes of such changes, they certainly are consistent with increased stresses associated with climate warming and the habitat losses it is causing.

Observations of bears and their behaviors should be recorded systematically wherever possible. In locales where behavioral observations can be quantified, such as at den emergence (Smith et al. 2007), doing so may provide early indicators of changes that precede detectable changes in survival or recruitment. Although opportunities to quantitatively describe changes in polar bear foraging behaviors are few, monitoring places where this is possible might also provide early clues of change. Activity budgets, and hunting success of bears of different ages- and sex-classes, and with different ages of cubs, have been quantified in Radstock Bay (Stirling 1974; Stirling and Latour 1978; Stirling and Øritsland 1995). Similarly, 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). Re-establishing these studies may provide an opportunity to understand changes that have occurred in recent decades. In places like Churchill, where behaviors have been recorded consistently (Stirling and Parkinson 2006; Towns et al. 2009) the information may be relevant to testing of hypotheses related to whether the subpopulation is being food stressed. Also, where possible, data relative to hunting success could inform energetics models and therefore be useful for projection purposes.

Recommended research elements for monitoring of changes in polar bear behavior are listed in Table 12.

Tab. 12. Recommended research elements for monitoring of change in polar bear behavior.

ESSENTIAL MONITORING/RESEARCH PARAMETER	RECOMMENDED RESEARCH ELEMENTS	COMMENTS
Behavioral change	• Observations, facilitated by radio-telemetry and other intensive monitoring and study, swimming, unusual hunting strategies, taking of alternate prey, erratic and anomalous behaviors (*e.g.* cannibalism, digging through ice). • Documentation of problem bears; age and body condition. • Studies of changes in movements and home range sizes. • Studies of changes in denning chronology, timing of appearance on land. • Registration of occurrence of hybrids.	

Polar bear research

Concerns about the impacts of polar bear research have been raised by both community members, management agencies and scientists (Cattet et al. 2008). Most commonly, concerns are expressed about potential negative effects of handling polar bears, the number of bears being captured and handled, and the impacts of wearing a radio collar or other monitoring devices. Example questions include: do radio collars impact a bear's ability to hunt seals, or does the disturbance by helicopters while bears are hunting or mating, have lasting effects on their welfare? There are also concerns about the safety of eating meat from bears that have been chemically immobilized, and wastage of polar bear meat can occur when people do not want to consume bears that have been drugged.

Research on polar bears may have impacts on the individual, although quantitative analyses are limited (Ramsay and Stirling 1986; Amstrup 1993; Derocher and Stirling 1995; Messier 2000; Lunn et al. 2004; Rode et al. 2007). Short term effects of capture are unavoidable but appear to have minimal lasting effect (Messier 2000). Possible effects on individuals must be balanced with information needs for management, conservation, and international agreements. The effects relative to information needs must be judged by management/co-management authorities, affected communities, and researchers. Impacts of polar bear research vary depending on the research and the level of invasiveness. To minimize or eliminate impacts, 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. In addition, investigators should systematically record responses to their study methods to be sure they are minimizing negative effects.

Recommended research elements for monitoring of potential effects of research activities on polar bears are listed in Table 13.

Tab. 13. Recommended research elements for monitoring of effects of research activities on polar bears.

Essential monitoring/Research parameter	Recommended research elements	Comments
Polar bear research	• Quantitative assessments of effects of handling and other research activities on reproduction, survival, stature and behavior. • Comparisons among areas and over time frame controlling for environmental factors.	

Traditional Ecological Knowledge (TEK) and Community-Based Monitoring (CBM)

One step towards facilitating conservation efforts for polar bears may be to increasingly engage local people in decision-making and as stakeholders in the research and monitoring of polar bears (Vongraven and Peacock 2011; Peacock et al. 2011). TEK and CMB can play an important role in collecting data while also engaging the public that lives in polar bear habitat. The local monitoring of harvest is a natural fit for CBM. Governments can require and design the collection of harvest data and samples, but after training, individuals in communities can often be relied upon to carry out monitoring, if local government representatives are not available. Data on catch-per-unit effort and geographic distribution of hunting effort can also provide useful metrics that, over time, might be useable as an index of population size or trend. It is essential, however, that the validity of such indices be confirmed independently with some other quantitative methodology.

The use of community-based monitoring or research does not imply that TEK be used in preference to science, but rather that there is an opportunity to build synergy between systematically collected TEK and scientific data, while simultaneously increasing the participation of local users in the management of their resource and facilitating dialog between local people and government. Further, the collection of TEK can generate scientific hypotheses on causation and mechanisms of ecological change for polar bears (Peacock et al. 2011).

Realistically, estimates of abundance may not be possible over much of polar bear range. Where abundance cannot be estimated, however, there might be opportunity to develop indices to ongoing trends in abundance. In areas where polar bears are harvested, systematic monitoring of the sex and age of the harvest can provide reproductive and survival information. Visual observations from hunters, if standardized and validated, along with community-based observations made by snow scooter, 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 could provide an index to population trend. In areas where denning is common, systematic community-based surveys of denning could provide an index of trend in the population.

A requirement for using these kinds of observations as indices of trend is that the methods be validated. Changed frequencies of sightings, for example, might reflect altered distributions rather than altered numbers (*cf.* 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 consort with all available information. In the more remote polar bear subpopulations, there will not be much other information. So an additional requirement for interpreting these observations is comparing them to trends in the same observations collected where more intensive monitoring is occurring (*e.g.* Western Hudson Bay, Southern Beaufort Sea). 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 is also occurring, a relationship between the high and low intensity techniques may be established. Such a relationship could then be extrapolated to areas where only indices are available. Such "validation" can elevate confidence in indices monitored elsewhere.

Examples of elements where TEK and/or CBM may supplement scientific monitoring and research are listed below. This is not an exhaustive list but rather a sampling of the kinds of activities that could be helpful in understanding trends in polar bear welfare:

- Standardized visual observation of distribution of bears or track counts from snow machines, ATV, boat or dog team
- Reports of litter size (age) of observed bears
- Proportion of family groups observed
- Catch per unit effort (and observations per unit effort)
- Harvest monitoring (age, sex)
- Sampling program (tissues, teeth, etc. for determination of sex and age distribution in harvest, genetic mark-recapture, pollutant studies, studies of stress, etc.)
- Tag returns
- Change in body condition from measuring girth and fat thickness
- Reports of prey type and distribution and changes in prey preferences of polar bears
- Observations of invasive species
- Observation of behavior
- Reports of human-bear conflicts

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