Literature Review and Method Development for Incorporating Indigenous Knowledge into an Integrated Population Model for the Southern and Northern Beaufort Sea Polar Bear Subpopulations

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June 28, 2022

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Executive Summary

The Southern Beaufort Sea (SB) and Northern Beaufort Sea (NB) polar bear subpopulations are managed jointly by multiple organizations within Alaska and the Inuvialuit Settlement Region (SB subpopulation) and within Nunavut and the Inuvialuit Settlement Region (NB subpopulation). In recent years, commissioners of the Inuvialuit-Iñupiat Agreement have prioritized including Indigenous Knowledge (IK) in abundance estimates for SB polar bears and planning an IK workshop for a future Inuvialuit-Iñupiat meeting. In 2020, the Wildlife Management Advisory Council (NWT) (WMAC (NWT)) for the Northwest Territories portion of the Inuvialuit Settlement Region in Canada, North Slope Borough (NSB) in Alaska, and the Wildlife Management Advisory Council of Canada's Yukon North Slope (WMAC (NS)), jointly contracted Stephen R. Braund and Associates (SRB&A) and Eric Regehr (hereafter "study team") for the project "Incorporating Indigenous Knowledge of Northern and Southern Beaufort Sea Polar Bears into an Integrated Population Model" (hereafter "IPM-IK project"). The purpose of the project is to develop a potential framework for incorporating IK into an IPM for SB and NB polar bears, with a focus on incorporating IK as a source of information. While this project develops methods for incorporating IK into an existing western science framework, the process is based on the acknowledgment that IK and western science are equally valid and important intellectual traditions. A key component of the overall project is consulting with IK holders to provide input into project methods and results.

Research objectives for the project are summarized in the following tasks:

- Task 1: Conduct a literature review of IPMs and assess methods to incorporate IK into IPMs
- Task 2: Identify and review adequacy of available IK literature for inclusion in an IPM for the SB and NB subpopulations
- Task 3: Develop an IK interview protocol after identifying any potential gaps in the IK literature which could be addressed through fieldwork on SB and NB subpopulations
- Task 4: Provide updates, plan future workshops, and conduct sensitivity analysis planning

This report summarizes the results of Tasks 1 and 2. For Task 1, the study team performed a literature review of efforts to incorporate IK in quantitative ecological models for wildlife, with a focus on IPMs and other demographic models. The literature review identified three general functions of IK in quantitative ecological modeling and associated management and conservation practices: (1) incorporating IK as a source of information, (2) incorporating IK as part of a collaborative process that helps legitimize findings and decisions in the eyes of local communities or resource users, and (3) incorporating IK as a method to increase community capacity and empowerment. General themes identified in the literature review regarding the use of IK include the importance of appropriately selecting IK respondents, involving IK in all steps of the research process, considering potential biases, and conducting sensitivity analyses to evaluate the impact of IK on model outputs. In summary, the literature review showed that while there is an increasing body of knowledge related to IK and ecological modeling, there is little precedent for systematically integrating IK into an IPM in the manner the study team is presenting for the SB and NB subpopulations. Nonetheless, the literature review provided valuable insight into the general motivations and methods for incorporating IK into ecological models and the challenges that can be expected when trying to bridge these two knowledge systems.

To the study team's knowledge, Regehr, Hostetter, Wilson, Rode, Martin, and Converse (2018a) is the only published study that has used IK to inform an IPM that estimates abundance of a wildlife population. Therefore, the framework proposed in this report to incorporate IK into IPMs is based on

Regehr et al. (2018a); original thinking based on the combined study team experience in IK, social science, and ecological modeling; and adaptation of approaches that have been used to incorporate IK into other types of models. The study team proposed a general framework and methodology for incorporating IK into an IPM. This framework is built upon key building blocks including the identification of IPM objectives and eight IPM parameters, the categorization of IK into 10 topics and 24 associated IK variables, the establishment of five IK variable criteria corresponding to potential model input types, and identification of seven ways to collect IK. The study team believes this framework is broad enough for potential applicability in other realms of ecological modeling. It is not a rigid step-by-step formula for seamlessly integrating IK with scientific knowledge. This type of framework is in its relative infancy and will involve thorough, side-by-side, iterative collaboration between modelers and IK experts.

The objective of Task 2 was to identify and review the adequacy of available IK literature for inclusion in an IPM for the SB and NB subpopulations. After developing a general framework to guide the incorporation of IK into an IPM and identifying the list of24 IK variables, the study team conducted a literature review of available SB and NB polar bear IK to evaluate whether the IK was adequate for use in the SB and NB polar bear IPM or whether the study team believed that additional fieldwork was warranted to collect pertinent information.

Recognizing that the goal of an IPM is to learn and draw conclusions about specific biological populations of polar bears, the study team filtered all results to IK related only to NB or SB populations. This broadly addressed the IPM's IK criteria for spatial coverage. The study team also filtered the results to exclude IK publications prior to 2001, which broadly addressed the IPM's IK criteria for temporal scale, as the SB-NB IPM will likely incorporate data from 2001 to present. Lastly, after reviewing a broad range of studies that may have included, but did not target, polar bears, the study team chose to focus this initial assessment on IK studies that addressed polar bears only and not broader IK studies that addressed multiple resources. The study team applied the framework to the four most current and comprehensive studies identified in the literature review (Braund, Lawrence, Sears, Schraer, Regehr, Adams, Hepa, George, and Von Duyke 2018, Joint Secretariat 2015, Voorhees 2019, Slavik 2013).

Based on an assessment of the four IK studies reviewed for this report, seven IK variables (harvest effort, harvest reporting, harvest sampling, litter size [yearlings], management consideration, sustainability, and value of information) were not addressed in such a manner that they could influence the SB-NB IPM. Of the remaining 17 IK variables, most were found to be useful for influencing parameterization and structure of the IPM, with a smaller number influencing model purpose or prior distributions. None of the IK sources reviewed for this study provided information that could be used directly as data inputs, although several identified potential covariates that could be developed using other data sources.

The review of IK literature in Task 2 identified data gaps and helped formulate recommendations for future IK studies that could inform the SB-NB IPM. The study team identified data gaps related to the seven IK variables which were not addressed by the existing IK literature in a manner that could influence the SB-NB IPM. Additionally, the study team identified five IK variables for which future IK collection efforts could be revised to improve the ability of the information to contribute to the SB-NB IPM. These variables—Bear Age, Bear Sex, Body Condition, Mortality, and Relative Abundance—are among the most directly relevant variables to consider when conducting an IPM. Finally, the study team identified general recommendations for improving future IK data collection methods to better align with the general structure and requirements of an IPM.

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List of Acronyms

C0	Cubs-of-the-year
C1	Yearling cubs
CS	Chukchi Sea
GIS	Geographic Information System
HRA	Harvest Risk Assessment
IGC	Inuvialuit Game Council
IK	Indigenous Knowledge
IPM	Integrated Population Model
IUCN	International Union for the Conservation of Nature
LEK	Local Ecological Knowledge
MQS	Multiyear Quota System
NB	Northern Beaufort
NSB	North Slope Borough
SB	Southern Beaufort
SRB&A	Stephen R. Braund & Associates
TEK	Traditional Ecological Knowledge
WMAC (NS)	Wildlife Management Advisory Council North Slope
WMAC (NWT)	Wildlife Management Advisory Council Northwest Territories

Introduction

Project Background

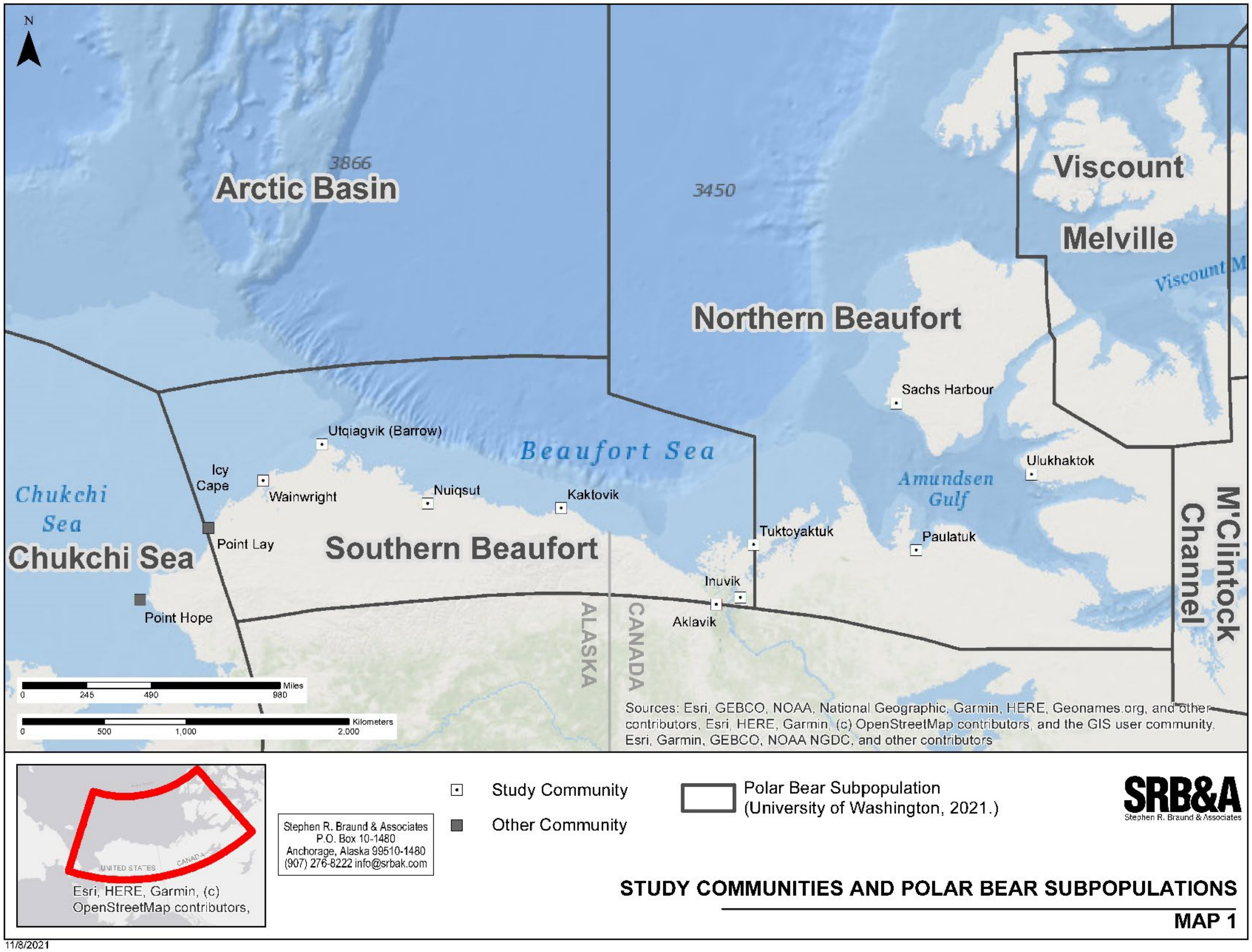
The Southern Beaufort Sea (SB) and Northern Beaufort Sea (NB) polar bear subpopulations ranges include Alaska and the Inuvialuit Settlement Region (SB subpopulation) and Nunavut and the Inuvialuit Settlement Region (NB subpopulation) (Map 1). Effective monitoring of polar bear subpopulations is necessary for informing management decisions. Estimates of subpopulation size are used, along with other lines of evidence, to establish and adjust regulated subsistence harvest levels. Over the last two decades, the Inuvialuit Game Council (IGC) and commissioners of the Inuvialuit-Iñupiat Agreement (Brower, Carpenter, Branigan, Calvert, Evans, Fischbach, Nagy, Schliebe, and Stirling 2002) have prioritized including Indigenous Knowledge (IK) in abundance estimates for SB polar bears and planning an IK workshop for a future Inuvialuit-Iñupiat meeting. The North Slope Borough (NSB) in Alaska has worked with researchers in developing new methods to incorporate IK into integrated population models (IPMs) for polar bears, which culminated in an IPM for the Chukchi Sea (CS) polar bear subpopulation that was informed by IK for that region (Braund et al. 2018, Regehr et al. 2018a). In this report, the term "integrated population model" refers to a quantitative ecological model, often implemented within a **Bayesian statistical framework**[1], that can use multiple types of input data to estimate abundance, reproduction, and other biologically meaningful parameters for a wildlife population (Kéry and Schaub 2012). Many aspects of this report are applicable to other quantitative ecological models (e.g., capture-recapture models) that are not strictly "IPMs" according to certain definitions of the term.

In 2020, the Wildlife Management Advisory Council (NWT) (WMAC (NWT)) for the Northwest Territories portion of the Inuvialuit Settlement Region in Canada, NSB in Alaska, and the Wildlife Management Advisory Council (North Slope) (WMAC (NS)) of Canada's Yukon North Slope, jointly contracted Stephen R. Braund and Associates (SRB&A) and Eric Regehr (hereafter "study team") for the project "Incorporating Indigenous Knowledge of Northern and Southern Beaufort Sea Polar Bears into an Integrated Population Model" (hereafter "IPM-IK project"). The purpose of the project is to develop a potential framework for incorporating IK as a source of information for generating an IPM for SB and NB polar bears and employing IK to guide the research/project process (Figure 1). While this project develops methods for incorporating IK into an existing western science framework, the process is based on the acknowledgment that IK and western science are equally valid and important intellectual traditions. A key component of the overall project is consulting with IK holders to provide input into project methods and results.

Research objectives for the project are summarized in the following tasks:

- Task 1: Conduct a literature review of IPMs and assess methods to incorporate IK into IPMs
    - Perform a literature review of efforts to use IK to inform IPMs for other species or systems (pages 6-9)
    - Review the list of **IK variables** developed for the CS IK workshops (pages 11-13)
    - Review which IK variables from the CS workshops were used/not used in the CS-IPM and reasons for not using (e.g., spatial, temporal, sample size limitations) (pages 11-13)

[1] Glossary terms are bolded the first time they are mentioned



MAP 1: STUDY COMMUNITIES PROVIDING IK FOR THE SB-NB IPM

- Assess differences (if any) between the CS-IPM and the anticipated structure and parameter space (i.e., the number and types of parameters, such as survival probability, that appear in the model) of the proposed SB-NB IPM (pages 13-14)
    - Determine what IK variables (from the CS-IPM effort or new variables) could be used in the SB-NB IPM to inform prior distributions of parameters, as data that contribute to parameter estimation, and to inform the purpose and structure of the IPM (e.g., to allow temporal variation in a biological parameter) (pages 25-29)
    - Determine functional relationships between IK variables and the parameters and structure of the SB-NB IPM (e.g., whether an IK variable has a positive, linear relationship with a demographic parameter) (pages 29-32)
    - Assess what data are needed for each IK variable to make it useful in the IPM with the potential to make a quantitative impact (pages 25-32)
- Task 2: Identify and review adequacy of available IK literature for inclusion in an IPM for the SB and NB subpopulations (Pages 35-48)
    - Review relevant IK literature and determine if the IK literature address any of the SB-NB IPM IK variables identified in Task 1
    - If yes, determine if the IK is adequate to incorporate into the IPM (e.g., potential to make a quantitative impact)
    - If adequate, determine if the data are available and in a suitable format to incorporate into the IPM
- Task 3: Develop an IK interview protocol after identifying any potential gaps in the IK literature which could be addressed through fieldwork on SB and NB subpopulations (forthcoming)
- Task 4: Provide updates, plan future workshops, and conduct sensitivity analysis planning (forthcoming)

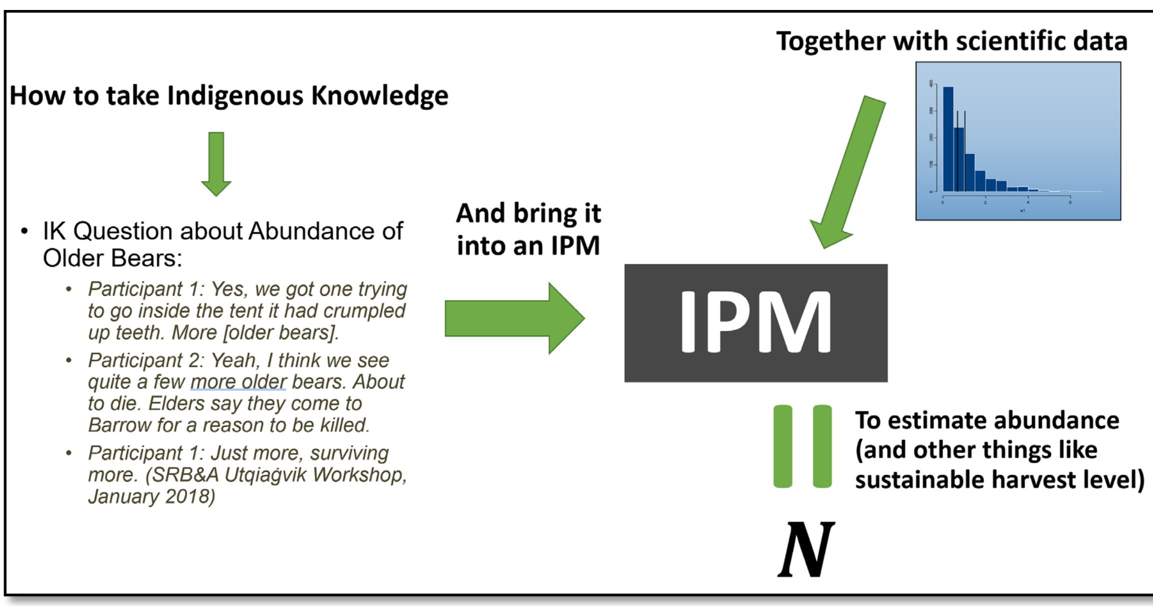


FIGURE 1: GOAL OF THE IPM-IK PROJECT

This report summarizes the results of Tasks 1 and 2. Under Task 1, the study team reviewed the CS-IPM (Regehr et al. 2018a) and the pilot study to collect IK that might be used in the CS-IPM (Braund et al. 2018), conducting a literature review of other efforts to incorporate IK into IPMs and similar ecological models, and analyzing how future IK efforts could be incorporated into an IPM for the SB and NB polar bear subpopulations. As part of this task, the study team developed a methodological framework with approaches and ideas to incorporate IK into an IPM for the SB and NB polar bear subpopulations. The study team also developed a glossary of key terms (see Appendix A).

Concurrent with Task 1, the NSB contracted the study team to begin identifying and reviewing the adequacy of available IK information for inclusion in an IPM for the SB and NB subpopulations (i.e., Task 2). As part of Task 2, the study team analyzed IK information from relevant sources using the methodological framework developed by the study team in Task 1.

Future tasks associated with this project include the study team's identification of potential IK gaps to be addressed through fieldwork, and development of an IK-collection protocol (Task 3; contracted by NSB). The final task (Task 4; contracted by WMAC-NS) associated with this project consists of the study team providing updates to the Inuvialuit-Iñupiat and Inuvialuit-Inuit Commissioners at project meetings, planning future workshops, and identifying benefits and approaches for sensitivity analyses to evaluate the quantitative impact of IK on model outputs. Study team members contributing to this report included Stephen Braund, Paul Lawrence, and Liz Sears (Stephen R. Braund & Associates), and Eric Regehr (University of Washington).

Indigenous Knowledge and Ecological Modeling

In recent years there has been a push for the scientific community to consider and include different knowledge systems in environmental research (Henri, Provencher, Bowles, Taylor, Steel, Chelick, Popp, Cooke, Rytwinski, McGregor, Ford, and Alexander 2021). This is based on the understanding that the experience-based knowledge held by local communities and Indigenous peoples can contribute to scientists' understanding of the biological and physical environment. While the primary goal of this project is to develop methods to incorporate IK into an existing western science framework, the process acknowledges that these two knowledge systems are equally valid and important. Thus, while the term "incorporate" is accurate to describe the primary goals of this project, it is not intended to downplay the value of IK as a knowledge system.

Several related terms appear in the literature to describe local or traditional-based systems of knowledge. The terms Indigenous knowledge, aboriginal ecological knowledge, traditional knowledge, traditional ecological knowledge, traditional environmental knowledge, and Inuit Qaujimajatuqangit are all based on the acknowledgement that Indigenous peoples who live on the land and harvest its resources have an intimate understanding of their environment grounded in a long-term relationship with the land, ocean, rivers, ice, and resources (Stevenson 1996). These terms refer to the cumulative body of knowledge, beliefs, and practices applied to environmental, spiritual, and social realms. This understanding includes knowledge of the anatomy and biology of resources based on centuries of harvesting and processing, species distribution and migration, animal behavior, seasons, weather and climate, hydrology, sea ice, currents, how ecosystems function, and the relationship between the environment and the local culture. Such knowledge is based on "multi-generational sharing and building on direct observations made on the daily processes of safely and successfully obtaining food and satisfying material needs" (Whiting, Griffith, Jewett, Clough, Ambrose, and Johnson 2011).

The terms local knowledge, local ecological knowledge (LEK), and community knowledge generally focus on the knowledge gained from an individual's observations over their lifetime based on their interactions with the environment. This type of knowledge can speak to more current events and changes in the environment. Early-Capistrán, Solana-Arellano, Abreu-Grobois, Narchi, Garibay-Melo, Seminoff, Koch, and Saenz-Arroyo (2020) state that "LEK can be defined as place-based empirical knowledge, held by a specific group of people about their surrounding environments and biota (as cited in Belisle, Asselin, LeBlanc, and Gauthier 2018). LEK does not require that knowledge-holders be Indigenous, nor embedded in a broader shared culture, and thus can be applied to people and communities with relatively short histories of interactions with a specific environment (as cited in Narchi, Cornier, Canu, Aguilar-Rosas, Bender, Jacquelin, Thiba, Moura, and de Wit 2014)."

For brevity and consistency, and because the primary residents and knowledge holders within the range of the SB and NB polar bear subpopulations are Indigenous, this report will use the term "Indigenous Knowledge (IK)" to encompass the various terms and concepts described above. Within this broad definition, the study team considered observations and samples reported by hunters about polar bears (e.g., the sex and age of harvested bears) as a type of IK, because harvest strategies are often driven by IK regarding the appropriate age, sex, timing, and location of a harvested resource, and these observations can provide quantitative data from Indigenous communities for input into an IPM.

Ecological models are simplified representations of a complex reality (Box 1976) that help understand natural systems, forecast the future, and provide managers with information for decision-making. The structure and function of most ecological models are subjective (i.e., depend on the experience and perspectives of the modeler), making them an appropriate place to combine different forms of expertise and information, including IK. Quantitative ecological models that consider IK have become more common in the past 10 years (e.g., Belisle et al. 2018), driven in part by conventions and declarations involving or requiring consideration of both scientific[2] information and IK (e.g., the Convention on Biological Diversity <https://www.cbd.int/>).

For polar bears, consideration of IK is mandated by multiple Land Claims Agreements and treaties (e.g., the Inuvialuit Final Agreement). To date, the primary approach to research and management of polar bears has been to consider scientific studies and IK as separate lines of information, as opposed to bringing the two knowledge types into the same analytical framework. This idea that IK should remain separate from scientific studies was supported by the International Union for the Conservation of Nature (IUCN) Polar Bear Specialist Group (PBSG) in a statement in 2014: "…it is not the role of the PBSG to integrate information that is not based on scientific design into its advice for decision makers" (full statement available at <http://pbsg.npolar.no/export/sites/pbsg/en/docs/TEK-statement-PBSG2014.pdf>). Therefore, despite the publication of several IK studies on polar bear in recent years (e.g., Joint Secretariat 2015, Voorhees 2019, Slavik 2009), efforts to bridge science and IK have been rare.

[2] In this document the term science (or western science) refers to the knowledge system that is rooted in philosophy of Ancient Greece and the Renaissance and which emphasizes analytical and reductionist methods focused on objective and quantitative information transmitted through academic and literate means (see Mazzocchi 2006).

A recent example of such an effort to incorporate science and IK in the study of polar bears, Regehr et al. (2018a) used inference from IK about the status of the CS subpopulation to justify the use of **informative prior distributions** on survival probability in an IPM. The types of IK that informed Regehr et al. (2018a) included existing qualitative studies (Voorhees, Sparks, Huntington, and Rode 2014, Kochnev and Zdor 2016) and the results from a pilot study designed to collect IK specifically to inform management models for CS polar bears (Braund et al. 2018).

Task 1 Results (Literature Review and Methodological Assessment)

IPM and IK Literature Review

Review of Efforts to Incorporate IK into Modeling

The study team performed a literature review of efforts to incorporate IK in quantitative ecological models for wildlife, with a focus on IPMs and other demographic models. The search was performed using the Clarivate Web of Science database to access scientific publications from 1900-present. First, the study team defined the following four search sets:

> Set 1: "local knowledge" OR "Indigenous knowledge" OR "traditional ecological knowledge" OR "local ecological knowledge" OR "traditional knowledge" OR "Inuit Qaujimajatuqnagit" OR TEK OR TK OR LK OR LEK
>
> Set 2: “integrated population model”
>
> Set 3: “Bayesian”
>
> Set 4: ("estimat*" OR "model*") AND ("survival" OR "abundance" OR "vital rate" OR "growth rate" OR "population" OR "demograph*")

The words “AND” and “OR” represent search conditions, and an asterisk (*) represents a wildcard that will match any character. For example, searching on the term “model*” returned results containing “model”, “modeling”, “modelling”, “modeler”, and so forth. The study team recorded the number of papers returned for each search set. Second, the study team performed literature searches using combinations of search sets (e.g., Set 1 and Set 2; Set 1 and Set 3; Set 1 and Set 4), and excluded papers that did not use search terms in the desired context (e.g., papers in which “lek” referred to a breeding site for birds) or were not related to wildlife or fisheries research, management, or conservation. Third, the remaining papers were categorized by year of publication, primary topic, secondary topic (if applicable), and taxon, to obtain an overview of how IK has been used in quantitative ecological models for wildlife. The study team closely reviewed the papers that were most relevant to the IPM-IK project.

A total of 97 papers met the combined search sets and were relevant to the current study (Appendix B). Zero papers were returned from the combination of search sets 1 (IK) and 2 (IPM). This indicates that incorporating IK into IPMs is a novel approach. Ten papers were returned from the combination of search sets 1 (IK) and 3 (Bayesian), the earliest of which was published in 2008. This reflects that use of Bayesian methods to incorporate IK into quantitative models is a recent advancement. Belisle et al. (2018) identified Bayesian models as a promising analytical approach for incorporating LEK. To our knowledge, Girondot and Rizzo (2015) provided the first example of using LEK as prior information in a Bayesian model of reproductive phenology for sea turtles. Of the remaining eight papers from search sets 1 and 3, six were related to some aspect of fisheries management (e.g., species distribution, harvest effort, sustainability). One paper evaluated cumulative impacts on a social-ecological system (Mantyka-Pringle, Jardine, Bradford, Bharadwaj, Kythreotis, Fresque-Baxter, Kelly, Somers, Doig, Jones, Lindenschmidt, Slave, and Delta 2017), and one paper modeled habitat suitability for multiple threatened species (Tantipisanuh, Gale, and Pollino 2014). The remaining 87 papers were returned from the combination of search sets 1 and 4 (i.e., IK and modeling).

While the earliest paper resulting from the combined search sets was published in 1998, the frequency of publications increased after that, with 84 percent of papers published in the past decade (Figure 2). Most papers dealt with mammals or fish (here referring to all non-mammalian marine species; Figure 3). The most common primary topics were demography, habitat use and distribution, and harvest and management (Figure 4). Approximately 80 percent of the papers dealing with demography were focused on recent or long-term trends in species abundance, as perceived by local communities or resource users. Only two papers returned in the literature search addressed polar bears. Kochnev (2018) used IK on the distribution and abundance of polar bear dens in Chukotka, Russia. York, Dowsley, Cornwell, Kuc, and Taylor (2016) compared assessments of the demographic status of Canadian polar bear subpopulations based on scientific studies and IK, suggesting that incomplete geographic sampling (e.g., during capture-recapture studies) has led to negative bias in scientific assessments of demographic status. This phenomenon is documented in the scientific literature (Peñaloza, Kendall, and Langtimm 2014), and Regehr, Ben-David, Amstrup, Durner, and Horne (2009) presented a case study for the SB polar bear subpopulation that evaluated negative bias in estimates of survival and abundance resulting from incomplete geographic sampling and the high mobility of polar bears.

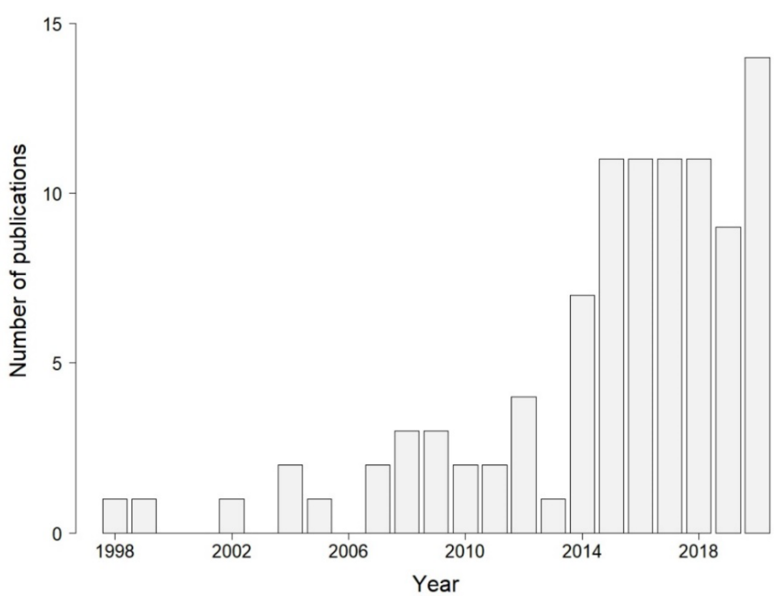


FIGURE 2: NUMBER OF SCIENTIFIC PUBLICATIONS RESULTING FROM THE LITERATURE SEARCH ON INDIGENOUS KNOWLEDGE AND QUANTITATIVE ECOLOGICAL MODELING USING THE CLARIVATE WEB OF SCIENCE DATABASE. SEARCH SETS ARE DEFINED IN THE MAIN TEXT.

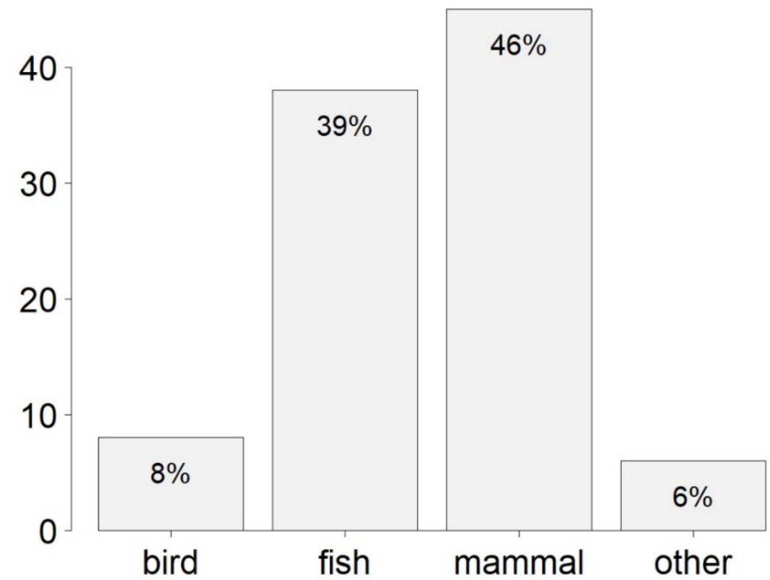


Figure 3: Distribution of taxa represented in the literature search on Indigenous Knowledge and quantitative ecological modeling using the Clarivate Web of Science database.

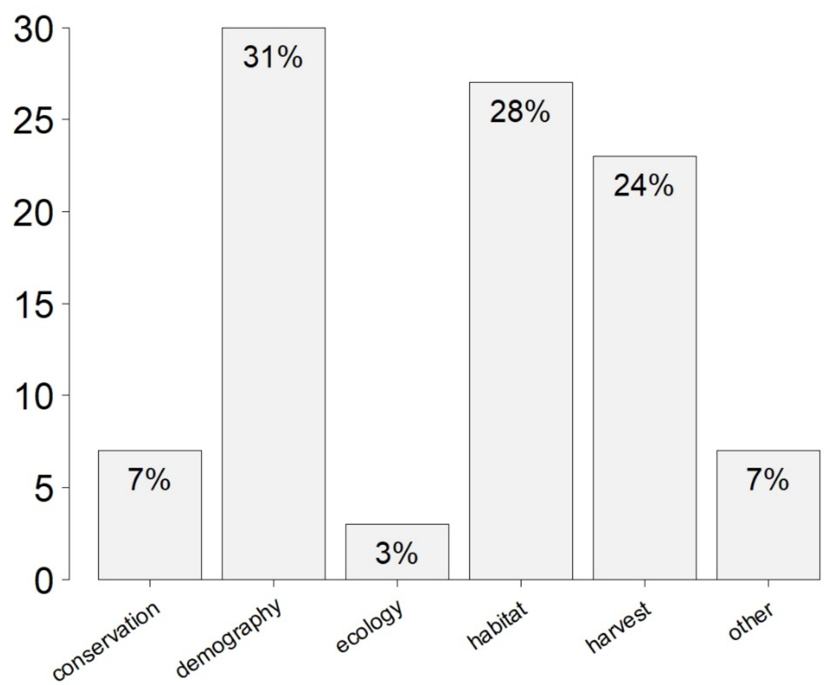


Figure 4: Distribution of primary topics represented in the literature search on Indigenous Knowledge and quantitative ecological modeling using the Clarivate Web of Science database.

The literature review identified three general functions of IK in quantitative ecological modeling and associated management and conservation practices: (1) incorporating IK as a source of information, (2) incorporating IK as part of a collaborative process that helps legitimize findings and decisions in the eyes of local communities or resource users, and (3) incorporating IK as a method to increase community capacity and empowerment. This project is focused on function (1), incorporating IK as a source of information, but recognizes the value and importance of functions (2) and (3) in improving and facilitating community input into scientific processes. In fact, if function (1) is successfully accomplished, it can contribute to functions (2) and (3). The literature indicates that, compared to information from scientific studies, IK may be cheaper, faster to collect, and is based on richer and longer-term interactions with the environment. Collection of IK is typically conducted using interview-based methods from the social sciences (Huntington 2000). General themes identified in the literature review regarding the use of IK include the importance of appropriately selecting IK respondents, involving IK in all steps of the research process, considering potential biases, and conducting sensitivity analyses to evaluate the impact of IK on model outputs. The following two subsections (Motivations and Methods to Incorporate IK in Quantitative Ecological Models and Challenges with Incorporating IK in Quantitative Ecological Models) outline approaches and ideas from the literature review that the study team considered relevant to the goals of the current IPM-IK project.

Motivations and Methods to Incorporate IK in Quantitative Ecological Models

The literature review identified case studies in which IK was incorporated into quantitative ecological modeling efforts for a wide array of purposes, including the following:

- Management
  - Define management objectives
  - Develop management actions and strategies
  - Evaluate effectiveness of actions and strategies
  - Monitor harvest
  - Evaluate sustainability of harvest
  - Provide feedback in an adaptive management framework
- Modeling
  - Define the purpose of a model
  - Define the structure of a model
  - Demography (especially of long-term trends in abundance)
  - Ecological relationships
  - Habitat use and distribution (especially for cryptic species)
- Other
  - Conservation and threat assessment
  - Develop data collection methods
  - Evaluate ecosystem health
  - Monitor biodiversity

In most case studies, IK was used as a source of data for modeling. For example, IK obtained through interviews provided information on the relative abundance, habitat use, or subsistence harvest of wildlife. The analytical frameworks used to incorporate IK included simple summaries of data without additional statistical interpretation (e.g., presenting raw counts or numbers), simple statistical models such as linear regression, **species distribution models** (e.g., resource selection functions), **customized management tools** such as species-specific equations used to calculate harvest levels (Cuyler, Daniel, Enghoff, Levermann, Moller-Lund, Hansen, Damhus, and Danielsen 2020), and **Bayesian Belief Networks** (e.g., Mantyka-Pringle et al. 2017). Several studies used scientific data to validate IK, or vice versa (Polfus, Heinemeyer, Hebblewhite, and Taku River Tlingit First 2014). One study used a hierarchical modeling framework to account for potential false negatives and positives in occupancy information obtained from IK (Madsen, Elliot, Mjingo, Masenga, Jackson, May, Roskaft, and Broekhuis 2020).

Challenges with Incorporating IK in Quantitative Ecological Models

Based on the literature review and experiences with Regehr et al. (2018a) and Braund et al. (2018), the study team identified several general challenges with incorporating IK into quantitative ecological models, including the following:

- Combining concepts and methods from social science and the natural sciences
    - Requires an interdisciplinary approach
    - Requires developing common terms and definitions
    - Requires making the distinction between observations (e.g., data points in the natural sciences) and inferences (e.g., qualitative conclusions in the social sciences, which may be based on many observations and experiences)
- Quality of the IK information collection process
    - Some types of information must be collected using a systematic and rigorous process
    - Requires documentation of the elicitation process (e.g., method to select participants, sample size, methods to account for uncertainty, potential biases)
- Consistency between modeling objectives and the degree of IK involvement
    - Requires identifying why IK is included and what benefits it provides (e.g., does IK provide valuable data for a model or is IK included to improve the collaborative process). Superficial use of IK can be counterproductive
    - Caution is required when attempting to validate IK through the lens of scientific studies
- Consistency of scale and scope between IK and parameters in the model
    - If IK is used to inform parameters, the temporal and spatial scale of the IK must be consistent with the temporal and spatial scale of the parameter. For example, IK on relative abundance within a localized area may not provide valid information about a parameter representing absolute population-level abundance
- Establishing relationships between qualitative information from IK and quantitative aspects of a model
    - This requires thorough and transparent justification for how IK is linked to components of a quantitative ecological model (e.g., model structure, **IPM parameters**, **prior distributions**). For example, justification of why knowledge from IK was translated into a particular statistical distribution representing prior information about a model parameter

In summary, the literature review showed that while there is an increasing body of knowledge related to IK and ecological modeling, there is little precedent for systematically integrating IK into an IPM in the manner the study team is presenting for the SB and NB subpopulations (see below). Nonetheless, the literature review provided valuable insight into the general motivations and methods for incorporating IK into ecological models and the challenges that can be expected when trying to bridge these two knowledge systems.

Methodological Assessment

Evaluating the CS-IPM and IK Integration Efforts

Before developing a general framework for incorporating IK into an IPM for the SB and NB subpopulations, the study team reviewed a previous effort to incorporate IK into an IPM for the CS subpopulation. Braund et al. (2018) documented IK for CS polar bears during a pilot study designed to inform demographic modeling. Findings from Braund et al. (2018) were incorporated into an IPM used to estimate survival, abundance, and other biological parameters for the CS subpopulation (Regehr et al. 2018a), and in a harvest risk assessment (HRA) used to evaluate the biological effects of human-caused removals and inform management decisions about subsistence harvest (Regehr, Von Duyke, Wilson, Polasek, Rode, Hostetter, and Converse 2021b, Regehr, Polasek, Von Duyke, Wilder, and Wilson 2018b).

For the CS subpopulation, researchers incorporated IK by using it to provide evidence for and justify the establishment of **informative prior distributions** for sex- and age-specific survival probability. Specifically, Regehr et al. (2018a) developed a prior distribution for survival based on empirical estimates of survival from scientific case studies for 12 polar bear subpopulations with available data. This approach assumed that the survival of CS bears was similar to survival of other polar bear subpopulations that have been studied (i.e., that there was not anything exceptional about the CS subpopulation that would cause it to have survival rates that were outside of the range that had been previously estimated for polar bears). Considering that climate change is the primary long-term threat to polar bears (Regehr, Laidre, Akçakaya, Amstrup, Atwood, Lunn, Obbard, Stern, Thiemann, and Wiig 2016), justification for this choice of priors required evidence that CS polar bears have not experienced unprecedented declines in survival resulting from sea-ice loss or other factors. This justification was provided, in part, by information on several IK variables (Braund et al. 2018). IK holders stated that overall abundance of CS bears was stable or increasing in recent decades and that the level of abundance in 2017 was average-to-good. Numbers of cubs and older bears were reported as increasing, which suggested a combination of positive recruitment and high adult survival. IK holders also reported that prey species (primarily ringed seals and bearded seals) were abundant. Furthermore, there were no perceived changes in polar bear health or body condition (i.e., fatness), and health in 2017 was considered average-to-good. Multiple scientific studies have shown that polar bear reproduction and survival are positively related to body condition (e.g., (Molnár, Derocher, Thiemann, and Lewis 2010). In summary, the choice of prior distributions for survival probability in the CS-IPM was informed by the following IK variables in (Regehr et al. 2018a):

1. Overall abundance
2. Recruitment (number of cubs)
3. Number of older bears (survival)
4. Prey species (seals)
5. Polar bear health or body condition (fatness)

IK holders participating in Braund et al. (2018) reported changes in the sea ice including earlier break up, later freeze up, thinner ice, and more interannual variability, which have collectively led to more polar bears on land. However, current sea-ice conditions, in conjunction with abundant seals and other factors, were perceived as sufficient to support a healthy and stable polar bear population. Collectively, these perspectives from IK were largely consistent with scientific data on the positive status of ice seals (Crawford, Quakenbush, and Citta 2015), positive body condition and recruitment of CS polar bears

(Rode, Regehr, Bromaghin, Wilson, St. Martin, Crawford, and Quakenbush 2021), changing sea-ice conditions (Stern and Laidre 2016), and increased land use by CS polar bears (Rode, Wilson, Regehr, Martin, Douglas, and Olson 2015). The combined weight of evidence from the IK variables and scientific studies listed above were used as justification for the use of informative priors. Regehr et al. (2018a) demonstrated that using informative priors led to higher estimates of survival compared to an identical IPM that used **vague priors**. Higher estimates of survival translated into higher estimates of population growth rate, which in turn led to higher estimates of sustainable harvest level during the HRA (Regehr et al. 2021b).

Other IK variables reported in Braund et al. (2018) were not directly used to inform the IPM, except to confirm that they did not contradict the variables listed above or the general agreement between IK and scientific studies on the status of CS bears. At the time, no additional variables were directly considered because this was the first-ever attempt to incorporate IK in an IPM for polar bears, and project members had not fully established the logical connections between IK variables and model variables.

The CS-IPM did not include data for research-marked bears that were harvested and reported to the management authorities. This represents the omission of valuable information given that population studies that directly include data from harvest returns are commonly conducted for polar bears (e.g., live-capture dead-recovery models (Peacock, Laake, Laidre, Born, and Atkinson 2012). The CS-IPM did not include harvest returns because during the study period from 2008–2016 only five research-marked bears were reported in the CS harvest, and this was not a large enough sample to justify the additional model structure needed to make use of these data. The low number of research-marked bears that were reported is due to the combination of relatively low harvest rates in the CS subpopulation (Regehr et al. 2021b), incomplete harvest reporting in the U.S. (Schliebe, Benter, Regehr, Quakenbush, Omelak, Nelson, and Nesvacil 2016), and no official harvest reporting in Russia (Kochnev and Zdor 2016). If a management system with accurate harvest reporting had been in place for the CS subpopulation, it would have likely been possible to include harvest returns in the model and obtain more accurate estimates of survival and abundance.

Although the IPM-IK project is focused on incorporating IK into IPMs and other quantitative ecological models used to estimate population parameters (e.g., survival, abundance), the study team also reviewed how IK was used to inform an HRA for the CS subpopulation, because some concepts in that process are relevant to the current application. The HRA for the CS polar bear subpopulation (Regehr et al. 2021b) used estimates of vital rates and abundance from Regehr et al. (2018a) in a matrix population model to project the CS polar bear subpopulation forward in time, subject to changing environmental conditions and a wide range of harvest strategies. Because it was not possible to accurately forecast the status of the CS subpopulation based on available scientific information, the HRA considered three alternative scenarios for future changes in environmental **carrying capacity** resulting from sea-ice loss. The HRA incorporated some perspectives from IK by including an environmental scenario in which carrying capacity remained stable until the year 2036, despite observed and projected sea-ice loss, and subsequently declined. This scenario was considered because IK and scientific data indicated that sea-ice changes to date have not been harmful to the body condition and reproduction of CS polar bears (Rode et al. 2021), and because IK presents polar bears as intelligent and adaptable animals that can respond to environmental change (although IK holders also acknowledged the potential for continued ice loss to eventually be negative for polar bears). Since publication of the HRA as a management report (Regehr et al. 2018b), a scientific study was released that forecasts changes in survival and reproduction for the CS subpopulation based on the duration of the seasonal fasting period (i.e., the summer months when the region is largely ice free and bears cannot hunt seals in their preferred sea-ice habitats) as predicted by global climate models (Molnár, Bitz, Holland, Kay, Penk, and Amstrup 2020). Findings from Molnár et al. (2020) suggest that the CS subpopulation could experience demographic declines around the year 2040, which is broadly consistent with the environmental scenario discussed above.

The HRA reflected some IK variables from Braund et al. (2018) in terms of practical aspects of implementing a managed polar bear harvest. Specifically, the biological effects of harvest were evaluated under a multiyear quota system (MQS) that allowed unused portions of a harvest quota to be carried forward from one year to the next (Regehr et al. 2018b). The MQS was designed to accommodate interannual variability in polar bear harvest resulting from variation in the availability of bears to hunters, subsistence need, etc. Although the MQS was originally developed by the governmental and Native partners responsible for co-management of CS bears under the U.S. Marine Mammal Protection Act, it embodied some key findings from Braund et al. (2018). Specifically, IK holders expressed concern that a quota could result in increased polar bear harvest because hunters may feel the need to fill the quota every year due to competition and to avoid the perception that the entire quota was not needed. The MQS was intended to meet the legal requirement of identifying an annual taking limit (i.e., quota) for the CS subpopulation while incorporating flexibility to address hunters' concerns in a manner that does not have negative demographic effects on the subpopulation (Regehr et al. 2018b).

Assessing Differences between CS-IPM and Proposed NB and SB IPM

Before developing a framework to incorporate IK into an IPM for SB and NB polar bear subpopulations, the study team assessed the differences between the CS-IPM and proposed SB-NB IPM. The CS-IPM was built around a life cycle graph, originally proposed by Regehr, Hunter, Caswell, Amstrup, and Stirling (2010), that represents important sex, age, and reproductive stages for polar bears, including the extended maternal care of cubs. The CS-IPM included multiple biological parameters for sex- and age-specific survival, reproduction (e.g., breeding, weaning of two-year-old bears), abundance, and movement of bears in and out of the core sampling area (see Table S1 in (Regehr et al. 2018a) for a full list of parameter, data, and indexing definition for CS-IPM). During capture-recapture studies for the CS subpopulation, it was not logistically possible to distribute sampling effort throughout the subpopulation boundary. Therefore, Regehr et al. (2018a) estimated polar bear density (i.e., bears/km^2) within the core area where sampling occurred, then extrapolated density to the rest of the subpopulation area using resource selection functions derived from satellite telemetry data for adult female polar bears (Wilson, Regehr, Rode, and St Martin 2016). The CS-IPM also included multiple parameters related to study design and sampling processes including the probability of resampling a bear after its initial capture and the probability that satellite telemetry radio collars would fail. Furthermore, the CS-IPM included remote observations of polar bears based on radiotelemetry data (e.g., a bear was known to be alive and outside of the sampling area because it was wearing a functioning radiocollar), which resulted in uncertainty about the biological state of some bears (e.g., a female that was wearing a radiocollar and was known to be alive—but was not visually observed—could have been alone or with cubs) that required additional model structure (i.e., this was a multi-event model where one observation event could map to several states; (Pradel 2009)). The CS-IPM was a true IPM in that it combined multiple types of data (live captures, count data, cub-of-the-year and yearling litter sizes, and radiotelemetry data) and explicitly linked vital rates (e.g., reproduction and survival) to changes in subpopulation composition and abundance.

The IPM for the SB and NB polar bear subpopulations will be similar to the CS-IPM because polar bear life history and research methods are similar among the subpopulations. It is anticipated that the SB-NB IPM will include variants of all parameters listed in Table S1 of Regehr et al. (2018a), with the following exceptions and additions:

- Sampling effort will be more evenly distributed throughout the SB and NB subpopulation boundaries. Therefore, it will be possible to estimate abundance directly instead of extrapolating density from a core sampling area (noting that sampling in offshore areas may still be limited due to logistical constraints).
- Harvest reporting for the SB and NB subpopulations is near complete in Canada and, in the US, is likely more complete than in the CS subpopulation. Therefore, the structure of the SB-NB IPM will be extended to include harvest tag returns for research-marked bears. This will require including parameters for sex- and age-specific harvest reporting (*r*, defined as the probability that a bear was killed and reported by humans, conditional on death). This will allow for robust estimation of harvest mortality and un-harvested survival probability. Because the SB-NB IPM will include movement among geographic states (see below), the model will also include harvest return data for bears that are first marked in the SB or NB and later harvested in a different region.
- The IPM will likely incorporate data for both the SB and NB subpopulations into one metapopulation model. This will allow parameters to be shared across subpopulations (e.g., the model could estimate an average survival probability for adult females in both the SB and NB, if the data provided support for such an approach). The metapopulation model will allow for movement of polar bears between the SB and NB subpopulations, as well as temporary and permanent emigration with respect to both subpopulations (i.e., it will recognize that bears can leave the SB and NB region and never return). Regehr et al. (2009) demonstrated that failure to model the movement of bears in and out of the SB subpopulation boundary can lead to biased estimates of survival and abundance.
- The SB-NB IPM will include data for live captures as well as observations of individual polar bears based on genetic analysis of tissue samples obtained from a biopsy dart, whereas the CS-IPM only included data from live captures. Unlike live captures, biopsy sampling does not provide a vestigial premolar tooth that can be used to estimate a bear's age. Therefore, the SB-NB IPM will likely require additional structure to account for the fact that biopsy-darted bears can be subjectively assigned to an age class but cannot be assigned a data-based numeric age.
- Because the SB and, to a lesser extent, the NB are well studied polar bear subpopulations, the SB-NB IPM will include a longer time series of data that starts in 2001, the year when sampling in the US portion of the SB region became standardized. Furthermore, because there was some level of sampling that occurred in both subpopulations prior to 2001, the model will likely include initial captures (but not recaptures) prior to 2001.
- Since 2001, several studies in the SB and NB have provided data on individually marked bears outside of designed, springtime capture-recapture studies. For example, sampling has occurred in the US portion of the SB region in autumn as part of short-term live-capture studies (Whiteman, Harlow, Durner, Anderson-Sprecher, Albeke, Regehr, Amstrup, and Ben-David 2015)

and using less-invasive methods such as hair snares around the carcasses of bowhead whales taken for subsistence (Herreman and Peacock 2013). This type of auxiliary data may be included in the SB-NB IPM if exploratory analyses indicate that the benefits of using the data outweigh the additional model structure required to do so.

Proposed Framework to Incorporate IK into an IPM

To the study team's knowledge, Regehr et al. (2018a) is the only published study that has used IK to inform an IPM that estimates abundance of a wildlife population. Therefore, the framework proposed in this report to incorporate IK into IPMs is based on Regehr et al. (2018a); original thinking based on the combined study team experience in IK, social science, and ecological modeling; and adaptation of approaches that have been used to incorporate IK into other types of models. While the focus of this report is on incorporating IK as a source of information into an IPM, it also advances a framework that could help legitimize findings and decisions in the eyes of local Indigenous peoples by moving beyond the "anecdotal" label often given to IK and towards a framework that emphasizes the strength of IK and science (i.e., "two-eyed seeing" (Mantyka-Pringle et al. 2017)). The study team's proposed framework to incorporate IK into an IPM was based on six conceptual building blocks, which are shown on Figure 5 and discussed in the following sections.

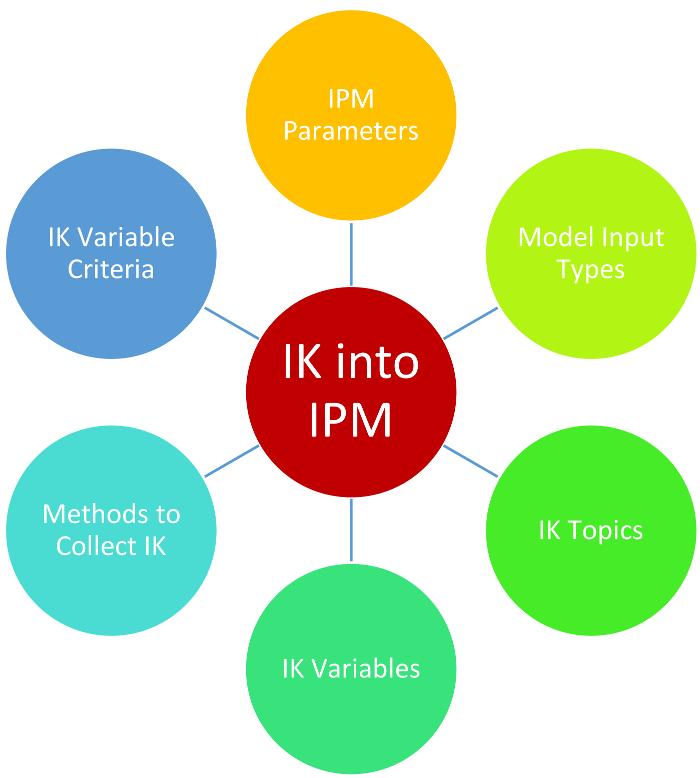


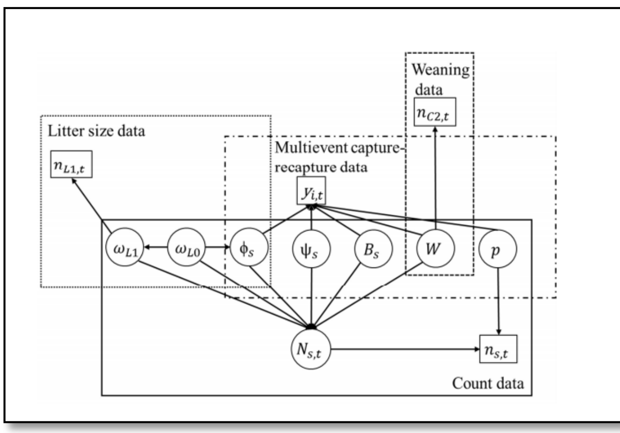
FIGURE 5: BUILDING BLOCKS OF THE FRAMEWORK TO INCORPORATE IK INTO AN IPM

Integrating IK into an IPM requires a clear statement of the objectives of the IPM and the demographic parameters that it will estimate (hereafter "IPM parameters"). For the IPM-IK project, the study team developed a preliminary definition of the overall objective of the IPM, as follows:

Evaluate the demographic status of the SB and NB subpopulations, with a focus on obtaining accurate estimates of abundance and trend. Analyses should integrate all available sources of data that are relevant to this objective, including scientific data and IK. To the extent possible, the IPM should provide information needed to address conservation and management questions, including questions related to the demographic effects of habitat loss and human-caused removals.

IPM Parameters

Based on this objective, the structure of the CS-IPM (Regehr et al. 2018a), and other demographic analyses for polar bears (e.g., Lunn, Servanty, Regehr, Converse, Richardson, and Stirling 2016), the study team developed a list of potential IPM parameters that could be informed by IK. This list does not reflect all parameters that will be estimated by an IPM, some of which are considered "nuisance parameters" that are required to explain variation in the data but are not directly relevant to biology or demography. For example, the CS-IPM estimated the probability that a radiocollar will fail. This parameter was needed to interpret patterns in the CS polar bear data but is not relevant to the biology of CS bears or to polar bear management and conservation in general. Furthermore, some of the IPM parameters listed below are generalized, as they may correspond to multiple specific parameters in the IPM. For example, although "Breeding probability" appears once in the list below, the IPM may include several age-specific breeding probabilities (see Figure 6 example showing IPM structure with multiple survival probability parameters).



Data	
$y_{i,t}$	Observation event of individual i at year t
$n_{s,t}$	Number of individuals in state s captured at year t
$n_{L1[1:3],t}$	Number of observed age-one litters with one, two, and three cubs at year t
$n_{C2,t}$	Number of observed age-two individuals at year t
$n_{weanC2,t}$	Number of observed independent age-two individuals at year t
$R_{i,t}$	Binary indicator, where 1 indicates individual i received a collar at year t, and 0 otherwise
F	Distribution of age-classes across the entire population, used to initialize the integrated population model

Parameter	Definition
ϕ_{AF}	Adult female (≥ 4 years) survival probability
ϕ_{SF}	Subadult female (2-3 years) survival probability
ϕ_{AM}	Adult male (≥ 5 years) survival probability
ϕ_{SM}	Subadult male (2-4 years) survival probability
ϕ_{L0}	Age-zero litter survival probability (i.e., at least one cub survives), conditional on adult female survival
ϕ_{L1}	Age-one litter survival probability (i.e., at least one cub survives), conditional on adult female survival
ϕ_{C0}	Age-zero cub (C0) survival probability, conditional on adult female survival
ϕ_{C1}	Age-one cub (C1) survival probability, conditional on adult female survival

FIGURE 6: EXAMPLE OF IPM STRUCTURE WITH MULTIPLE DATA AND PARAMETER COMPONENTS (DETAILS IN REGEHR ET AL. 2018)

Accordingly, descriptions of the IPM parameters are generalized and do not represent full technical specifications. Generalized IPM parameters include the following:

1. Abundance and trend – the number of animals in a clearly defined "study population" and/or the change in numbers over a certain period. The IPM may provide estimates of abundance for different study populations due to seasonal movements of polar bears. For example, estimates of abundance could refer to the number of animals in a geographic region at a certain time (e.g., the number of animals within the SB subpopulation boundary in spring) or to the number of animals that may use a geographic region over a longer period.

2. Survival probability – the probability that a bear will survive a certain period. Survival probability and other vital rates in the IPM will likely be referenced to the period from the spring of calendar year *t* to the spring of calendar year *t*+1. The IPM will likely estimate separate survival probabilities for dependent young (i.e., C0s [cubs-of-the-year] and C1s [yearling cubs] with their mothers) and independent bears (i.e., bears age ≥ 2 years).
3. Breeding probability – the probability that an adult female bear available to breed in the spring of year *t* will reproduce successfully and be accompanied by C0s in the spring of year *t* + 1.
4. Litter size – the probability that an adult female with dependent young will have 1, 2, or 3 C0s or C1s.
5. Relationships between vital rates (i.e., survival and reproduction rates) and environmental conditions – information about how environmental conditions (e.g., sea-ice extent) may influence, or be correlated with, vital rate(s). There are several ways to incorporate such relationships into the IPM.
6. Movement probability – the probability that a polar bear will move between two geographic regions over a certain period. For example, the IPM may estimate the probability that a bear will move from the SB to the NB subpopulation boundary between the spring of year *t* and the spring of year *t*+1.
7. Harvest mortality – the probability that a bear that dies was killed by humans and reported to the responsible management authorities. Harvest mortality is a component of overall mortality probability (i.e., where mortality is defined as 1 – survival probability).
8. Environmental carrying capacity – the number of animals that an environment can support in absence of direct human-caused mortality or disturbance. Depending on how an IPM is structured, carrying capacity itself may not appear as IPM parameter. However, information related to carrying capacity can potentially influence multiple aspects of the model. For example, if carrying capacity is known or suspected to decline, it may be necessary to allow for a declining trend in annual estimates of abundance.

Model Input Types

The study team's proposed framework focuses on five types of model input (hereafter referred to as "model input types") through which IK could be incorporated into an IPM:

1. Model purpose – the reasons a model is built and what it is used for
2. Model structure – how the model is constructed and organized
3. Parameterization - how IPM parameters vary in time and space, and among bears
4. Prior distributions – statistical representations of available information before building an IPM
5. Data – quantitative inputs to the IPM that are directly used to estimate model parameters

Model Purpose

Model purpose refers to the reason the model is built and what it is used for. IK could be used to develop a model that is clear in its focus and addresses key concerns of resource users, local communities, and other stakeholders. For example, if IK indicates that cub mortality is a major concern, it would be possible to organize data collection and modeling in a manner that focuses on cub survival (perhaps at the expense of other, less important variables). As another example, if IK indicated that a certain group of polar bears (e.g., adult males) had become less common and stakeholders sought an explanation or solution, a model could be developed with the specific purpose of evaluating how environmental conditions, harvest, or other factors affect adult males.

Similarly, IK can be used to develop scientific hypotheses that will be evaluated using the model. For example, if IK suggested that poor recruitment resulting from habitat loss was the cause of declining abundance, the model could be used to evaluate whether recruitment alone was sufficient to explain the observed trend in abundance. Individual hypotheses will tend to be more specific than the overall model purpose.

Finally, IK can be used to interpret, compare, or validate other information. For example, agreement between conclusions from IK and the results of a scientific study could lead to stronger inference. Similarly, disagreement between IK and science could motivate new studies or analyses to investigate apparent differences. While this application of IK may not appear directly related to model "purpose," it is included here because the study team did not consider it as a separate "model input type". In practice, the degree of consistency between IK and other information could influence an IPM in several ways, for example by justifying the use of certain data (e.g., consistent observations from IK and science about how ice conditions affect bears could justify the use of sea-ice **covariates** to explain patterns in vital rates) or by highlighting the need to investigate apparent disagreement among information from different sources.

Model Structure

Model structure refers to how the model is constructed, which includes selecting and defining the biological states, processes, and parameters in the model and how these elements relate to each other and the input data. Here, "biological states" refers to different groups or classes of polar bears that are of biological interest. For example, a simple model could have two biological states representing females and males, with separate parameters for female and male survival probability; whereas a more complex model could have multiple biological states representing different sex, age, and reproductive classes (e.g., subadult males, subadult females, single adult females, adult females with dependent young). The important concept is to develop an IPM with a structure that is biologically realistic for the study species (here, polar bears) and is suitable for answering the primary questions of interest. For example, if IK variables suggest emigration from the population (e.g., if bears commonly move between two geographic regions), one may need to use a model with multiple biological states representing polar bears in different geographic areas (i.e., such that a bear could leave the study area and temporarily reside in a different area). Models with multiple geographic states are becoming increasingly common in ecological investigations (e.g., Lebreton, Nichols, Barker, Pradel, and Spendelow 2009) and often have specific data requirements, such as telemetry data on animal movements or harvest tag returns from adjacent subpopulations.

Parameterization

Parameterization refers to how IPM parameters (e.g., survival probability) vary in time and space, and among bears. For example, if IK indicated that abundance changed over a certain period, the IPM could be parameterized to reflect this change (i.e., the model would calculate different levels of abundance before and after the period, instead of calculating a single, average abundance). An IPM could have a highly flexible parameterization. For example, it could estimate independent, annual survival probabilities for bears in multiple biological states (e.g., sex, age, and reproductive classes). Such a model would require a lot of data because it is estimating a lot of parameters. In contrast, an IPM could have a constrained parameterization that estimates a single, time-constant survival probability for all bears, regardless of age or sex. This model would not require as much data but would sacrifice biological accuracy. The final parameterization of an IPM often reflects a compromise between the type and amount of data available, and the degree of detail required for the model to be biologically meaningful.

Biological hypotheses are often tested by comparing alternate parameterizations of a statistical model. For example, the hypothesis that male survival is increasing could be tested by comparing an IPM with time-constant male survival to an IPM with a time-varying male survival. Statistical methods can indicate which parameterization of the model provides a better "fit" (i.e., explanation of patterns in the data) and whether the information derived from additional IPM parameters is worth the data required to estimate them.

Prior distributions

Prior distributions are statistical representations of information that is available before conducting a specific study or building a specific model (e.g., a priori knowledge about the likely values of a model parameter based on other case studies or knowledge of species' life history). Model purpose, structure, and parameterization define what an IPM looks like and can be used for, while prior distributions and field data (see next) represent the information that goes into an IPM. This information is processed according to the model's internal structure and parameterization, producing quantitative estimates of IPM parameters as output.

IK can be used to develop informative prior distributions for IPM parameters when the model is built within a Bayesian statistical framework. Using IK to develop informative prior distributions requires a clear understanding of the relationship between the IK variable and the IPM parameter. In some cases, it also will require translating the IK into quantitative terms. As a potential method to accomplish this, the study team proposes an equivalency approach under which qualitative IK is used to establish equivalence between an IPM parameter in the model being developed, and the known value of that parameter from a different (i.e., already completed) model or system. For example, if there are IK variables that have been correlated with high relative survival probability (e.g., good body condition, low harvest, plentiful prey), then modelers could have the prior expectation that survival will be similar to, or in a specific quantile of, survival probabilities that have been estimated for polar bears under similar conditions in other case studies. In other words, IK reflecting positive body condition and a healthy age composition could potentially be used to justify the assumption of equivalence between survival rates in the subpopulation of interest, and survival rates in a second subpopulation that also exhibited positive body condition and a healthy age composition. Then, quantitative estimates of survival obtained from a demographic model for the second subpopulation could be used to develop informed priors on survival for the subpopulation of interest.

There are likely additional ways in which IK could be used to inform prior distributions. Even if IK does not provide information on the absolute value of an IPM parameter, it may provide information on the relative values of two or more parameters (i.e., that one parameter is higher or lower than another). For example, it would be possible to specify an informed prior distribution for breeding probability that forces the parameter to be higher for one time period relative to another time period (or for one group of bears relative to another group of bears, etc.), based on IK about that parameter, without specifying anything else about the actual values of breeding probability. Because using IK to inform prior distributions is a new concept, these and other potential applications require further development within an actual IPM.

Data

Data are specific, quantitative inputs to a model (e.g., field observations of litter size). Using an IK variable as data will generally require a survey or systematic observations. For example, the reported locations of harvested bears constitutes data that are directly relevant to estimating movement probability. In some cases, "data" could consist of a covariate that explains variation in a model parameter. For example, if a time series of catch-per-unit-effort (CPUE) based on IK was believed to reflect changes in abundance, it would be possible to model abundance as a function of CPUE. Finally, if an IPM or related model included conditional probability tables (i.e., tables that express the probability of one event given that another event has already occurred; for example the probability of a population decline given that habitat has declined) like those in Bayesian Belief Networks, it would be possible to use IK to inform the conditional probabilities (Amstrup, Marcot, and Douglas 2008).

Methods to Collect IK

To better understand how IK best fits into the five model input types, it is useful to describe the most common types of IK and how they are collected, as the method for collecting IK influences the potential outputs and relative applicability to an IPM. Figure 7 displays seven common methods for collecting and documenting IK. Multiple methods may be used in a single project and often the goals of the project determine the way that IK is documented. The following sections provide an overview of these seven methods, benefits and drawbacks of each, typical sample sizes and methods to select respondents, representativeness of the sample to the entire community, and common formats for the associated IK information.

FIGURE 7: SEVEN METHODS FOR COLLECTING AND DOCUMENTING IK

Oral Histories

Oral histories (also sometimes referred to as life histories) typically are conducted when a project seeks to record observations over an individual's lifetime, or stories and knowledge that have been passed down over generations. The benefit of this approach is that it provides contextual information regarding local history and environmental change. Oral histories can provide observations over a long period of time. Because of the broad scope of this approach, it is one of the least structured methods and tends to gather little quantitative information. IK from life histories can best serve an IPM by informing the model structure or purpose. Generally, oral history projects have a small sample size that is limited to community elders or respected community members as recommended by local or tribal organizations. Quotes, transcripts, and digital recordings are the most common outputs of this approach.

Stakeholder Engagement

IK collected through stakeholder engagement has the broadest community reach. Forums for this approach include project introductory meetings, scoping, testimony, and review and feedback sessions. This approach also includes such things as advisory committees or boards (e.g., a caribou subsistence panel). This type of engagement allows for the identification of real-time issues, concerns, and knowledge relevant to current developments, regulations, and agency decisions. It provides high-level input that is best used for guiding a potential study and its goals and outcomes, and therefore is best suited to informing the structure or purpose of a quantitative ecological model. Stakeholder engagement can be hampered in that the background or experience of a speaker is often unknown, and public forums are not guided by a set protocol structure. Stakeholder engagement through panels or advisory boards, whose members are typically selected through recommendations by existing community organizations, can help address some of the drawbacks of this approach by identifying experienced IK holders. Quotes and transcripts are the most common outputs of this approach.

Semi-directed Interview

Semi-directed interviews focus on a set of key topics. The interviews are guided by these key topics, which allows for an in-depth exploration of related information, but also allows for respondents to expand to related topics resulting in robust interviews. Similar to oral histories, this approach produces primarily qualitative information over quantitative information, and the target respondents are usually limited to a subset of knowledgeable individuals for a particular topic. Because of its stronger focus on specific topics, IK from semi-directed interviews can serve an IPM both by informing the model structure or purpose or providing information on model parameterization or prior distributions. Respondent quotes by topic are the typical outputs. This approach may also employ ranking exercises (e.g., prime/poor habitat, healthy/contaminated, body condition). Ranking exercises are an effective way of translating a qualitative knowledge set such as IK into a quantitative format which are more likely to be suitable for incorporation into an IPM. For example, IK holders can draw on the body of knowledge regarding a certain topic such as animal habitat, which is determined by a multitude of factors (e.g., ground cover, type of vegetation, precipitation, elevation, slope), and use their accumulated knowledge of these factors to rank areas as poor, suitable, or optimal habitats (see Polfus et al. 2014). In another example, Braund et al. (2018) had respondents rank the body condition of polar bears using a standardized fatness index ranging from skinny to very fat.

Workshops and Focus Groups

Workshops and focus groups involve IK collection from multiple participants simultaneously and are similar to semi-directed interviews in their focus on a set of key topics. One benefit of this approach over semi-directed interviews is that a workshop setting with multiple participants can lead to real-time identification of discrepancies in observations among local residents, and workshop discussions can help reach consensus or explain these discrepancies. Unresolved discrepancies may be clues to areas of future research. The presence of multiple participants can also encourage and cue memories in respondents related to specific topics. While initial topics are selected by the interviewer, the workshop approach often results in discussions expanding to related topics, resulting in robust workshop discussions. In some cases, workshop participants may be less likely to speak up in a group environment, while others may dominate a conversation, and thus a workshop approach may not always get as detailed information as semi-directed interviews. Proportional piling exercises allow workshop participants to provide visual estimates of population and other metrics (e.g., health, size, relative distribution) using piles of beans, rice, or other small objects. These exercises can help workshop participants reach consensus and provide more quantitative information. If workshops are used, it is usually best to aim for three to five participants per workshop to allow for consensus within discussions while providing adequate opportunities for all individuals to participate. Implementing a respondent nomination process can ensure those with the most relevant knowledge participate. Information outputs and relevant model input types are similar to that of semi-directed interviews.

Participant Observation and Informal Interviews

Participant observation is the most “hands on” approach to gathering IK and usually involves accompanying knowledgeable individuals into field settings. Respondents often are chosen through a nomination process focused on local experts regarding a particular IK topic. This approach will include multiple trips or interviews with the same respondent(s) over time. By choosing this method, the researchers can gain more insight into a topic through their on-site observations and there are multiple opportunities for questions and follow-ups. This approach is time consuming, however, and may not be as systematic as a guided interview or more structured survey. The format of IK collected varies but field and researcher notes are one common output, and all model input types could potentially be informed by this approach. The more structured and replicable the collection, the greater the ability to use as model data inputs. For example, in cases where the harvest events are localized in time and space (e.g., Nuiqsut whaling events from Cross Island (Galginaitis 2018); Nuiqsut Arctic cisco fishing in late fall in lower Colville Delta; (ABR and SRB&A 2007); polar bear harvesting during spring whaling for Point Lay (Braund et al. 2018)), participant observation could provide the documentation necessary to use harvest mortality events as data inputs for an IPM. Figure 8 provides an example of the type of information that could be collected from participant observation IK documentation efforts.

Active Harvester and Key Informant Interviews

Active harvester collection employs semi-structured protocols that emphasize systematic and replicable collection of information. Typical topics include subsistence use areas, geographic information system (GIS) tracks and waypoints, harvest locations, timing of subsistence activities, frequency and duration of subsistence activities, and status and observed changes of subsistence species and environmental conditions. This method focuses on individuals with the most knowledge about an activity or topic in a community and provides a combination of quantitative and contextual qualitative information. While the relatively small sample size of respondents may not permit the rigorous statistical testing and validation that larger surveys would provide, the sampling methods generally target a large portion of highly active and knowledgeable harvesters that are representative of the community. Sample size is fluid, but researchers typically want to achieve topical saturation (i.e., similar observations were repeated and no additional data were found with which to develop new model properties), thematic saturation (additional data did not produce new emerging themes), data saturation (new data repeated what was expressed in previous data) (see Early-Capistrán et al. 2020), or some combination thereof. Identification of active harvesters usually starts with a nomination of individuals by community organizations (e.g., city, municipality, tribal council, hunter trapper committee) followed by implementation of a snowball method of respondent selection where interviewees nominate other active harvesters and key informants in their community.

Daily Report Form, Cross Island Subsistence Whaling Documentation, 2 September 2011

"Active" Boats Summary

Date	Crew	Boat	Track #	Crew #	Time out	Time in	TOT min	HOURS	MIN	RT	F_PT	Track?
9/2/2011	BO	BO1	BO1_090211	4	12:50	20:15	445	7	25	69.5	24.9	yes
9/2/2011	BO	BO2	BO2_090211	4	12:47	20:13	446	7	26	75.9	25.3	yes
9/2/2011	IAN	IAN1	IAN1_090211	5	15:36	22:45	429	7	9	69.9	20.9	yes
9/2/2011	IAN	IAN2	IAN2_090211a	3	13:19	20:26	427	7	7	70.1	23.3	yes
9/2/2011	IAN	IAN2	IAN2_090211b	3	21:31	24:48	197	3	17	19.3	7.5	yes
9/2/2011	IP	IP1	IP1_090211	3	12:17	24:52	755	12	35	87.4	23.9	yes
9/2/2011	IP	IP2	IP2_090211	3	12:20	24:49	749	12	29	102.0	24.0	yes
9/2/2011	IP	IP3	IP3_090211	2	12:13	22:11	598	9	58	104.0	23.7	yes
9/2/2011	NUK	NUK1	NUK1_090211	4	12:43	22:46	603	10	3	50.5	9.2	yes
9/2/2011	NUK	NUK2	NUK2_090211a	4	11:08	19:56	LOGISTICAL TRIP TO WEST DOCK					no
9/2/2011	NUK	NUK2	NUK2_090211b	4	20:50	24:50	240	4	0	20.6	7.6	yes
9/2/2011	TAL	TAL1	TAL1_090211	5	15:44	24:56	552	9	12	71.5	20.9	yes
9/2/2011	TAL	TAL2	TAL2_090211	3	15:45	24:49	544	9	4	68.0	20.9	yes

"Inactive" Boats

Date	Crew	Boat	Notes
None			

Strikes Used

Date	Time Struck	Length	Sex	Whale ID	Miles from Cross Island	Bearing from Cross Island	Notes
02 Sept.	20:35	52'1"	F	11N1*	7.9	63° true	Taalak, landed

Waypoints

Date	Crew	Waypoint	Lat/Long	Time	Notes	Type
9/2/2011	BO1	BO1_090211a	N70 28.617 W147 06.092	15:14	Where BO1 slowed looking for a whale	C
9/2/2011	BO2	bo2_090211a	N70 28.452 W147 05.942	15:14	BO2 reported position next to mother and calf pair	W
9/2/2011	BO2	BO2_090211b	N70 28.196 W147 05.307	15:21	Marked point for mother and calf pair	C
9/2/2011	GEN	GEN_090211a	N70 28.356 W147 07.235	14:41	"Cluster" of whales, general area	C
9/2/2011	GEN	GEN_090211b	N70 27.649 W147 03.314	16:12	General location where boats slowed after the 16:07 whale sighting (not localized)	C
9/2/2011	GEN	GEN_090211c	N70 28.759 W147 00.119	17:17	General area where boats slowed, one boat reported sighting a log, but no further whale sightings	C
9/2/2011	GEN	GEN_090211d	N70 31.650 W147 18.574	18:54	General area where most boats gave up looking for the whales they had been seeing. Most headed in the direction of CI with a few taking less direct routes.	C
9/2/2011	IAN1	ian1_090211a	N70 27.412 W147 56.717	15:48	IAN1 boat position when barge sighted	Tr
9/2/2011	IAN1	ian1_090211b	N70 25.585 W148 01.563	15:48	Estimated position of barge that was sighted	B
9/2/2011	IAN1	IAN1_090211c	N70 30.338 W147 16.377	17:51	IAN1 recorded coordinates when some other boat respots whale in front of his boat. These are clearly coodinates for a later position (Com Center recorded the time of the observation, and filled in the coordinates later, when they were given)	C

Figure 8: Example of Participant Observation Form for Cross Island Whaling (Galginaitis 2014)

Active harvesters are also often involved in documenting harvest reports and collecting biological samples. The basic information collected in harvest reports or biological samples may not be considered strictly IK but can provide quantitative information from Indigenous communities for input into an IPM. In addition, harvest strategies are often driven by IK regarding the appropriate age, sex, timing, and location of a harvested resource. Lastly, these types of studies can be structured to collect additional IK observations and context that help identify related research topics that could be addressed through harvest reporting or biological sampling (e.g., causes of disease, abnormal mortality events, nuisance versus purposeful hunts). This approach is also beneficial in that it increases community capacity and empowerment toward designing, participating in, and implementing harvest reporting and biological sampling studies.

IK collection efforts with active harvesters offers a range of potential information outputs from respondent quotes to numerical, range, ordinal, categorical, and percentage variables. It also includes GIS and other place-based information. Because of the various types of information that this approach can gather, it can inform all IPM input types from model purpose and structure to quantitative data. For example, SRB&A's typical active harvester protocol includes sections that address community concerns (which could inform model purpose), changes over time (which could inform parameterization), and yearly observations on health, distribution, and abundance (which could be used as data if the spatial and temporal scope of observations corresponded to IPM parameters).

Surveys

Surveys offer the most structured method for collecting IK and are usually based on achieving a statistical sample (e.g., 80%) or census of households in a community. This approach systematically collects data and is meant to statistically represent the whole community or region. It can also be combined with key informant interviews to provide a broader context to interpret the results. While this approach draws on the IK of informants to provide answers, the output is typically in a western science quantitative format. Due to its structured, systematic, and replicable nature, surveys are excellent in providing quantitative data that can be used in an IPM. These inputs can be numerical, range, ordinal, categorical, and percentage data. Some surveys can be designed to also collect open-ended questions which results in quotes.

IK Collection Methods Applicable to IPM

Figure 9 provides a summary of the seven methods and how they can best be used to inform an IPM. The figure is arranged from those methods that are the most qualitative in their results to the most quantitative and which type of model inputs are best served by the resulting information. It should be noted that the categories are fluid and can be tailored to various model needs and purposes, but in general fit the organization shown on the figure.

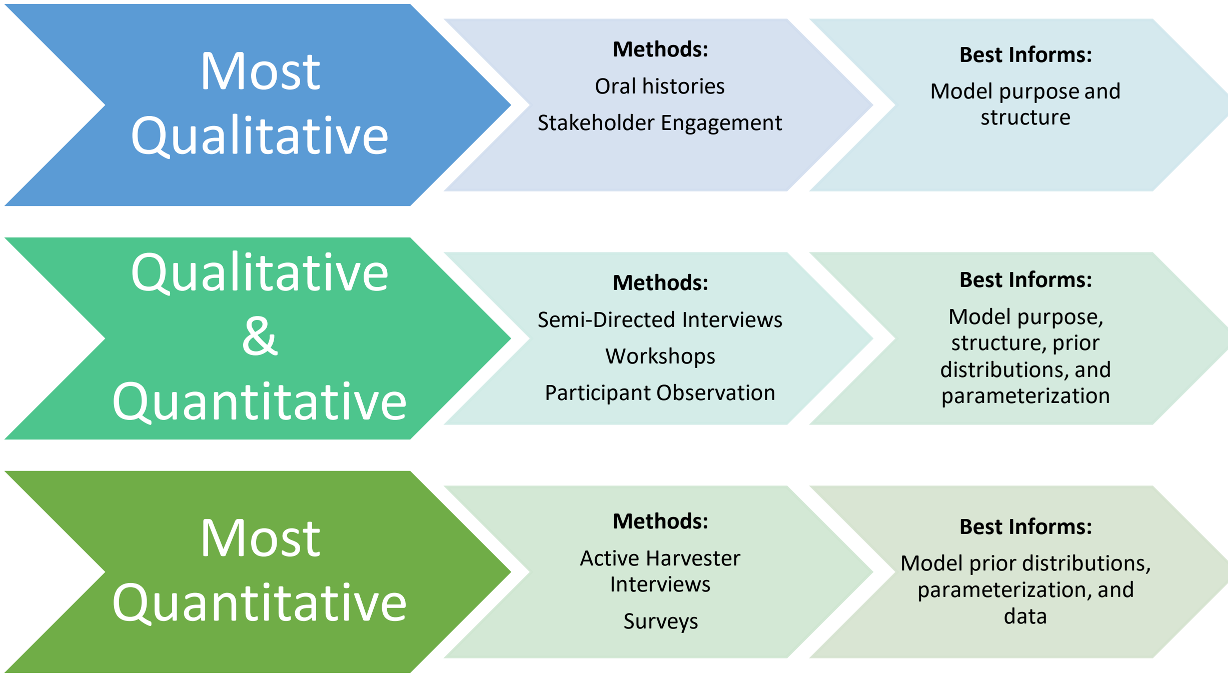


FIGURE 9: METHODS TO COLLECT IK AND BEST APPLICATIONS TO AN IPM

IK Topics and Variables

Following the IPM and IK literature review, the study team compiled a list of IK topics and variables that were potentially relevant to an IPM for polar bears. The initial list was informed by the CS pilot study (Braund et al. 2018) as well as the study team's broader IK literature review, IK protocols for other projects, and study team expertise. To ensure a comprehensive review, the study team started by creating a list of broad IK topics under which related IK variables could be grouped. The 10 IK topics and their definitions are as follows:

1. Abundance and Reproduction – knowledge related to vital rates (e.g., reproduction and survival), population composition, and numbers of animals.
2. Distribution – knowledge regarding the seasonal movements and spatial distribution of polar bears.
3. Habitat – knowledge related to the physical environment used by polar bears, including important sea ice and terrestrial habitats.
4. Harvest Practices – knowledge associated with the hunting and harvests of polar bears.
5. Health – knowledge regarding overall health and prevalence of diseases or sickness.
6. Prey Species – knowledge related to prey abundance and health.
7. Management – knowledge related to Indigenous management systems, perspectives, and practical aspects of general polar bear management (e.g., human-bear conflicts and deterrent methods).
8. Research – knowledge that evaluates the role of IK in polar bear research activities or uses IK to inform and develop research methods.
9. Traditional Uses – knowledge regarding various uses of polar bear including ways to process, clean, stretch, and sew polar bear hides for clothing or handicrafts or use polar bear meat/fat as a food resource.

10. Legends and Beliefs – knowledge associated with stories, legends, and spiritual practices and beliefs regarding interaction with polar bears.

The study team then identified IK variables that fall under these topics and could potentially contribute to the objectives of the SB-NB IPM (section IPM Parameters). Specifically, to determine whether an IK variable was applicable, the study team evaluated whether it contained IK that could influence one or more IPM parameters through one of the model input types, as discussed above. This resulted in a total of 24 IK variables, with the largest number (nine) falling under the IK topic "Abundance and Reproduction" (Table 1).

Table 1: Polar Bear IK Topics, IK Variables, and Definitions

IK Topic	IK Variable	IK Variable Definition
Abundance & Reproduction	Bear Age	Relative age (i.e., younger, juvenile, mature, older)
Abundance & Reproduction	Bear Sex	Male or female
Abundance & Reproduction	Body Condition	Fat or skinny, sometimes recorded as a standard five-point body condition index
Abundance & Reproduction	Harvest Effort	Catch-per-unit-effort (CPUE)
Abundance & Reproduction	Litter Size (cubs-of-the-year)	Cub-of-the-year (C0) presence and litter size
Abundance & Reproduction	Litter Size (yearlings)	Yearling (C1) presence and litter size
Abundance & Reproduction	Mortality	Observations of dying or dead bears (e.g., natural mortality, cannibalism)
Abundance & Reproduction	Relative Abundance	Abundance relative to a specific location or time period
Abundance & Reproduction	Resilience to Change	Response/resilience to climate change; key demographic and ecological relationships
Distribution	Range and Seasonal Movements	Range distribution (large-scale) and seasonal movement patterns (small-scale) during spring, summer, fall, and winter
Habitat	Sea Ice Habitat	Definition of important sea-ice habitat and changes over time
Habitat	Terrestrial Habitat	Definition of important terrestrial habitat and changes over time
Harvest Practices	Harvest Reporting	Date, location, sex, age class of harvested bears
Harvest Practices	Harvest Sampling	Proof of sex, tooth for age determination, tissue sample for genetics, whether the bear had research marks [e.g., lip tattoo and plastic ear tags]
Harvest Practices	Targeted vs. Opportunistic Harvests	Selection for sex or age class
Health	General Bear Health	Broad observations of health (e.g., strong, weak, energetic, tired, dirty, poor fur, injured)
Health	Observations of Disease or Sickness	Specific observations of disease or sickness in alive and harvested bears
Prey species	Prey Abundance	Abundance of various prey animals (e.g., various species of seals); indices of prey availability to polar bears (e.g., condition of observed prey carcasses)
Prey species	Prey Health	Health of various prey animals (e.g., various species of seals)
Management	Sustainability	What are the best practices for ensuring a sustainable polar bear population? Are current harvest levels sustainable?
Management	Management Considerations	What are most important management and conservation concerns/objectives/actions/needs for polar bears?
Research	Scientific Findings	Agreement/disagreement with scientific findings
Research	Value of Information	Value of different information types (e.g., science, IK)
Research	Research Considerations	What are the most important research concerns/actions/needs for polar bears?

As a result of this evaluation, the study team excluded the "Traditional Uses" and "Legends and Beliefs" IK topics from further consideration because they were the least likely to provide information related to IPM parameters. Figure 10 provides an example illustration of this evaluation process, and Table 2 shows the IK variables that were retained and their potential applicability to the model input types and IPM parameters.

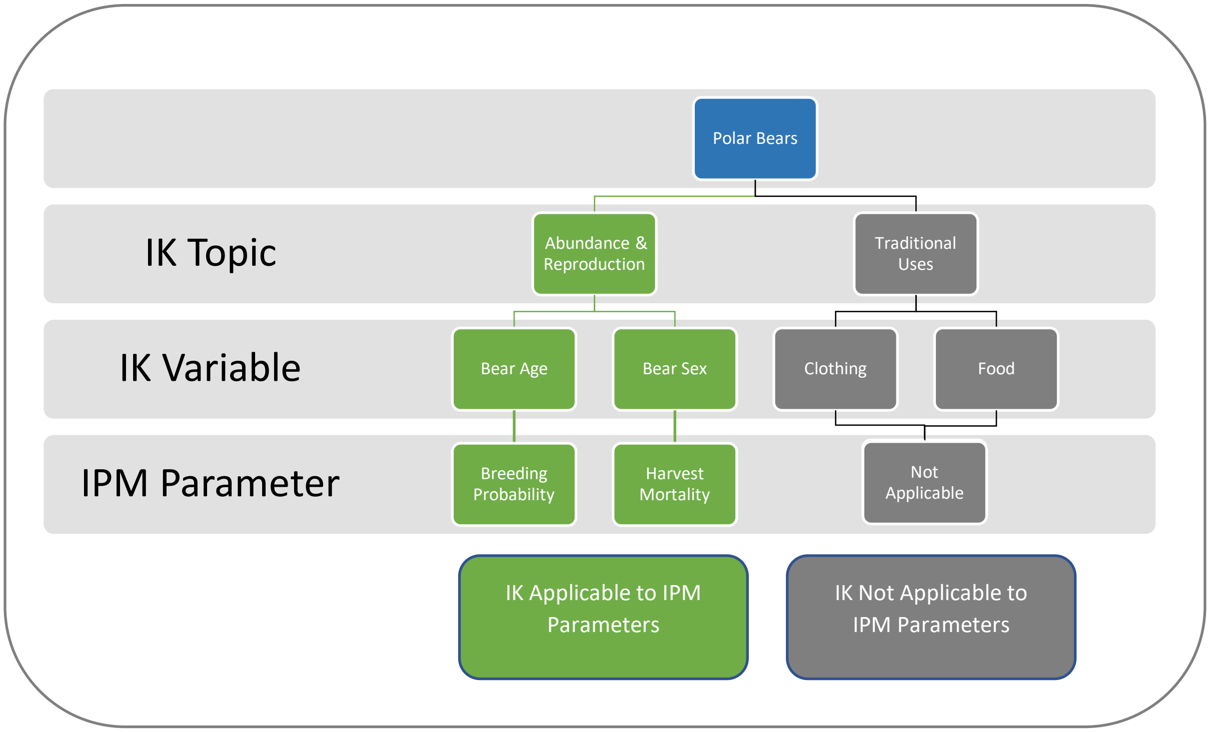


FIGURE 10: EXAMPLE CONCEPT OF IK VARIABLE SELECTION PROCESS

TABLE 2: POLAR BEAR IK VARIABLES, MODEL INPUT TYPES, AND IPM PARAMETERS FOR AN IPM

IK Topic	IK Variable	Model Purpose	Model Structure	Parameterization	Prior Distributions	Data	IPM Parameters
Abundance & Reproduction	Bear age			X	X	X	breeding probability, survival, harvest mortality
Abundance & Reproduction	Bear sex			X	X	X	survival, harvest mortality
Abundance & Reproduction	Body condition		X	X	X	X	breeding probability, survival
Abundance & Reproduction	Harvest Effort			X	X	X	abundance and trend, harvest mortality
Abundance & Reproduction	Litter Size (cubs-of-the-year)		X	X	X	X	breeding probability, litter size, survival

IK Topic	IK Variable	Model Purpose	Model Structure	Parameterization	Prior Distributions	Data	IPM Parameters
Abundance & Reproduction	Litter Size (yearlings)			X	X	X	breeding probability, litter size, survival
Abundance & Reproduction	Mortality		X	X	X	X	survival
Abundance & Reproduction	Relative abundance			X	X		abundance and trend
Abundance & Reproduction	Resilience to Change		X	X		X	relationships between vital rates and environmental conditions; carrying capacity
Distribution	Range and Seasonal movements	X	X	X	X		movement probability
Habitat	Sea Ice Habitat		X	X	X		carrying capacity, abundance and trend
Habitat	Terrestrial Habitat		X	X	X		carrying capacity, breeding probability (if denning habitat), abundance and trend
Harvest Practices	Harvest Reporting		X			X	survival, harvest mortality, abundance and trend
Harvest Practices	Harvest Sampling		X			X	survival, harvest mortality, abundance and trend
Harvest Practices	Targeted vs. Opportunistic Harvests		X	X	X		harvest mortality
Health	General bear health			X	X		breeding probability, survival
Health	Observations of disease or sickness		X	X	X		survival
Management	Management Considerations	X	X				no direct IPM parameters
Management	Sustainability			X	X		harvest mortality
Prey species	Prey Abundance			X	X	X	multiple IPM parameters
Prey species	Prey Health			X	X	X	multiple IPM parameters
Research	Research Considerations	X	X				no direct IPM parameters
Research	Scientific Findings	X	X				no direct IPM parameters
Research	Value of Information	X	X				no direct IPM parameters

As shown in Table 2, in some cases, a single IK variable could be used for more than one model input type (e.g., purpose, structure, priors, parameters, or data) and could relate to more than one IPM parameter, depending on the quality and details of the underlying information. Also, some of the IK variables in Table 2 could potentially correspond to several, related types of information. For example, the IK variable "Basic harvest reporting" has multiple components including the sex, age, and location of harvested bears. Lastly, Table 2 represents a general framework that shows what IK variables could be best suited to inform different model input types and IPM parameters. It is not a rigid structure and, depending on the type of IK and type of IPM, certain IK variables may inform other input types and parameters than specified in Table 2 (e.g., Litter Size Yearlings informing Model Structure).

IK Variable Criteria

Each of the 24 IK variables in Table 2 could contain information that is relevant to an IPM. While all IK variables can provide valuable information for ethnographic, management, scientific, and cultural heritage purposes, for IK variables to be useful in an IPM framework, they must meet certain criteria. The study team developed criteria for including IK variables in an IPM at the level of the five model input types. As noted above, this approach provides a general framework for incorporating IK into IPMs, which the study team considered more useful than developing specific criteria for each IK variable defined in the SB-NB IPM (also, such definitions are not yet available because the SB-NB IPM is under development). Generally, inclusion criteria for IK variables progress from less rigorous and quantitative (i.e., qualitative), to more rigorous and quantitative, in the following order of input types: model purpose, model structure, parameterization, prior distributions, and data. Importantly, criteria to use information from IK as data are more rigorous than the criteria for IK to inform model structure or model purpose. IK that is used as data inputs will usually be the most quantitative in form, whereas IK that informs prior distributions, parameterization, and model structure or purpose can be more qualitative. For example, information falling under the IK variable "Bear Age" would have different potential uses in an IPM depending on whether the available information was a subjective assessment of changes in population age structure over time (e.g., a shift toward younger bears) vs. a sample of numeric age data obtained from premolar teeth extracted from harvested bears. Application of specific criteria for each IK variable will require knowledge of the type of information that is available or can be collected for a particular application.

The study team focused on the following considerations when developing criteria for each of the model input types:

1. Spatial coverage of IK must be known and align with the spatial coverage of the IPM.
2. Temporal coverage of IK must be known and align with the temporal coverage of the IPM.
3. The IK collection method will affect multiple aspects of the IK and how it can be used in an IPM. For example, the collection method may affect sample size and scope of inference.
4. The baseline or relative context must be known for IK that uses comparisons, expresses relative values, or addresses changes. For example, if IK indicates that abundance is "high" it would be necessary to understand the baseline abundance against which this assessment was made (e.g., whether the IK refers to high abundance around a community, or high abundance of a larger biological population).
5. The functional relationships between the IK, the IPM, and the model input type must be defined. For example, IK about breeding probability is only relevant if the IPM includes biological

states or processes that are related to reproduction. In some cases, for IK to be relevant to an IPM, it will be necessary to express the IK in a quantitative format and establish the functional relationship between the IK and specific IPM parameters. This is most applicable to prior distributions and data. For example, if IK related to polar bear survival provides the basis for an informative prior on a survival probability, it would be necessary to translate the IK into a statistical distribution that is suitable for use as a prior in an IPM.

These considerations are summarized in Figure 11. Specific criteria for each model input type are discussed in the following section.

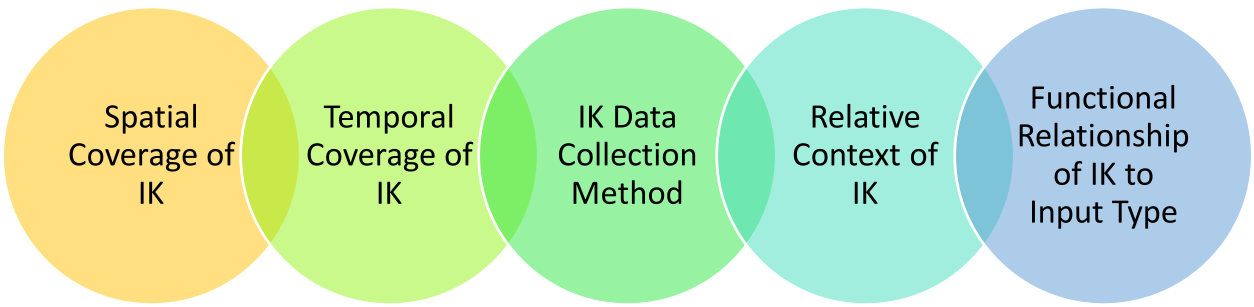


FIGURE 11: FIVE CRITERIA CONSIDERATIONS FOR INCORPORATING IK VARIABLES INTO IPM INPUT TYPES

IK Variable Criteria by Model Input Type

Model Purpose Criteria

To inform model purpose the IK should express a common concern, question, or goal that is suitable for investigation using an IPM. For example, if the IK shows a widely held concern regarding survival of first year cubs (C0s), a model could be developed to produce the best possible estimates of survival probability for dependent young. Depending on data requirements and other factors, developing a model that is focused on a primary purpose (e.g., C0 survival) may require other compromises in terms of excluding other IPM parameters or estimating them with lower accuracy. Because of its high-level focus, the model purpose can be informed by IK that comes from both local (e.g., community) or regional geographic scales (e.g., province or borough). IK to inform model purpose does not need to be subpopulation specific if common management considerations across jurisdictions lead to similar modeling priorities (e.g., estimating abundance to inform sustainable harvest). The IK should reflect recent information, and if older than one polar bear generation (approximately 11.5 years (Regehr et al. 2016), it may need to be re-evaluated. Species-specific generation length is often used to define a biologically relevant timeframe for ecological models and conservation assessments (IUCN Standards and Petitions Committee 2019). The study team proposed one polar bear generation as a guideline for the temporal scale of IK to inform model purpose, because one generation represents a period over which substantial demographic change could occur based on the life history of polar bears. In general, IK to inform model purpose will not have to meet strict criteria and can be garnered from a variety of IK collection methods including oral histories, stakeholder engagement, semi-directed interviews, workshops, and participant observation.

Model Structure Criteria

IK that is relevant to model structure is more technical and focused than IK for model purpose, although some overlap is possible. IK to inform model structure should relate to biological states (i.e., classifications or attributes of individual animals), processes, or parameters in the IPM. For example, if IK indicated that male bears are more likely to disperse than female bears, the structure of the model would need to include biological states reflecting both the sex and location of bears (e.g., a biological state comprising females within the subpopulation boundary and a separate biological state comprising males outside of the subpopulation boundary), a process allowing bears to transition among geographic states but not sex states, and parameters representing probabilities of transitioning among states (e.g., movement probabilities). The structure of an IPM should be consistent with data that are available for the biological population of interest, which for polar bears will generally mean that the spatial scale of IK should be relevant to the subpopulation(s) being studied. Unlike model purpose, IK used to inform model structure could potentially come from the entire body of recorded IK and not have temporal limitations. For example, IK from the 1970s explaining that young, male bears are most likely to approach humans and therefore have higher harvest mortality than other sex and age classes, may remain relevant because it reflects biological attributes of polar bears that do not change over time. IK collection methods to inform model structure are the same as those for model purpose.

Parameterization Criteria

The purpose and structure of a model will determine which IPM parameters it contains. Model parameterization refers to how each IPM parameter is allowed to vary in time, space, and among individual bears. IK used to inform parameterization generally addresses variation in certain components of a model (e.g., biological states, process, or the structure of the model itself) that can be captured by specifying variation in IPM parameters. IK used to inform parameterization will generally need to have the same spatial (no broader than subpopulation) and temporal scale of the corresponding IPM parameter. For example, if IK suggested that survival changed during a period of interest, the IPM could be parameterized to allow for time-varying survival (i.e., instead of estimating a single, time-constant survival probability). In some cases, using IK to inform model parameterization will require establishing a functional relationship between the IK variable and the IPM parameter. For example, if IK suggested that survival increased gradually and steadily, the IPM could be parameterized with a monotonic, linear trend in survival probability. Conversely, if IK suggested that survival varied from year-to-year but did not exhibit a clear trend, the IPM could be parameterized to allow for interannual variation in survival (i.e., such that a separate value of survival probability is estimated each year, with no pre-determined correlation structure among years). IK collection methods to inform model parameterization are the same as those for model purpose and structure.

Prior Distributions Criteria

IK to inform prior distributions must map to a specific IPM parameter and be on similar spatial (no broader than subpopulation[s]) and temporal scales as the IPM parameter. Furthermore, it is necessary to establish the relative context of the IK (see following section) and translate it into a quantitative format. For example, IK suggesting that abundance is currently "high" must specify a baseline for this assessment (e.g., abundance 20 years in the past). Then, it would be necessary to develop a statistical distribution that represents a plausible range of abundances that are "high" relative to 20 years in the past. Such a distribution could potentially be based on an upper quantile of the sampling distribution of abundance from a separate, earlier study. Using IK to develop informative priors will generally require consistent observations within the IK variable (e.g., that IK on relative abundance indicates a change at the subpopulation level rather than short-term variation in the number of bears using specific areas). If the IK is ambiguous or conflicting (e.g., if there is an equal weight of evidence for increasing and decreasing population trends) there may not be enough confidence to translate the IK into an informative prior distribution, which could justify use of an uninformative (i.e., vague) prior that reflects a lack of a priori knowledge about the parameter in question (e.g., an uninformative prior for survival probability could assume any value from 0 to 1, whereas an informative prior would likely restrict survival probability to more biologically plausible values for polar bears, such as within the range 0.60 to 0.95). Using IK to justify the use of informative priors represents a valid and meaningful use of IK. Conflicting IK is often the result of differences in collection methodologies, spatial and temporal scales of collection, and even interviewer bias. It does not necessarily mean the IK is inaccurate. The IK collection methods best suited for obtaining information on prior distributions are semi-directed interviews, workshops, participant observation, active harvester interviews, and surveys.

Data Criteria

Data, the final model input type, usually consist of observations related to, or biological samples obtained from, the biological population of interest. This requires the IK to be in a quantitative format and use standardized methods for collection and quality control. Because of the data's direct influence on model results, both the spatial and temporal scales of the IK variable should be aligned with the corresponding IPM parameter. In many cases, this means that the IK needs to reflect the entire biological population of interest. However, if IK or other information were previously used to establish a finer-scale model structure, it may be possible to use IK as data on this scale. For example, if IK indicated that bears were healthier in the western half of a biological population, it would be possible to specify a model structure that estimated separate biological parameters for western and eastern bears. Under this finer-scale model structure, quantitative IK that only related to western bears could be potentially used as a data input.

In some cases, it may be possible to use qualitative IK to justify the use of quantitative data from a different, non-IK source. For example, if IK indicated that polar bear survival was related to the spring sea-ice breakup date, quantitative data on breakup could be obtained from satellite telemetry (e.g., Stern and Laidre 2016) and used as a covariate to explain interannual variation in survival probability.

Sample size is important when considering whether to include quantitative IK as a data model input, because the amount of information contained in the IK must be sufficient to influence the corresponding IPM parameters. In general, the larger and more statistically representative the sample, the greater the confidence in using IK directly as a data input into an IPM. Because of the need for quantitative data, IK that is used as data will generally come from active harvester interviews or designed survey protocols or other systematic processes (e.g., harvest management). For the data model input type, relative context is not a critical criterion because the specific context of the data is included in the definition of the data point.

Other Considerations for Incorporating IK into an IPM

Other considerations include whether the IK was focused on polar bears or obtained from a more general study that looked at multiple subsistence resources. In the study team's experience, IK that comes from topic-specific studies (e.g., polar bear only) versus a broader, multiple-resource study (e.g., land mammals, marine mammals, fish, birds, marine invertebrates, and vegetation) is more focused because topic-specific studies allow for greater exploration of knowledge for that resource than a study that is attempting to address the breadth of an IK holder's knowledge for multiple resources.

It will not always be possible to identify a one-to-one relationship between an IK variable and an IPM parameter. Rather, use of IK in an IPM may reflect multiple lines of evidence based on multiple IK variables, which individually provide a relatively weak or uncertain signal but together allow for stronger inference. This was the approach taken by Regehr et al. (2018a) in the IPM for CS polar bears, where consistency among multiple types of IK was used to justify informative prior distributions for survival probability. In some cases, it may not be necessary for an IK variable to include a strong signal (e.g., to indicate clearly that something has changed) for the information to be useful in an IPM. For example, if there was a robust effort to collect IK on changes in abundance, and the responses demonstrated varying or conflicting perspectives among IK holders, these findings could be interpreted as justification for "letting the data speak for themselves" and not using an informative prior distribution for population trend. Decisions about how IK is used in an IPM will not occur in a vacuum, but rather in the context of other biological information from IK and scientific studies. For example, IK could provide observations of an unusually high number of dead seals in a portion of a population's range. If there was corresponding scientific evidence (e.g., for an unknown mortality event, such as occurred for ice seals in the Bering and Chukchi seas the past decade), the information from IK and scientific studies could be used together to determine how the phenomenon was incorporated in the IPM (e.g., to determine the spatial and temporal scale of potential changes in polar bear survival resulting from reduced prey). This requires that the people responsible for developing the IPM have a detailed understanding of the study system and previous investigations. Finally, many elements of scientific inquiry must be considered when evaluating the usefulness of IK to an IPM. These include issues related to observability (i.e., the extent to which a phenomenon of interest can be perceived and reported), variability, sample size, replication, and causation vs correlation.

Furthermore, depending on the type of information that is contained by an IK variable, it may be necessary to address uncertainty and variation in the IK. These concepts can be approached by evaluating variation within and among respondents. There are several potential methods that could be used to translate uncertainty and variation in an IK variable into an IPM. For example, individual response units in the IK (e.g., at the level of a single person or community) could be combined into an overall distribution. If necessary, response units could be weighted according to sample size or other criteria (e.g., based on the IK collection method—see above).

Task 1 Summary

The study team has proposed a general framework and methodology for incorporating IK into an IPM. This framework is built upon key building blocks including the identification of IPM objectives and eight IPM parameters, the categorization of IK into 10 topics and 24 associated IK variables, the establishment of five IK variable criteria corresponding to potential model input types (Figure 12), and the identification of the seven ways to collect IK. The study team believes this framework is broad enough for potential applicability in other realms of ecological modeling. It is not a rigid step-by-step formula for seamlessly integrating IK with scientific knowledge. The study team recognizes that this type of framework is in its relative infancy and will involve thorough, side-by-side, iterative collaboration between modelers and IK experts. The study team's application of this framework to polar bear IK for the forthcoming SB-NB IPM is presented in the following section.

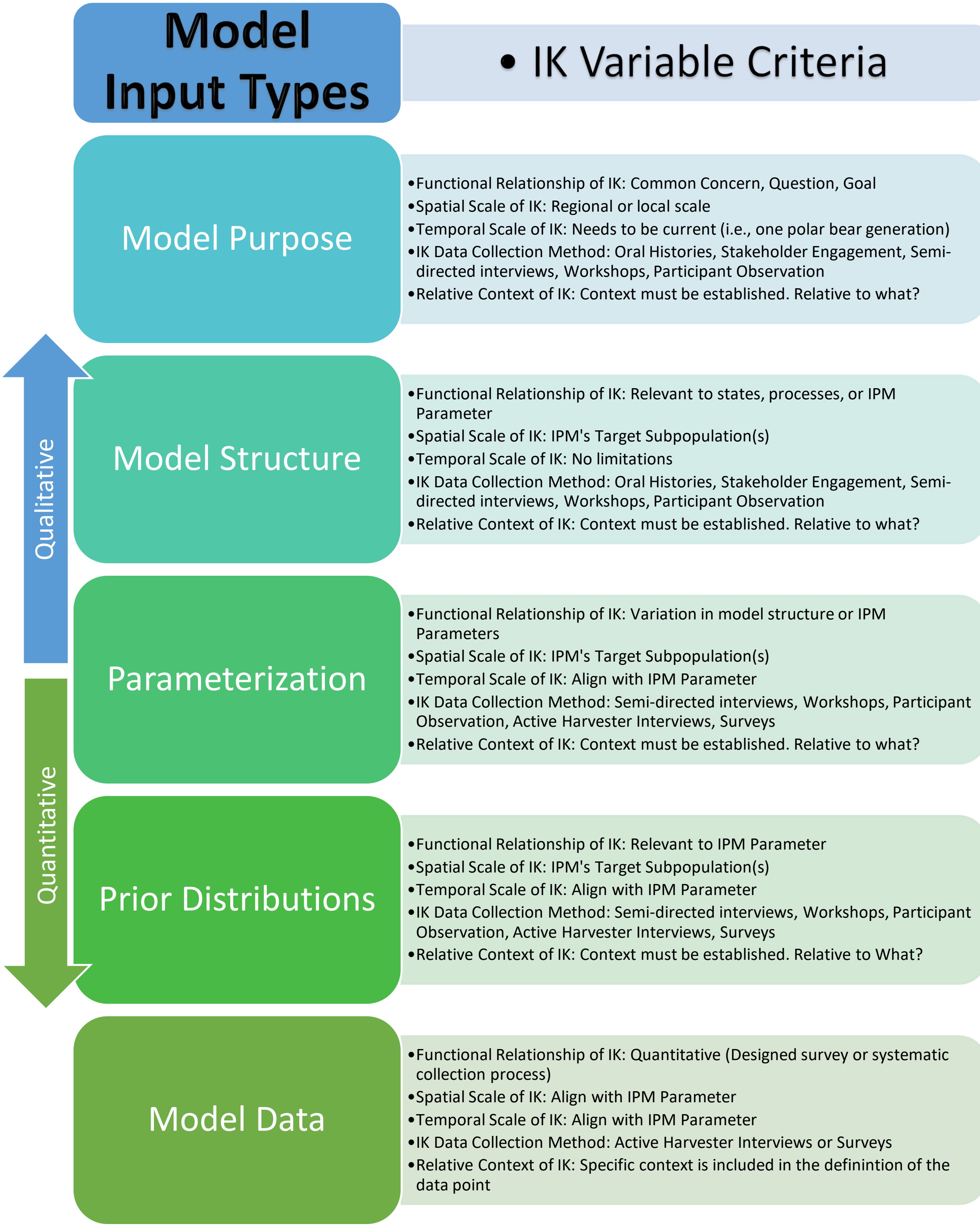


Figure 12: Criteria for Including IK in IPM Input Types

Task 2 Results (Identify and Review Adequacy of IK Literature)

Incorporating Existing Polar Bear IK into an IPM

The objective of Task 2 was to identify and review the adequacy of available IK literature for inclusion in an IPM for the SB and NB subpopulations. After developing a general framework to guide the incorporation of IK into an IPM and identifying the list of 24 IK variables, the study team conducted a literature review of available SB and NB polar bear IK to evaluate whether the IK was adequate for use in the SB and NB polar bear IPM or whether the study team believed that additional fieldwork was warranted to collect pertinent information. Similar to the initial literature search, the study team conducted polar bear IK searches using internet and academic search engines, which included reviewing additional publications cited in the material found during the initial literature search.

Recognizing that the goal of an IPM is to learn and draw conclusions about specific biological populations of polar bears, the study team filtered all results to IK related only to NB or SB populations. This broadly addressed the IPM's IK criteria for spatial coverage. The study team also filtered the results to exclude IK publications prior to 2001, which broadly addressed the IPM's IK criteria for temporal scale, as the SB-NB IPM will likely incorporate data from 2001 to present. Lastly, after reviewing a broad range of studies that may have included, but did not target, polar bears, the study team chose to focus this initial assessment on IK studies that addressed polar bears only and not broader IK studies that addressed multiple resources. Details about spatial and temporal scale, as well as relative context and IK collection methods, are provided in Appendix C. As a result of this process, the study team identified six publications that could potentially inform the SB-NB IPM (Table 3). The study team applied the framework to the four most current and comprehensive studies (Braund et al. 2018, Joint Secretariat 2015, Voorhees 2019, Slavik 2013).

TABLE 3: POLAR BEAR IK STUDIES THAT COULD POTENTIALLY INFORM SB-NB IPM

Title	Citation	Applied IK-IPM Framework?	Broadest Spatial Scale	Temporal Scale	IK Collection Method
Polar Bear TEK: A Pilot Study to Inform Polar Bear Management Models. Utqiagvik, Alaska: North Slope Borough Department of Wildlife Management.	(Braund et al. 2018)	Yes	Wainwright and Utqiaġvik Area of Observation within SB range	Present Status (2017)	Workshops
Inuvialuit and Nanuq: A Polar Bear Traditional Knowledge Study. Inuvik, NWT, Canada.	(Joint Secretariat 2015)	Yes	Aklavik, Inuvik, Sachs Harbour, Tuktoyaktuk, Paulatuk, Ulukhaktok Area of Observation within SB and NB range	Lifetime (Pre-2013)	Semi-directed, Workshops
Iñupiaq Knowledge of Polar Bears in the Southern Beaufort Sea. Polar Bears International.	(Voorhees 2019)	Yes	Wainwright, Utqiaġvik, Nuiqsut, and Kaktovik Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed
"Knowing Nanuut: Bankslanders knowledge and indicators of polar bear population health."	(Slavik 2013)	Yes	Sachs Harbour Area of Observation within NB range	Present Status (2008-2010)	Semi-directed, Participant observation, Workshops

Title	Citation	Applied IK-IPM Framework?	Broadest Spatial Scale	Temporal Scale	IK Collection Method
Inuvialuit Knowledge of Nanuq: Community and Traditional Knowledge of Polar Bears in the Inuvialuit Settlement Region	(Slavik 2009)	No	NA	NA	NA
Report on the Consultation in the Northwest Territories Inuvialuit Settlement Region in February 2009 on the Proposed Listing of Polar Bear as a Species of Special Concern Under the Federal Species at Risk Act.	(Canadian Wildlife Service 2010)	No	NA	NA	NA

Assessing the IK through the Proposed Framework

To determine whether the four studies referenced above could potentially inform the SB-NB IPM, the study team first assessed which of the 24 IK variables were addressed in the related reports. In some cases, a report made brief mention of an IK variable but did not provide sufficient information to be used in an IPM. For example, the Joint Secretariat (2015) report addressed the IK variable of Harvest Effort with in-depth descriptions of hunting practices, but did not provide a summary or focused discussion of harvest effort as it would relate to abundance and trend, harvest mortality, or other IPM parameters. Thus, the IK variable of Harvest Effort from that study would not be able to inform the SB-NB IPM.

Appendix C contains the study team's worksheets for assessing the IK variables through the framework developed in Task 1, to determine their potential applicability to the SB-NB IPM. Because the SB-NB IPM has yet to be fully developed, these preliminary assessments are intended to provide guidance for future work and do not represent firm decisions about how IK will be used in the SB-NB IPM. The following sections summarize information related to each IK variable from the four reviewed studies, including discussion of the potential influence of the information on the SB-NB IPM.

Bear Age

Braund et al. (2018) reported IK that indicated stable or increasing cub populations, with older bears increasing in Wainwright and Utqiaġvik in the last 10 years, although the study did not document observed causes for the change. Information from Voorhees (2019) primarily focused on younger bears being less wary and more problematic, and older bears staying away from town. That study also discussed fewer observations of large bears, which could potentially indicate fewer older bears. The Joint Secretariat (2015) report primarily provided information about general characteristics (e.g., size, behavior, appearance) of older and younger bears, but did not discuss the incidence of age groups (e.g., numbers of older versus younger bears). That study indicated that the condition of bears' teeth (e.g., broken, short) and scarring are sometimes indicators of bear age. Further, the IK noted a similar number of maternity dens, which could indicate similar numbers of maternal-age females, although these observations also could reflect changes in reproductive rates and denning locations. No information was given on trends in bear age (i.e., "bears are getting older" or "we only see young bears"). Finally, Slavik (2013) did not specifically address bear age but provided some IK regarding indicators of bear age, including fewer "large" bears and an observation of fewer older bears based on teeth condition.

Based on these IK results, the study team identified several ways in which IK information on bear age could influence the SB-NB IPM. Age-related behavioral differences, specifically the tendency of younger bears to enter communities, are consistent with general information about polar bears from other IK and scientific studies (e.g., Dyck 2006), suggesting age-related variation in survival probability and harvest mortality. These patterns could be reflected through the parameterization of the IPM. Also, information about possible changes in age structure (e.g., fewer older bears) suggest that the IPM could be parameterized to allow for temporal changes in demographic composition.

Bear Sex

None of the four reviewed sources provided IK on sex composition or changes in sex composition over time. Braund et al. (2018) documented IK focused on hunting preferences, with males the primary target of subsistence hunters, and hunting of females discouraged from December through June. Similarly, Voorhees (2019) results indicate some avoidance of female bears by Utqiaġvik hunters, but note that residents reported difficulty distinguishing sex of bears while hunting. Neither the Joint Secretariat (2015) report nor Slavik (2013) collected information regarding harvest selection preferences by sex, or how bear sex influences survival.

These IK results suggest that parameterization of the IPM reflect sex-specific survival probability and harvest mortality, which is consistent with other IK and scientific studies on polar bears (e.g., Lunn et al. 2016).

Body Condition

Braund et al. (2018) documented IK that indicated good body condition based on the polar bear fatness index. Voorhees (2019) indicated that IK about body condition was variable, with some reporting bears in good condition with adequate fat, and others observing an increase in skinny or smaller bears near the communities of Kaktovik, Utqiaġvik, and Nuiqsut (Cross Island), which may be a result of hungry bears investigating potential attractants (e.g., remains of subsistence-harvested bowhead whales). The Joint Secretariat (2015) did not report results related to body condition. Finally, Slavik (2013) reported IK of smaller and skinnier bears, and fewer large bears. Similar to Voorhees (2019), Slavik (2013) indicated that observations related to smaller bears could be related to changes in distribution, with larger bears moving farther north in recent years.

Body condition in polar bears is positively correlated with reproductive success and survival (Rode, Amstrup, and Regehr 2010, Rode, Atwood, Thiemann, St. Martin, Wilson, Durner, Regehr, Talbot, Sage, and Pagano 2020). These IK results do not appear to suggest consistent values of body condition (e.g., uniformly “good”) that could be used to inform the magnitude of survival probabilities through, for example, informative prior distributions. However, the IK could suggest a gradient in body condition across the study area, with better body condition in the west and poorer body condition in the east. This pattern would be broadly consistent with other studies indicating spatial variation in biological productivity and demographic status for Arctic marine vertebrate species in the SB-NB region (Harwood, Smith, George, Sandstrom, Walkusz, and Divoky 2015, Harwood, Smith, Melling, Alikamik, and Kingsley 2012). Spatial variation in the status of polar bears suggests that the structure of the IPM could include multiple geographic states, potentially allowing for different patterns in vital rates (e.g., values of reproduction and survival) and biological conditions across the study area. Additional consideration is needed to determine whether this geographic structure could follow the SB and NB subpopulation boundaries, or whether there is a more biologically accurate method to separate the study area into geographic units.

Harvest Effort

None of the four reviewed sources provided IK regarding harvest effort that could potentially relate to polar bear abundance or reproduction. Braund et al. (2018) provides example indicators of harvest effort (e.g., successful hunting days); however, these indicators are not generalizable to the study communities. Voorhees (2019) addresses harvest effort in terms of targeted versus opportunistic hunting patterns (see "Targeted vs. Opportunistic Harvests," below). The Joint Secretariat (2015) discusses hunting practices and strategies but does not provide information on harvest effort that could inform bear abundance or reproduction. Similarly, Slavik (2013) discusses hunting practices and strategies and notes that harvest effort is strongly tied to variation in bear distribution; however, no overall indicators of harvest effort are provided. Slavik (2013) reports IK about potential impacts of climate change and loss of sea ice on harvest effort in the future.

These IK results do not appear to provide information that is useful as an input to the SB-NB IPM.

Litter Size (cubs-of-the-year)

Braund et al. (2018) documented IK that indicates stable cub populations in Wainwright and increasing cub populations with younger mothers in Utqiaġvik. Two cubs are the most commonly observed litter size according to Braund et al. (2018). Voorhees (2019), the Joint Secretariat (2015), and Slavik (2013) also report that two cubs are the most commonly observed litter size among IK holders. Slavik (2013) and Joint Secretariat (2015) also report periodic observations of up to three cubs. IK from all reviewed studies indicates that stable litter size (two cubs per mother) is a sign of a healthy polar bear population.

These IK results could influence the SB-NB IPM in several ways. Observations of litter sizes of up to three cubs indicate that the structure of the model should include biological states for adult females with one, two, or three cubs. This is like the approach taken by Regehr et al. (2018a) for the CS subpopulation, whereas some previous models for the SB subpopulation (e.g., Regehr et al. 2010) used a maximum litter size of two cubs. Observations that litter size has been relatively stable suggest a time-constant parameterization for C0 litter size and survival. Finally, this IK provides some degree of quantitative information on C0 litter size (i.e., that two cubs are most common) that could potentially be used to develop an informative prior distribution for litter size. How this information is used in the IPM is potentially complicated by the fact that IK observations tended to not distinguish between cub-of-the-year and yearling litters.

Litter Size (yearlings)

The IK from the four reviewed studies did not provide a discussion of yearling cubs that would relate to the IPM parameters of breeding probability, litter size, or survival. IK observations were primarily related to litter size with no indication of cub age. One report noted that observations of litter size made by IK holders typically do not distinguish between C0s and C1s (Braund et al. 2018). These IK results do not appear to provide information that is useful as an input to the SB-NB IPM.

Mortality

The four reviewed studies did not provide information on overall mortality rates or trends in mortality rates. However, in two studies (Voorhees 2019, Slavik 2013), IK holders indicated that they rarely encounter deceased bears or carcasses. Voorhees (2019) noted higher bear mortality near Kaktovik. The Joint Secretariat (2015) provided some IK on causes of mortality, including old age, starvation, fights, and accidents.

These IK results do not provide information suggesting that there have been highly unusual mortalities or noticeable changes in mortality patterns for SB and NB bears, with the caveat that polar bear mortalities can be difficult to observe (e.g., if the bears die on the offshore sea ice). Lacking information on unusual mortality events, this suggests that the structure and parameterization of the IPM could reflect standard processes related to polar bear survival as understood from other scientific and IK studies.

Relative Abundance

The four reviewed studies provide varying IK observations on relative abundance. Braund et al. (2018) reports IK observations of increased or stable overall populations since the passing of the Marine Mammals Protection Act (MMPA) in 1972, with Wainwright and Utqiaġvik IK holders describing polar bear populations as average and good, respectively. Similarly, the Joint Secretariat (2015) documented IK from the Inuvialuit Settlement Region that indicates stable polar bear populations, and increased polar bear density near communities and along the shore. Voorhees (2019) documented IK of both decreased (Kaktovik, Utqiaġvik) and increased (Nuiqsut/Cross Island, Utqiaġvik) local abundance of polar bears, with a higher incidence of observations of decreased local abundance. Finally, Slavik (2013) documents IK that while overall polar bear abundance fluctuates naturally over time, recent years have seen fewer bears coming into the community due to changes in distribution (see "Range and Seasonal Movements," below).

These IK results do not provide consistent information on the relative abundance of polar bears across the study area, suggesting that there have not been large, observable changes in abundance within the spatial and temporal scope of the IK. This information appears inconsistent with some recent scientific studies (Bromaghin, Douglas, Durner, Simac, and Atwood 2021, Bromaghin, McDonald, Stirling, Derocher, Richardson, Regehr, Douglas, Durner, Atwood, and Amstrup 2015), which could motivate further investigation. Although it is unlikely that this information would lead to a model that only estimates time-constant abundance, given that previous scientific studies have estimated declining abundance in some areas, it could influence model parameterization by highlighting the need to compare support in the data for models with time-constant vs. time-varying abundance. Furthermore, IK holders identified patterns in local abundance that were likely influenced by polar bear distribution and behavior (e.g., the tendency of bears to come into communities), thus acknowledging the potential for different perceptions about abundance across the SB-NB range based on when and where observations or studies took place.

Resilience to Change

Three of the four reviewed studies (Braund et al. 2018, Joint Secretariat 2015, Slavik 2013) indicate that polar bears are adaptable, while the fourth study (Voorhees 2019) does not address this IK variable. In two of the studies (Joint Secretariat 2015, Slavik 2013) IK holders were unsure about the ability of polar bears to adapt to future changes such as climate change and development. Slavik (2013) found that some IK holders believe future changes (development, climate change and changes in sea ice) may affect polar bear populations in the short term, but that they will adapt in the long-term. In fact, IK holders indicated that polar bears may adapt to a reduction in sea ice and benefit from the increased access to prey and decreased pressure from hunters.

These IK results recognize that environmental change can impact polar bear populations but suggest that polar bears are resilient and that their response can be variable (e.g., that reduced sea ice resulting from climate warming may not always impact bears negatively). The potential for reduced sea ice to benefit polar bears under some conditions is consistent with scientific expectations (Derocher, Lunn, and Stirling 2004), and there is evidence from recent case studies (Laidre, Atkinson, Regehr, Stern, Born, Wiig, Lunn, Dyck, Heagerty, and Cohen 2020) that climate warming has temporarily benefited bears in some regions of the high Arctic where biological productivity was historically limited by heavy, multiyear sea ice. Given that the SB-NB subpopulations span approximately 10 degrees of latitude, this information could provide additional justification for model structure and parameterization reflecting multiple geographic states, especially in how bears are responding to environmental change. For example, if changes in sea-ice conditions are used as a covariate to explain interannual variation in polar bear vital rates, IK regarding the resilience of polar bears together with scientific studies demonstrating geographic variation in the response of polar bears to climate warming could be used to suggest that structure and parameterization of the IPM include different relationships between ice and vital rates that differ between the southern and northern extremes of the study area.

Range and Seasonal Movements

Three of the four reviewed studies (Braund et al. 2018, Voorhees 2019, Slavik 2013) document IK indicating that polar bears are now found more frequently on land due to changes in sea ice. Both Braund et al. (2018) and Voorhees (2019) report that SB polar bears are more frequently found on land, particularly during the summer. In Voorhees (2019), IK holders report greater incidences of large gatherings of polar bears. The Joint Secretariat (2015) documented IK from the Inuvialuit Settlement Region, which is within the SB-NB polar bear range, that indicates no change in polar bear distribution, aside from changes in denning (see “Terrestrial Habitat,” below), and an increase in polar bear visits to Sachs Harbour due to more open water in fall. These IK holders indicate that changes in distribution have not had an impact on polar bear abundance. Finally, Slavik (2013) documents IK from Sachs Harbour that females and younger bears are more frequently found in inland areas during the summer and early fall (August and September), and that the increased open water season has affected polar bear distribution by causing them to travel inland and farther north.

These IK results suggest increased land use by polar bears in many parts of the SB-NB region, which is consistent with several scientific studies (e.g., Atwood, Peacock, McKinney, Lillie, Wilson, Douglas, Miller, and Terletzky 2016, Wilson, Regehr, Martin, Atwood, Peacock, Miller, and Divoky 2017). This information could affect the SB-NB IPM in several ways. First, observations of changes in land use could provide additional motivation for the IPM to be structured to include data from land-based studies in the SB-NB region (e.g., individual identities based on genetic samples collected around bowhead whale remains). This is important because it is currently unclear whether the sample size of land-based data is sufficient to justify their inclusion in the model, given that this would require additional model structure and a more complex parameterization. If land-based data are included, these IK results suggest that there have been changes over time in seasonal movements that is directly related to environmental factors (e.g., sea-ice availability), which could affect model parameterization and motivate use of remote-sensing sea-ice data (Stern and Laidre 2016) as a covariate to explain variation in land use. If stakeholders are concerned about trends toward more bears on land for longer periods, this information could affect model purpose. For example, results from the IPM could potentially be used to project future land use based on projections of sea-ice conditions from global climate models.

Sea Ice Habitat

All four reviewed studies documented IK of a reduction in sea-ice habitat over time that has resulted in seasonal changes to polar bear distribution, concentrating polar bears along the coast and in inland areas during the summer and fall (see "Range and Seasonal Movements," above). In Voorhees (2019), IK holders also note the impact of wind conditions on the presence of sea ice. In Braund et al. (2018) and Slavik (2013), IK holders note that ice with pressure ridges and leads represents good habitat where polar bears are frequently found. Slavik (2013) notes that this type of ice provides easy access to seals and is unsafe for humans thereby reducing hunting pressure on bears in these areas. Polar bears are rarely found on solid ice with little open water. In the Joint Secretariat (2015), IK holders indicated that while there have been substantial changes in sea-ice conditions over time related to climate change, annual changes in sea ice conditions have always occurred and therefore polar bears are accustomed to adapting to these changes.

IK results regarding increased occurrence and wider distribution of polar bears in coastal and inland areas could affect the SB-NB IPM by highlighting the importance of including both pelagic and terrestrial geographic states in the model structure, and by suggesting model parameterizations in which movement probabilities are related to environmental covariates (e.g., if bears were more likely to come onshore in a year with early sea-ice breakup). Information about the types of sea ice that are most important to polar bears could affect data inputs to the IPM by informing or validating environmental covariates that are used to explain interannual variation in multiple vital rates (Stern and Laidre 2016). For example, sea ice "with pressure ridges and leads" will be characterized by a certain thickness, age, and concentration that scientists may not have previously considered when identifying important sea-ice habitats for polar bears. These IK results appear broadly consistent with scientific studies that document reductions in sea-ice concentration and extent resulting from environmental change (e.g., Notz and Community 2020).

Terrestrial Habitat

IK observations focused on changes in denning locations and factors that affect denning locations. In Braund et al. (2018) and Voorhees (2019), Iñupiaq IK holders reported an increase in denning on land, although denning can also occur on ice when grounded. Voorhees (2019) indicates that observations of increased denning on land could be due to less multiyear ice. Overall, IK holders in Wainwright, Utqiaġvik, Kaktovik, indicate that denning is not common within their areas of observation. IK discussions in the Joint Secretariat (2015) and Slavik (2013) focused more on the factors that affect denning locations; in particular, in both reports IK holders indicated that changing snow and wind conditions affect where polar bears den. Slavik (2013) documents IK that Banks Island—particularly West and South Banks Island—is a key denning location for NB polar bears, with multiple den locations identified. Deep snow provides ideal denning conditions, and a lack of snow may result in a bear moving their den even after having their young. Wind direction affects snow accumulation which can create good conditions for dens; changes in the direction of prevailing winds may change denning locations in the future.

IK results regarding increased denning on land are relevant to changes in land use, as discussed above under "Range and Seasonal Movements" and "Sea Ice Habitat". Information on IK about the specific locations of dens on land is probably not directly useful to the IPM given that the model will have limited spatial resolution (e.g., it may include several geographic states, but will not include detailed representations of how bears move and where they den). Information about habitat characteristics that are important for denning could be useful in other scientific analyses, such as modeling the distribution of suitable denning habitats based on abiotic factors including snowfall, wind, and topography (Liston, Perham, Shideler, and Cheuvront 2016).

Harvest Reporting

Three of the four reviewed studies (Braund et al. 2018, Voorhees 2019, Slavik 2013) provided no harvest reporting data which could inform the IPM parameters of survival, harvest mortality, or abundance and trends. The Joint Secretariat (2015) provided 228 harvest locations within respondents' living memory. Of the harvest locations with data on harvest timing, 95 percent were between December to May.

Information from IK on the timing of polar bear harvest could potentially inform model parameterization, especially if the IPM includes high-resolution temporal structure (e.g., if the model allows for movement between land and sea ice using 6-month time steps, rather than the usual approach of using annual time steps). However, these IK results would not be used as the primary source of information about harvest timing in the SB-NB IPM, because the polar bear harvests, in this case, are better represented in the official repository of polar bear harvest data which is held by management authorities with a legal responsibility to monitor harvest. Usually, these management authorities consist of co-management entities working with regional or federal governmental organizations. Accurate harvest records provide a critical source of data for IPMs and other demographic models for polar bears, directly impacting the precision and accuracy of multiple IPM parameters. The most important data and samples from harvested bears for use in an IPM include the following: date of harvest, location of harvest, bear sex, bear age class, bear body condition, vestigial premolar tooth (which can be used to estimate age; (Calvert and Ramsay 1998)), any biological sample that can be used for genetic identification, and information about physical research markings (e.g., presence of a lip tattoo or GPS tracking device).

Harvest Sampling

None of the four studies reviewed for this assessment provided harvest sampling data which would inform the IPM parameters of survival, harvest mortality, and abundance and trends. The focus of this review was on IK studies rather than harvest studies. As discussed above, accurate harvest data are an important source of data for an IPM.

Targeted vs. Opportunistic Harvests

IK holders generally reported both targeted and opportunistic harvests of polar bears, with opportunistic harvests somewhat more common among Iñupiaq hunters in Wainwright, Nuiqsut, and Kaktovik compared to those hunters in Utqiagvik (Braund et al. 2018, Voorhees 2019). On the other hand, the Joint Secretariat (2015) indicates that Inuvialuit hunters generally partake in planned or targeted polar bear hunts, with opportunistic hunts occurring periodically. Slavik (2013) also includes descriptions of Inuvialuit hunting activities which characterizes their hunts as "high-investment, high-risk, and high-reward," indicating that polar bear hunting is a targeted event among Sachs Harbour residents.

These IK results, in combination with results from other IK and scientific studies, suggest variation by sex and age in survival probability and harvest mortality, which could affect parameterization of the IPM. Specifically, other IK and scientific studies have shown that opportunistic harvests tend to focus on young, male polar bears (i.e., those bears most likely to approach humans). Similarly, targeted harvests often select for certain types of bears (e.g., large males).

General Bear Health

Three of the four reviewed studies (Voorhees 2019, Joint Secretariat 2015, Slavik 2013) reported IK of fewer large bears, although in Slavik (2013) and Voorhees (2019), IK holders note that the decrease in large bears could be due to a change in distribution (e.g., larger bears staying out on multi-year ice). Observations regarding polar bear body condition were variable across the four studies, and IK holders generally note that the presence of skinny bears is normal and dependent on age of bear, ice conditions, and prey availability. Braund et al. (2018) reports a consensus among IK holders that polar bears are healthy and that there have been no changes to overall health. Aside from skinny bears, IK holders across all reviewed studies did not report incidences of sickness or disease (see "Observations of Disease or Sickness," below). Finally, Slavik (2013) documented IK holders' views regarding the importance of stomach contents as an indicator of polar bear health, harvest success, and nutritional stress. For example "pure blubber" in a polar bear's stomach indicates high hunting success and the ability to eat only the favored parts of a seal, whereas the presence of other seal parts in stomach contents indicates poor hunting success and the need for additional nutrition. Slavik (2013) also reports IK on the link between a higher number of seal kill sites indicating healthier polar bear populations and hunting success.

These IK results may suggest changes in the demographic composition of the SB-NB subpopulations, given that three of the four studies indicated fewer large bears. Both the structural size and body condition of polar bears is positively related to survival and, in the case of females, cub production (Rode et al. 2020, Rode et al. 2010). As discussed above, fewer large bears could indicate declines in adult survival, which would be reflected in parameterization of the IPM (e.g., by estimating annual survival rates instead of a multiyear average). If the IK regarding fewer older bears was consistent with other lines of evidence from IK and scientific studies (e.g., if habitats were declining or bears were becoming thinner), this information could potentially be used to inform prior distributions on survival. For example, the prior distributions on survival for earlier time periods, when there were more larger bears, could be higher (e.g., representing an upper quantile of estimates from other case studies) than the prior distributions for later time periods. Changes in bear age, size, and related metrics must be evaluated in the context of both changes in survival and reproduction (e.g., lower proportions of larger bears could also reflect increasing numbers of smaller, younger bears due to good reproduction).

Observations of Disease or Sickness

Across all four of the reviewed studies, IK holders did not report any notable trends in observations of disease or sickness in polar bears. Skinny or apparently unhealthy polar bears are observed rarely but this is considered normal.

These IK results indicate that there have not been any large-scale, observable changes in disease or sickness of polar bears in the SB-NB region that could indicate catastrophic events such as the unusual mortality events (UME) that have occurred in the past decade for ice seals in the Bering and Chukchi seas. The study team noted that the absence of strong signals in IK results (in this case, the absence of an observable increase in disease) can be valuable because they suggest that ecological and demographic processes are functioning within normal bounds, which itself informs model structure and parameterization (e.g., if there had been a UME, the model would have to be modified accordingly—but in this case, such modification is not needed).

Management Considerations

One of the four reviewed studies (Braund et al. 2018) provided IK regarding management. Two of the studies (Joint Secretariat 2015, Slavik 2013) provided discussions of the history of polar bear management or researchers' thoughts on the importance of including IK and local perspectives in management decisions and processes. Braund et al. (2018) documented IK regarding local participation in management programs and how these programs can succeed. IK holders expressed a desire to participate in community-based management programs and stressed the need for local residents to have equal decision-making authority (rather than just "input"). The benefit of a holistic, ecosystem-wide approach which is based equally on western science and on IK was discussed both in Braund et al. (2018) and Slavik (2013).

Although these IK results are not directly applicable as one of the five IPM model input types identified by the study team, they are relevant to other uses of IK in quantitative ecological modeling as discussed in Task 1 of the IPM-IK project. Specifically, these comments highlight the important of stakeholder participation in the production of knowledge that is used to inform management.

Sustainability

One of the four reviewed studies addressed sustainability as it pertains to the IPM parameter of harvest mortality. In Braund et al. (2018), IK holders indicated that current harvest levels are adequate and sustainable, and that local communities self-regulate their harvests to ensure that they remain sustainable. The Joint Secretariat (2015) does not provide direct IK on sustainability but stresses the importance of Inuvialuit influence on management.

The IK results from Braund et al. (2018) suggest that current harvest levels are sustainable, presumably in the sense of not causing observable, negative population responses (e.g., declines or the depletion of a sex or age class). As presented, these IK results are likely not useful for the IPM because sustainability was not explicitly defined in Braund et al. (2018) and was not addressed in the other reviewed studies. However, if well-defined observations of sustainability were consistent across the study area, and if quantitative data were available on the numbers of harvested bears (e.g., from harvest reporting programs implemented by the responsible management agencies), this information could potentially be used to develop informed prior distributions on survival probability and harvest mortality. Specifically, the prior distribution on survival probability could be restricted to largely include values that would not result in rapid declines in abundance, when considering the known levels of harvest. It also may be important to collect IK on the reasons for changes in harvest levels (e.g., whether declining harvest was the result of declining abundance or of other factors such as reduced access to bears because of sea-ice conditions).

Prey Abundance

IK observations across the four reviewed studies were variable, with most IK indicating that prey abundance is stable or subject to natural fluctuations. Braund et al. (2018) documented IK of “good” prey populations, with populations characterized as “stable” in Wainwright and “increasing” in Utqiaġvik. Similarly, Voorhees (2019) documented good or stable prey abundance among IK holders in Utqiaġvik and Wainwright. Kaktovik reported a decrease in prey abundance due to reduced sea ice, and there was no consensus on prey abundance in Nuiqsut. Both the Joint Secretariat (2015) and Slavik (2013) documented IK that seal populations are cyclical or fluctuating, with Slavik (2013) noting that these fluctuations are attributed to changes in ice conditions and food availability. Among Inuvialuit IK holders, some report declining seal populations (Slavik 2013) or unusually large numbers of dead seals (Joint Secretariat 2015) in recent years. IK holders did not imply these changes in prey abundance had had an overall effect on polar bear abundance.

These IK results identify that prey abundance is subject to natural fluctuations. This information is consistent with scientific studies of ice seal and polar bear abundance and natality in the eastern Beaufort Sea (Stirling 2002) and could influence the IPM parameterization and input data by suggesting use of an index of seal productivity (e.g., ovulation rate, proportion of young in the harvest) for use as a covariate to explain temporal variation in polar bear vital rates. This would represent a novel approach for polar bear modeling given that previous studies for the SB and NB polar bear subpopulations (Stirling, McDonald, Richardson, Regehr, and Amstrup 2011, Bromaghin et al. 2015) have mostly used sea-ice conditions as a covariate to explain polar bear vital rates, which assumes that variation in sea-ice condition can explain both the availability of, and polar bears’ access to, their seal prey. Although IK holders did not imply these changes affected polar bear abundance, it is reasonable to posit such a connection given that ringed and bearded seals are the primary prey of polar bears and recent studies have shown that seal body condition influences polar bear body condition and recruitment (Rode et al. 2021).

Prey Health

Two of the four reviewed studies did not address prey health beyond observations on prey abundance (Braund et al. 2018, Joint Secretariat 2015). In Voorhees (2019), IK holders in Wainwright, Utqiaġvik, Nuiqsut, and Kaktovik characterized health of prey species as healthy/fat/good conditions. In Slavik (2013), Inuvialuit IK holders from Sachs Harbour noted a possible decline in body condition (e.g., skinny seals) due to a lack of ice to hunt from, others indicated that fluctuations in seal body condition are normal.

These IK results could potentially be used in a manner similar to information on the IK variable Prey Abundance, as discussed above.

Research Considerations

Two of the four reviewed studies provided limited IK related to research considerations. In both cases, Inuvialuit IK holders addressed the perceived impact of research activities on polar bear behavior and health. Joint Secretariat (2015) provided comments regarding the drawbacks of helicopter surveys and tranquilizing of polar bears, while both the Joint Secretariat (2015) and Slavik (2013) addressed general disturbance of polar bears associated with research activities. In Slavik (2013), IK holders noted that bears “spooked” by research activities tend to be less effective hunters and are less healthy.

These IK results could inform the purpose, structure, and parameterization of an IPM. Specifically, concerns about negative effects of capture on polar bear health could be explored by constructing the IPM in a manner that allows assessment of whether physical capture leads to a temporary (or permanent) decline in individual survival probability. This could be accomplished by developing the IPM to allow for a potential “trap effect” (i.e., change in survival following capture), which is common in capture-recapture studies of wildlife(Kendall, Barker, White, Lindberg, Langtimm, and Penaloza 2013). Although other scientific studies have addressed the potential effects of capture on polar bear movements, body condition, and survival (Thiemann, Derocher, Cherry, Lunn, Peacock, and Sahanatien 2013, Rode, Pagano, Bromaghin, Atwood, Durner, Simac, and Amstrup 2014), those investigations were not conducted in a capture-recapture or IPM framework, which likely represents the most powerful statistical approach to investigate the potential effects of research handling on the survival of independent bears.

Scientific Findings

One of the four reviewed studies (Braund et al. 2018) provided in-depth IK observations on scientific findings. In this study, IK holders agreed that scientific research can be useful in informing resource health and possibly resource abundance, but only with proper involvement of local residents and consideration of IK in interpretation of findings. IK holders noted problems with inaccurate population counts in the past which affected management decisions. Slavik (2013) made a general statement that IK holders are informed by various sources, including scientific studies.

These IK results do not directly inform any IPM parameters. However, concerns from IK about potential bias in previous scientific estimates of abundance could be used to influence model purpose and structure. Specifically, data-based scientific studies in the SB region have previously documented the potential for negative bias in estimates of polar bear abundance and survival, resulting from the movement of polar bears in and out of the geographic area exposed to sampling (Regehr et al. 2009). In a more recent estimate of abundance, Bromaghin et al. (2015) identified the potential for bias resulting from inconsistent sampling across the study area. Given that there are recognized sources of bias in estimates of abundance for polar bears, these perspective from IK could motivate structuring the IPM to specifically evaluate and, if possible, mitigate biases. This approach has been adopted in recent demographic modeling for some polar bear subpopulations in Canada, where capture data and movements data from radiotelemetry were analyzed together in an IPM (E. Regehr personal communication).

Value of Information

None of the four reviewed studies assessed for this project provided direct IK, aside from discussion of scientific research and findings (see above). The IK variable of Value of Information does not directly inform any IPM parameters, and IK from these four reviewed studies is not adequate to influence IPM structure or parameters.

Task 2 Summary

In summary, of the 24 IK variables, 17 were addressed in one or more of the reviewed studies in a manner that could potentially influence one of the five model input types for the SB-NB IPM (Table 4).The remaining 7 variables were not adequately addressed to influence one or more of the model input types, or there was a lack of consistency in the information from IK holders regarding the IK variable.

TABLE 4: POLAR BEAR IK VARIABLE ASSESSMENT FOR SB-NB IPM BASED ON FOUR REVIEWED REPORTS

IK Variable	Addressed in IK Reports at Level to Inform IPM?	Potential Model Input Types
Bear Age	Yes	Parameterization
Bear Sex	Yes	Parameterization
Body Condition	Yes	Structure, Parameterization
Harvest Effort	No	
Litter Size (cubs-of-the-year)	Yes	Structure, Parameterization, Prior Distribution
Litter Size (yearlings)	No	
Mortality	Yes	Structure, Parameterization
Relative Abundance	Yes	Parameterization
Resilience to Change	Yes	Structure, Parameterization
Range and Seasonal Movements	Yes	Purpose, Structure, Parameterization
Sea Ice Habitat	Yes	Structure, Parameterization
Terrestrial Habitat	Yes	Structure, Parameterization
Harvest Reporting	No	
Harvest Sampling	No	
Targeted vs. Opportunistic Harvests	Yes	Parameterization
General Bear Health	Yes	Parameterization, Prior Distribution
Observations of Disease or Sickness	Yes	Structure, Parameterization
Management Consideration	No	
Sustainability	No	
Prey Abundance	Yes	Parameterization, Data
Prey Health	Yes	Parameterization, Data
Research Considerations	Yes	Purpose, Structure
Scientific Findings	Yes	Purpose, Structure
Value of Information	No	

Several IK variables potentially influenced model purpose, including the importance of evaluating the potential negative effects of chemical immobilization on survival and focusing development of the IPM on mitigating potential bias in estimates of abundance. Several IK variables identified potential spatial variation in the ecological and demographic status of SB-NB polar bears, which could result in an IPM structure that included multiple geographic states. Multiple IK variables were relevant to parameterization, primarily the existence of sex- and age-based variation in survival and harvest mortality. Some of the available IK could contribute to development of informative prior distributions on litter size and survival, although this will likely require additional information from different sources including scientific studies. Several IK studies identified potentially important covariates that could be developed using other data sources including environmental (e.g., sea ice) or biological (e.g., seal productivity) covariates to model variation in polar bears vital rates. This information affects the parameterization of the IPM and serves, indirectly, as input data given that the IK could motivate inclusion of a data-based covariate that is obtained from a different source (e.g., from a seal harvest monitoring program, in the case of a covariate for seal productivity). Finally, none of the reviewed IK studies provided information that was directly useful as a data input to the IPM. This is not an unexpected outcome, considering that the studies (aside from the pilot study (Braund et al. 2018)) were not designed to collect quantitative information that could serve as data. Nonetheless, the available IK did include information that is relevant to how the IPM uses data from other sources. For example, some IK variables could help develop biologically meaningful environmental covariates that are related to polar bear vital rates, and the information from IK related to increasing land use could motivate the inclusion of scientific data from onshore studies that otherwise might have been left out due to relatively small sample sizes.

Data Gaps and Recommendations

Based on an assessment of the four IK studies reviewed for this report, seven IK variables (harvest effort, harvest reporting, harvest sampling, litter size [yearlings], management consideration, sustainability, and value of information) were not addressed in such a manner that they could influence the SB-NB IPM. Of the remaining IK variables, most were found to be useful for influencing parameterization and structure of the IPM, with a smaller number influencing model purpose or prior distributions. None of the IK sources reviewed for this study provided information that could be used directly as data inputs, although several identified potentially important covariates that could be developed using other data sources.

The review of IK literature in Task 2 identified data gaps and helped formulate recommendations for future IK studies that could inform the SB-NB IPM. Data gaps related to the seven IK variables for which the existing literature reviewed for this Project did not address in a manner that could influence the SB-NB IPM are as follows:

1. Harvest Effort – knowledge regarding the amount of effort required to successfully harvest polar bears was lacking in the IK studies but could be an indicator of potential changes in polar bear density, abundance, or distribution. Future IK efforts would benefit from documenting harvest effort (e.g., hunting days, CPUE, duration of hunting trip).
2. Harvest Reporting - Subsistence harvest of polar bears provides data that improve the accuracy and precision of demographic parameter from IPMs. Obtaining complete information and biological samples from harvested bears is among the most important and cost-effective ways to improve the performance of an IPM, however the thoroughness of reporting often differs by region (e.g., NWT, Alaska). Type of information that may be available include location of harvest, sex, premolar, baculum, tattoos (if present), ear tags (if present), fat, bone, skin with hair, uterus and ovaries, liver, colon, scat, intestine, gallbladder, meat, and stomach contents. The study team recommends a review of available harvest and sampling data from the responsible management authorities for the SB and NB subpopulations, similar to the review for the Chukchi Sea subpopulation by Schliebe et al. (2016), to assess the completeness of

quantitative harvest data and their applicability to the SB-NB IPM. Such a review would likely identify recommendations regarding the future collection of harvest related sampling data.

3. Harvest Sampling – see Harvest Reporting above
4. Litter Size (with differentiation between cubs-of-the-year and yearlings) - Breeding probability and cub survival are among the first demographic parameters to be affected by environmental change. Future IK studies could focus on trends in the body condition of cubs, overall numbers of cubs, and litter size. This information would be most useful if the distinction is made between cubs-of-the-year and yearlings.
5. Management Considerations– While management considerations are of less importance to an IPM, IK regarding how scientific data should influence management of polar bears could be valuable for future harvest risk assessments. Also, IK could be collected to identify local communities' preferred management objectives, for the purpose of ensuring that the IPM is capable of estimating the biological parameters necessary to evaluate management objectives (e.g., if there were an objective about adult male survival, the IPM would need to provide separate estimates of adult male survival).
6. Sustainability – IK should be collected on observations or perspectives that relate to a clear and specific definition of sustainability
7. Value of Information – having support for the findings of an IPM from stakeholder parties is critical to the long-term success of polar bear management. Future IK efforts would benefit from exploring which types of scientific information are viewed as most reliable, and why.

Along with the seven IK variables not adequately addressed in the literature, the study team identified five IK variables for which future IK collection efforts could be revised to improve the ability of the information to contribute to the SB-NB IPM. These variables are among the most directly relevant variables to consider when conducting an IPM and are as follows:

1. Bear Age - Changes in survival, reproduction, and harvest rate are known to affect the age of bears in a population. Given that structure size (e.g., height and length) is directly related to bear age and lifetime nutritional intake, future IK efforts could seek information on changes in structural size over the study period. This would require distinguishing between structural size and body condition (e.g., it's possible to have a very large [old] bear that is also thin).
2. Bear Sex - Changes in the sex composition of a population can provide information on sustainable harvest, given that many polar bear harvests are focused on male bears. Future IK collection efforts could target potential changes in the numbers of female and male bears over the study period.
3. Body Condition - Multiple scientific studies (e.g., Rode et al. 2021) have found that the structural size and body condition of polar bears are related to reproduction and survival. Furthermore, these metrics are readily observable. It would be valuable to focus future IK collection efforts on obtaining quantitative data on body condition (e.g., using the standardized 1-5 scale; (Stirling, Thiemann, and Richardson 2008)), including trends over the study period.
4. Mortality – Trends in polar bear mortality (or survival, given that mortality and survival are complementary) are difficult to observe without a designed study that follows the fates of individual animals, because polar bears are long-lived and spend much of their lives in remote areas that are not subject to direct human observation. Nonetheless, survival is a key IPM parameter that directly influences polar bear population status as well as management

considerations such as sustainable harvest. In particular, the survival of adult female polar bears is important (Regehr et al. 2021b). Thus, even small numbers of observations of polar bear mortality can be useful. For example, Amstrup, Stirling, Smith, Perham, and Thiemann (2006) documented three instances of intraspecific predation and cannibalism in the Beaufort Sea region, which were interpreted as indicators of a subpopulation under severe nutritional stress (this interpretation was consistent with demographic findings from subsequent scientific studies indicating that polar bear survival had declined during this period; (Regehr et al. 2010)). If specific observations of polar bear mortality are noted in future IK studies, it would be beneficial to collect as detailed information as possible including the location, date, environmental conditions, ecological context, and other relevant factors related to the observation.

5. Relative Abundance – Information on abundance is one of the most important outputs from an IPM. Furthermore, findings from scientific studies and perceptions from IK on relative abundance have differed for some other polar bear subpopulations (e.g., Regehr, Dyck, Iverson, Lee, Lunn, Norhtrup, Richer, Szor, and Runge (2021a)), which highlights the importance of collecting additional information from both types of knowledge and addressing apparent inconsistencies. Future efforts to collect IK on relative abundance should provide clear guidance on the timeframe (i.e., 2001 to present), seasonality (e.g., summer on land vs. winter on ice), and spatial scope (e.g., near communities vs. areas without human activity) of observations. Soliciting this level of detail throughout the range of a polar bear subpopulation would help synthesize individual or localized observations into a holistic picture of perceived changes in abundance.

In addition to recommendations specific to IK variables (see above), the study team identified additional general recommendations for improving future IK data collection methods to better align with the general structure and requirements of an IPM:

1. For future studies geared at collecting data for an IPM, it is important to collect IK that is specifically aligned with the time period of the IPM (i.e., 2001 through present).
2. Similarly, it is important to be as specific as possible about the relative context of IK that uses comparisons or addresses changes. For example, questions to solicit IK on changes in abundance could include an explicit statement of the baseline for comparison (e.g., changes in numbers of bears observed on the spring sea ice, away from attractants, over the study period).
3. Future IK studies could seek additional stakeholder input on model purpose. For example, are the two issues related to model purpose that were gleaned from the currently available IK (i.e., the potential negative effects of capture and concerns about bias in estimates of abundance) of primary importance? Are there other modeling objectives that could be integrated with the other objectives of the IPM?
4. IK can provide year-round observations by individuals with in-depth knowledge of an environment and its ecological relationships. In some cases, this information may provide insights that are not available from current scientific methodologies. Given that the primary long-term threat to polar bears is sea-ice change associated with climate warming, and that previous studies have demonstrated that the scientific understanding of environmental factors that drive polar bear population change is incomplete (e.g., Bromaghin et al. 2020), future IK studies could focus on identifying relationship between ecological or environmental factors and

polar bear vital rates. For example, observations from IK could identify aspects of prey population status that can be measured and are important to polar bear survival but have not been previously considered in scientific analyses.

5. Expanding the concepts in the preceding bullet, IPMs provide a method to incorporate information from IK and scientific studies. Future IK efforts could also focus on filling multiple types of data gaps in the available scientific information. For example, most scientific studies on polar bears in the SB-NB region have occurred in over a 1–2-month period in the spring. This highlights the importance of collecting IK about polar bears and other aspects of the ecosystem (e.g., prey health) in times and places that scientific observations are not being made.
6. The study team's review of currently available IK for the SB and NB polar bear subpopulations did not identify information that can be used direct as input data to an IPM. To the extent possible, future IK studies could focus on collecting specific types of information in a quantitative and systematic manner. For example, it may be possible for the responsible management authorities to work with hunters to obtain near real-time data on the sex, age, size and condition, and litter size of individual polar bears that were observed, but not harvested, during polar bear hunts or other activities.

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Appendix A – Glossary

- Bayesian Belief Networks – a graphical representation of relationships among random variables, which can use information from a variety of sources (e.g., field data, expert opinion) to estimate the probabilities of events of interest.
- Bayesian statistical framework – Bayesian statistics refer to a theory and approach in the field of statistics where probabilities are expressed as the degree of belief in an event, which can be informed by both data and prior information (e.g., the results of previous studies). Bayesian statistics offer a flexible method to develop quantitative ecological models, including integrated population models (IPMs), that use multiple types of data as inputs.
- Carrying capacity – the maximum number of individuals in a population that can be supported by the environment based on the available amounts of food, habitat, and other resources.
- Covariate - an independent variable that can influence the outcome of a given statistical trial, but which is not of direct interest (e.g., index of seal productivity as a covariate to explain temporal variation in polar bear vital rates).
- Density Dependence – demographic processes that change the birth or death rates as the density of animals on the landscape chances. For example, birth rates may decline when animal densities get high because there is increased competition for limited resources.
- IK variable – a discrete set of information from IK that is used to inform a model input type and its associated IPM parameter
- Informative prior distribution – in Bayesian statistics, prior distributions represent information that is known about an IPM parameter prior to fitting the current model. Informative prior distributions refer to the case when information is available beforehand, which can be represented by a specific statistical distribution and input to the model. In contrast, vague (or noninformative) prior distributions refer to the case when there is not any specific information about an IPM parameter that is known beforehand. When vague priors are used, results from the IPM will reflect only the input data from the current study and not any a priori or auxiliary information.
- Integrated population model – a type of quantitative ecological model that is highly flexible and can combine multiple types of data to estimate demographic parameters such as population abundance and trend. Integrated population models are often developed in a Bayesian statistical framework.
- IPM parameter – integrated population models seek to estimate parameters (e.g., reproductive rate, survival probability) that are of biological interest to the investigator. IPM parameters govern changes between biological states in the model. For example, survival probability is an IPM parameter that governs whether an individual in the model is alive or dead.
- Species Distribution Models – Quantitative ecological models that predict the distribution of animals in space and time as a function of environmental conditions.

Appendix B – Scientific publications represented in the literature search on Indigenous Knowledge and quantitative ecological modeling using the Clarivate Web of Science database

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Appendix C – Polar Bear IK Assessment for SB-NB IPM

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Bear Age	breeding probability, survival, harvest mortality	Stable or increasing cub populations. Older bears increasing in Wainwright and Utqiagvik in last 10 years. No reason as to why.	Wainwright and Utqiagvik's Area of Observation within SB range	Last 10 Years (2008-2017)	Workshops	Wainwright and Utqiagvik observations over past 10 years compared to lifetime	IK results suggest that the IPM could be parameterized to include age-related variation in survival probability and harvest mortality. Observations of potential changes in numbers of large bears (other studies have demonstrated a positive correlation between age and structural size) suggest that the IPM also could be parameterized to allow for changes in demographic composition.
Joint Secretariat 2015	Abundance & Reproduction	Bear Age	breeding probability, survival, harvest mortality	Provides information about general characteristics (e.g., size, behavior, appearance) of older and younger bears, but not the incidence of age groups (e.g., number of older versus younger bears). Condition of teeth (broken, short) and scarring is sometimes but not always an indicator of bear age. Similar numbers of maternity dens, thus similar numbers of maternal-age females. No information on trends in bear age (i.e., "bears are getting older" or "we only see young bears").	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok bear age observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Bear Age	breeding probability, survival, harvest mortality	Primarily focused on younger bears being less wary and more problematic and older bears staying away from town. Fewer large bears, which may indicate fewer older bears, but not necessarily.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik' bear age observations in last 15 years	
Slavik 2013	Abundance & Reproduction	Bear Age	breeding probability, survival, harvest mortality	One observation of fewer older bears, based on examination of teeth. Common observation of fewer large bears, which may be an indicator of age.	Sachs Harbour Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present (2008-2010)	Semi-directed	Sachs Harbor bear age observations, 2008-2010	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Bear Sex	survival, harvest mortality	Emphasized they mostly hunt males and that education outreach to encourage hunters not to harvest females particularly from December through June.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik 2017 hunting practices	These IK results suggest that the IPM could be parameterized to allow for sex-specific survival probability and harvest mortality.
Joint Secretariat 2015	Abundance & Reproduction	Bear Sex	survival, harvest mortality	No focus discussion identified regarding harvest selection based on sex or bear sex influencing survival.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok bear sex observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Bear Sex	survival, harvest mortality	Utqiagvik some preference toward avoiding female bears but distinguishing sex while hunting is hard. Other communities did not address topic	Utqiagvik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Utqiagvik's bear sex observations in last 15 years	
Slavik 2013	Abundance & Reproduction	Bear Sex	breeding probability, survival, harvest mortality	No IPM variable observations regarding bear sex	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present (2008-2010)	Semi-directed	Sachs Harbor bear age observations, 2008-2010	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Body Condition	breeding probability, survival	Wainwright and Utqiagvik said good in 2017 using polar bear fatness index.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik fatness observations over time	These IK results could suggest an east-to-west gradient in polar bear body condition, which would appear consistent with other studies on the demographic status of Arctic marine vertebrates. Spatial variation in body condition (which is positively related to polar bear reproduction and survival) could affect the structure of an IPM by considering multiple geographic states among which vital rates may vary.
Joint Secretariat 2015	Abundance & Reproduction	Body Condition	breeding probability, survival	Polar bear score card index was used but results do not appear to have been reported.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok body conditions observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Body Condition	breeding probability, survival	Variable. Many noted bears in good and fat conditions. Observations of increasingly skinny or smaller bears among some potentially tied to spatial scope of observations (just around the village) and attractants (e.g., bone pile) drawing in skinny bears.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range with emphasis on village/bone piles	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik' body condition observations in last 15 years	
Slavik 2013	Abundance & Reproduction	Body Condition	breeding probability, survival	Observations of smaller (overall size) and skinny bears with less fat content. Change in overall size attributed to larger bears possibly moving north or changing distribution patterns. Observations about change in fat content are variable and may be more subjective. Observations of skinny/starving bears are periodic and considered normal and part of the lifecycle of polar bears. Younger bears who just left their mother tend to be unhealthy/skinny.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-Directed	Sach's Harbor Body Condition observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Harvest Effort	abundance and trend, harvest mortality	Example indicators of harvest effort (e.g., successful days) reported but these are not generalizable to community levels.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik 2017 hunting practices	These IK results do not appear to provide information that is useful as an input to the IPM.
Joint Secretariat 2015	Abundance & Reproduction	Harvest Effort	abundance and trend, harvest mortality	Lots of discussion regarding hunting practices but no summary or focused discussion of harvest effort as it would relate to abundance and trend or harvest mortality IPM parameters (e.g., days hunting per harvested polar bear)	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok harvest practices prior to 2013	
Voorhees 2019	Abundance & Reproduction	Harvest Effort	abundance and trend, harvest mortality	See targeted vs. opportunistic below. No in depth discussion on harvest effort.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Abundance & Reproduction	Harvest Effort	abundance and trend, harvest mortality	Lots of discussion regarding hunting strategies. Harvest effort tied to polar bear distribution; some discussion of concerns that changes in sea ice will affect harvester travel and success.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor harvest effort observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Litter Size (cubs-of-the-year)	breeding probability, litter size, survival	Stable cub population in Wainwright and usually see one cub with mother. Increasing cub population with younger mothers in Utqiagvik and usually see two cubs with mother	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik litter size observations over time	These IK results suggest that the structure of the IPM should allow biological states for females with up to three cubs (some other models only consider two cubs). The quantitative information on litter size could potentially be used to inform prior distributions for related parameters in the IPM. Observations that litter size has been relatively stable suggest a time-constant parameterization for C0 litter size and survival.
Joint Secretariat 2015	Abundance & Reproduction	Litter Size (cubs-of-the-year)	breeding probability, litter size, survival	Pairs are usual which indicates a healthy population. No trend in fewer or more cubs	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok litter size observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Litter Size (cubs-of-the-year)	breeding probability, litter size, survival	Most often with two cubs with no change over time and in good condition.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik' litter size observations in last 15 years	
Slavik 2013	Abundance & Reproduction	Litter Size (cubs-of-the-year)	breeding probability, litter size, survival	Two cubs most common, with some observations of three cubs.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor Litter Size observations between 2008-2010.	

Litter Size (C1)

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Litter Size (yearlings)	breeding probability, litter size, survival	Yearlings vs. cubs of the year not typically an observation that IK holders made	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	These IK results do not appear to provide information that is useful as an input to the IPM; care must be taken when interpreting cub-of-the-year litter size information (see above) because of the tendency to not distinguish between cubs of different ages.
Joint Secretariat 2015	Abundance & Reproduction	Litter Size (yearlings)	breeding probability, litter size, survival	No discussion identified related to IPM parameters	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	No IK identified	
Voorhees 2019	Abundance & Reproduction	Litter Size (yearlings)	breeding probability, litter size, survival	No discussion identified related to IPM parameters	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Abundance & Reproduction	Litter Size (yearlings)	breeding probability, litter size, survival	No discussion specific to Yearlings	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor Litter size (yearlings) observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Mortality	survival	No data on mortality levels or trends. Health characterized as average to good.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	These IK results do not identify highly unusual mortality patterns for polar bears (noting that the ability to observe mortality in the wild is limited), which could suggest that the structure and parameterization of the IPM reflect standard processes related to polar bear survival as understood from other studies (i.e., the model does not need special features to accurately represent mortality).
Joint Secretariat 2015	Abundance & Reproduction	Mortality	survival	Provides information on causes of death. Causes include old age, starvation, fights, and accidents. No information on rates of mortality or trends in mortality aside from overall abundance being stable.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok mortality observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Mortality	survival	No focused discussion of mortality and effects on abundance. Few observations of deceased or ill bears, with more bear mortality reported in near Kaktovik.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's mortality observations in last 15 years	
Slavik 2013	Abundance & Reproduction	Mortality	survival	Few observations of deceased bears/bear carcasses.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor mortality observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Relative Abundance	abundance and trend	Increasing in Wainwright and Utqiagvik since 1972 and passing of MMPA. Wainwright described population as average in 2017; Utqiagvik described population as good in 2017.	Wainwright and Utqiagvik's Area of Observation within SB range	1972-2017	Workshops	Wainwright and Utqiagvik abundance observations pre-1972	These IK results do not identify large, observable trends in abundance across the study area. This information appears inconsistent with some recent scientific studies, which could motivate further investigation. Although it is unlikely that this information would lead to a model that only estimates time-constant abundance, given that previous scientific studies have estimated declining abundance in some areas (Bromaghin et al. 2015), it could influence model parameterization by highlighting the need to compare support in the data for models with time-constant vs. time-varying abundance.
Joint Secretariat 2015	Abundance & Reproduction	Relative Abundance	abundance and trend	Provides consensus workshop observations regarding more polar bears close to communities/shore, and that overall abundance is believed to be stable.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok abundance observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Relative Abundance	abundance and trend	Varied responses regarding abundance, with Wainwright and Kaktovik residents reporting decreased local abundance (last 10-15 years near Kaktovik), and Nuiqsut hunters reporting increased local abundance near Cross Island (last 20 years). Both reports of increased and decreased abundance by Utqiagvik hunters. Overall, more community observations of reduced local abundance.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's abundance observations in last 15 years	
Slavik 2013	Abundance & Reproduction	Relative Abundance	abundance and trend	No reported trend in overall abundance, with comments indicating that abundance fluctuates naturally over time. Overall trend of fewer bears coming into the community. Respondents note that bears are farther north, are moving to multi-year sea ice, and following prey species to new areas.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor relative abundance observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Abundance & Reproduction	Resilience to Change	relationships between vital rates and environmental conditions; carrying capacity	Workshop participants highlighted that polar bears are highly adaptable.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik adaptability observations over time	These IK results, together with related scientific studies, could suggest spatial variation in polar bears' response to environmental change across the SB-NB region (e.g., on a latitudinal gradient, given that less ice can temporarily benefit polar bears in regions historically characterized by heavy multiyear ice). Such variation would affect the structure and parameterization of the IPM.
Joint Secretariat 2015	Abundance & Reproduction	Resilience to Change	relationships between vital rates and environmental conditions; carrying capacity	Unknown what future effects could be but polar bears are viewed as adaptable and intelligent.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok resilience and adaptability observations prior to 2013	
Voorhees 2019	Abundance & Reproduction	Resilience to Change	relationships between vital rates and environmental conditions; carrying capacity	No focused discussion identified related to IPM parameters	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Abundance & Reproduction	Resilience to Change	relationships between vital rates and environmental conditions; carrying capacity	Varied responses regarding polar bear resilience to climate change and development. General consensus that polar bears may decline as sea ice declines and marine activity increases, but will ultimately adapt to the changes and may benefit from the inability of hunters to access them.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor resilience to change observations between 2008-2010.	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Distribution	Seasonal Movements	movement probability	Tied to ice movements and arrive near community in late fall/early winter and leave in spring with retreat of ice. More seen on land in summer than in the past.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik movement observations over time	These IK results could motivate inclusion of data from land-based studies in the SB-NB region, which would require additional model structure (i.e., geographic states corresponding to land use). Changes in land use over time could inform parameterization of movement probabilities between onshore and offshore states in the IPM. Could potentially affect model purpose if stakeholders are interested in projections of future land use as a function of environmental conditions.
Joint Secretariat 2015	Distribution	Seasonal Movements	movement probability	Other than denning (see terrestrial habitat below), aspects of polar bear distribution are relatively unchanged and have not had any impact on abundance of polar bears.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok movement observations prior to 2013	
Voorhees 2019	Distribution	Seasonal Movements	movement probability	Changing due to changes in sea ice. More presence on land than before, particularly in summer/early fall	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's movement observations in last 15 years	
Slavik 2013	Distribution	Seasonal Movements	movement probability	During mating season, bears migrate west and south along the coast of Banks Island from March to May, with a high concentration of bears near Cape Kellet during this time. Males follow the females. Bears inland during August/September, both females and young males. Fall time, bears wait by coastlines for freeze-up. Longer summers and shorter winters due to climate change are affecting seasonal polar bear distribution. Observed trends include more bears inland than in the past, and bears moving northward.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor seasonal movement observations between 2008-2010.	

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IK Source	IK Topic	IK Variable	Related IPM Parameter	IK Variable Summary	Spatial Scale	Temporal Scale	IK Data Collection Method	Relative Context of IK	
Braund et al. 2018	Habitat	Sea Ice Habitat	carrying capacity, abundance and trend	Pressure ridges and leads indicated good sea ice habitat while thin or slush ice is the worst habitat. Wainwright and Utqiagvik noticed later ice formation that was less thick beginning in 1990s. Wainwright also noted earlier break up. Both communities reported good ice conditions in 2017	Wainwright and Utqiagvik's Area of Observation within SB range	Beginning in 1990s to present (2017)	Workshops	Wainwright and Utqiagvik sea ice observations over time	See Seasonal Movements. These IK results could affect the IPM by highlighting the importance of including both pelagic and terrestrial geographic states in the model structure, and by suggesting model parameterizations in which movement probabilities are related to environmental covariates (e.g., if bears were more likely to come onshore in a year with early sea-ice breakup). Also, these IK results could affect data inputs to the IPM by informing or validating sea-ice covariates that are used to explain interannual variation in vital rates (if such relationships were supported by the data). IK observations appear broadly consistent with scientific data on reductions in sea ice.
Joint Secretariat 2015	Habitat	Sea Ice Habitat	carrying capacity, abundance and trend	Many changes in sea ice habitat due to climate change but nothing out of the ordinary regarding observed effects on polar bear	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok sea ice observations prior to 2013	
Voorhees 2019	Habitat	Sea Ice Habitat	carrying capacity, abundance and trend	Various dimensions of sea ice changing since 1980s and 1990s. Highlighted effects of wind on ice presence and not just temperature. Lack of ice concentrates polar bears along coast.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's sea ice habitat observations in last 15 years	
Slavik 2013	Habitat	Sea Ice Habitat	carrying capacity, abundance and trend	Overall decrease in sea ice during the summer due to climate change. "Young ice" with pressure ridges is best habitat due to the availability of seals and inability of human hunters to access bears on thin ice. Solid ice with little open water usually results in few bears in an area. Large, healthy bears tend to stay on multi-year ice. Less floating ice (ice floes) near shore has resulted in fewer bears near the shore during the summer and more bears along the beach.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor sea ice habitat observations between 2008-2010.	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Habitat	Terrestrial Habitat	carrying capacity, breeding probability (if denning habitat), abundance and trend	Polar bears tend to den on land but will also den on ice when grounded. Utqiagvik and Wainwright noted more denning on land.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik denning observations over time	See Seasonal Movements.
Joint Secretariat 2015	Habitat	Terrestrial Habitat	carrying capacity, breeding probability (if denning habitat), abundance and trend	Changing snow and wind conditions have influenced some den locations. Report has several maps of den locations	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok terrestrial habitat observations prior to 2013	
Voorhees 2019	Habitat	Terrestrial Habitat	carrying capacity, breeding probability (if denning habitat), abundance and trend	Spending more time on land in summer particularly noted in Utqiagvik and Wainwright. Denning occurs but is not common in Wainwright, Utqiagvik, and Kaktovik. Discussion of less denning out in ocean due to less multiyear ice. Wainwright and Nuiqsut noted more inland dens but also could be attributed to greater awareness due to development related studies.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's denning observations in last 15 years	
Slavik 2013	Habitat	Terrestrial Habitat	carrying capacity, breeding probability (if denning habitat), abundance and trend	Banks Island considered a key denning location for NB polar bears. Multiple locations of denning identified by respondents on Banks Island. Less commonly, respondents noted that bears may ben on multi year ice. Snow characteristics (e.g., snow density, quantity, location) affect denning behaviors and locations. Deep snow = ideal conditions for denning. Lack of snow may result in a bear moving to a different location, even after having young. Wind direction affects snow accumulation which affects denning. West and South Banks Island are ideal for denning due to prevailing wind conditions. Changing wind directions in recent years, in addition to erosion from climate change, may affect denning locations.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor Area terrestrial habitat observations, NB polar bear population	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Harvest Practices	Harvest Reporting	survival, harvest mortality, abundance and trend	No discussion identified related to IPM parameters other than that communities do participate in harvest reporting.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	Information on the timing of polar bear harvest could potentially inform model parameterization, especially if the IPM includes high-resolution temporal structure (e.g., if the model allows for movement between land and sea ice using 6-month time steps, rather than annual time steps). However, these IK results are unlikely to be used as a primary source of harvest information in the IPM, because the reviewed reports do not represent official repositories of quantitative and systematic data about polar bear harvest. Accurate harvest data, as obtained from the responsible management authorities, is an important data input to an IPM.
Joint Secretariat 2015	Harvest Practices	Harvest Reporting	survival, harvest mortality, abundance and trend	228 harvest locations within living memory. 95% of those with month data were between December to May	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok harvests prior to 2013	
Voorhees 2019	Harvest Practices	Harvest Reporting	survival, harvest mortality, abundance and trend	No Discussion Identified	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Harvest Practices	Harvest Reporting	survival, harvest mortality, abundance and trend	No Discussion Identified	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	No IK identified	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Harvest Practices	Harvest Sampling	survival, harvest mortality, abundance and trend	No discussion identified related to IPM parameters other than that communities do help in harvest sampling.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	See Harvest Reporting.
Joint Secretariat 2015	Harvest Practices	Harvest Sampling	survival, harvest mortality, abundance and trend	No discussion identified related to IPM parameters	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	No IK identified	
Voorhees 2019	Harvest Practices	Harvest Sampling	survival, harvest mortality, abundance and trend	No discussion identified related to IPM parameters	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Harvest Practices	Harvest Sampling	survival, harvest mortality, abundance and trend	No discussion identified related to IPM parameters	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor harvest reporting observations between 2008-2010.	

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IK Source	IK Topic	IK Variable	Related IPM Parameter	IK Variable Summary	Spatial Scale	Temporal Scale	IK Data Collection Method	Relative Context of IK	
Braund et al. 2018	Harvest Practices	Targeted vs. Opportunistic Harvests	harvest mortality	Wainwright and Utqiagvik reported somewhat equal levels of targeted versus opportunistic/nuisance harvests. Over 50% of "most recent" polar bear harvests by respondents were targeted hunts.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik harvest practices over time	These IK results suggest that the IPM could be parameterized to allow for sex-specific survival probability and harvest mortality.
Joint Secretariat 2015	Harvest Practices	Targeted vs. Opportunistic Harvests	harvest mortality	General consensus from interviews is that polar bear hunting is primarily planned and targeted, with opportunistic harvests occurring periodically. Topic did not seem to be explored in depth though.	See Map 5	Lifetime (Pre-2013)	Semi-directed; workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok harvest practices prior to 2013	
Voorhees 2019	Harvest Practices	Targeted vs. Opportunistic Harvests	harvest mortality	Hunting is primarily opportunistic in North Slope communities; some specialized, targeted hunting occurs in Utqiagvik.	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's harvest practices in last 15 years	
Slavik 2013	Harvest Practices	Targeted vs. Opportunistic Harvests	harvest mortality	No discussion identified related to IPM parameters	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor harvest practices between 2008-2010.	

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IK Source	IK Topic	IK Variable	Related IPM Parameter	IK Variable Summary	Spatial Scale	Temporal Scale	IK Data Collection Method	Relative Context of IK	
Braund et al. 2018	Health	General Bear Health	breeding probability, survival	Healthy and no changes to overall health or body condition	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik health observations over time	These IK results may suggest changes in demographic composition given that three of four reviewed studies indicated fewer large bears. Both body condition and structural size in polar bears are related to reproductive success and survival. This information could suggest parameterizing the IPM to allow for temporal changes in these vital rates. Furthermore, if other lines of evidence were in agreement, these IK results could suggest temporal variation in prior distributions on survival (e.g., lower values in more recent years). Caution must be exercised because changes in demographic composition are the result of multiple processes including births and deaths.
Joint Secretariat 2015	Health	General Bear Health	breeding probability, survival	Fewer big bears and less fat bears compared to mid-1980s.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok observations from recent years (2010s) compared to 1980s	
Voorhees 2019	Health	General Bear Health	breeding probability, survival	Smaller bears but could be due to spatial scale of observations. Also increase in "tired" bears	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's body condition observations in last 15 years relative to observations from 1950s and 1960s	
Slavik 2013	Health	General Bear Health	breeding probability, survival	Fewer big bears; skinny/starving bears are periodic and considered normal. Skinny bears associated with young/inexperienced bears, old bears, and "spooked" bears. No "diseased" bears. . Pure blubber in stomachs (versus all seal parts) is a sign of a healthy bear with no nutritional stress. Number of seal kill sites is also an indicator of polar bear hunting success and health.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor General Bear Health observations between 2008-2010.	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Health	Observations of Disease or Sickness	survival	Thin or sick polar bears seen from time to time but this has not changed noticeably from past	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik health observations over time	These IK results suggest that there have not been large-scale, observable changes in disease prevalence. This could suggest using a standard parameterization for survival probability in the IPM (e.g., allowing for normal temporal variation) instead of implementing a specialized structure, for example to allow for potential changes in polar bear survival associated with the unusual mortality event for seas in the western portion of the study area.
Joint Secretariat 2015	Health	Observations of Disease or Sickness	survival	Observations of what a sick polar bear looks like but no discussion of disease or sickness related to IPM parameters of survival and trends	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok sickness observations prior to 2013	
Voorhees 2019	Health	Observations of Disease or Sickness	survival	No notable trends or observations regarding sicknesses or disease	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's disease or sickness observations in last 15 years	
Slavik 2013	Health	Observations of Disease or Sickness	survival	No notable trends or observations regarding sicknesses or disease	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor disease or sickness observations between 2008-2010.	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Management	Management Considerations	no direct IPM parameters	Have participated in management programs, would participate in community based management programs, and more likely to follow outside organizations guidance if supported by strong science, local consultation and enforcement, equal decisions making authority, and consideration of entire ecosystem	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik experiences with various management agencies at local, state, and federal levels	These IK results do not appear to provide information that is useful as an input to the IPM.
Joint Secretariat 2015	Management	Management Considerations	no direct IPM parameters	History of PB management is presented. Emphasizes importance of Inuvialuit influence in management decisions but not much else.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok views on management prior to 2013	
Voorhees 2019	Management	Management Considerations	no direct IPM parameters	No Discussion Identified	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Management	Management Considerations	no direct IPM parameters	Some discussion of history of PB management, participation in co-management processes, and the researcher's thoughts on the importance of including IK and local residents in management decisions. No direct IK regarding management.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor management considerations observations between 2008-2010.	

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IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Management	Sustainability	harvest mortality	No indications that current harvest levels are not sustainable and emphasized communities can self-regulate	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik sustainability practices over time	As presented, these IK results are likely not useful for the IPM because sustainability was not explicitly defined in the reviewed studies. However, if sustainability was well-defined (e.g., not causing a population reduction), observations were consistent across the study area, and harvest reporting was accurate, it could be possible to use information on sustainability to inform prior distributions on survival and harvest mortality (e.g., such that the known harvest levels would not cause a large reduction in abundance that could likely be observed).
Joint Secretariat 2015	Management	Sustainability	harvest mortality	Not much IK on sustainability other than importance of Inuvialuit influence	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok views on sustainability prior to 2013	
Voorhees 2019	Management	Sustainability	harvest mortality	No discussion identified related to IPM parameters	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Management	Sustainability	harvest mortality	No discussion identified related to IPM parameters	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	No IK identified	

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IK Source	IK Topic	IK Variable	Related IPM Parameter	IK Variable Summary	Spatial Scale	Temporal Scale	IK Data Collection Method	Relative Context of IK	
Braund et al. 2018	Prey species	Prey Abundance	multiple IPM parameters	Wainwright identified stable prey populations; Utqiagvik noted increasing prey populations. Prey abundance reported as good in 2017	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik prey abundance observations over time	These IK results suggest that prey abundance was variable across the study area and that seal numbers are subject to natural fluctuations. This information could influence IPM parameterization and input data by suggesting use of a prey-related covariate (e.g., based on an index of seal productivity) to explain variation in polar bear vital rates. Although the IK did not link prey abundance to the status of polar bears, other scientific studies have provided direct evidence for such a relationship.
Joint Secretariat 2015	Prey species	Prey Abundance	multiple IPM parameters	Cyclical but had witnessed unusually large number of dead seals in previous two summers but did not imply it had affect on polar bear abundance	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok prey abundance observations prior to 2013	
Voorhees 2019	Prey species	Prey Abundance	multiple IPM parameters	Good/stable in Utqiagvik and Wainwright. No consensus in Nuiqsut. Fewer in Kaktovik due to reduced sea ice. Other species of seal becoming more abundant in Utqiagvik	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's prey abundance observations in last 15 years	
Slavik 2013	Prey species	Prey Abundance	multiple IPM parameters	Variable observations regarding seal population/health, with some indicating fewer seals, and others indicating that seal abundance fluctuates or is related to changes in distribution related to ice conditions and food availability.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor prey abundance observations between 2008-2010.	

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IK Source	IK Topic	IK Variable	Related IPM Parameter	IK Variable Summary	Spatial Scale	Temporal Scale	IK Data Collection Method	Relative Context of IK	
Braund et al. 2018	Prey species	Prey Health	multiple IPM parameters	No discussion identified related to IPM parameters	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	See Prey Abundance.
Joint Secretariat 2015	Prey species	Prey Health	multiple IPM parameters	See prey abundance IK variable	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok prey health observations prior to 2013	
Voorhees 2019	Prey species	Prey Health	multiple IPM parameters	Healthy/Fat/Good conditions	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's prey health observations in last 15 years	
Slavik 2013	Prey species	Prey Health	multiple IPM parameters	Possible decline in body condition although respondents indicate fat content fluctuates annually and seasonally.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor prey health observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Research	Research Considerations	no direct IPM parameters	None identified	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	These IK results could affect the purpose, structure, and parameterization of an IPM. Specifically, the IPM could be formulated to specifically investigate whether there are temporary declines in individual polar bear survival following chemical immobilization. This analytical approach has not been implemented before, and could help address concerns about the potential negative impacts of handling polar bears.
Joint Secretariat 2015	Research	Research Considerations	no direct IPM parameters	A few comments in appendix about drawbacks of helicopter surveys including overall disturbance and timing of surveys. Also drawbacks of tranquilizing.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok views on research prior to 2013	
Voorhees 2019	Research	Research Considerations	no direct IPM parameters	No Discussion Identified	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Research	Research Considerations	no direct IPM parameters	Some discussion of how research activities can "spook" bears causing them to be less effective hunters and resulting in skinnier or less healthy bears.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor relative abundance observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	IK Topic	IK Variable	Related IPM Parameter	IK Variable Summary	Spatial Scale	Temporal Scale	IK Data Collection Method	Relative Context of IK	
Braund et al. 2018	Research	Scientific Findings	no direct IPM parameters	Scientific findings have value particularly in areas such as resource health and possibly population counts as long as appropriate consideration of TEK and local resident involvement.	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	Wainwright and Utqiagvik experiences with scientific findings over time	These IK results could influence the purpose and structure of the IPM. Previous scientific studies have identified the potential for negative bias in estimates of abundance and survival for polar bears. Concern among IK holders about inaccurate population estimates could motivate structuring the IPM to specifically evaluate and/or mitigate potential sources of bias. This approach has been adopted recently in demographic analyses for some Canadian polar bear subpopulations.
Joint Secretariat 2015	Research	Scientific Findings	no direct IPM parameters	Discuss various concerns and benefits from IK holders regarding scientific findings.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok views on scientific findings prior to 2013	
Voorhees 2019	Research	Scientific Findings	no direct IPM parameters	No Discussion Identified	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Research	Scientific Findings	no direct IPM parameters	Briefly how IK holders today can be informed in part by scientific findings.	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	Sach's Harbor scientific findings observations between 2008-2010.	

Identify and Categorize IK					IK Variable Criteria				Consider Criteria and Identify Functional Relationship between IK Variable and IPM Parameter
IK Source	**IK Topic**	**IK Variable**	**Related IPM Parameter**	**IK Variable Summary**	**Spatial Scale**	**Temporal Scale**	**IK Data Collection Method**	**Relative Context of IK**	
Braund et al. 2018	Research	Value of Information	no direct IPM parameters	See scientific findings and management considerations above	Wainwright and Utqiagvik's Area of Observation within SB range	Present Status (2017)	Workshops	No IK identified	These IK results do not appear to provide information that is useful as an input to the IPM.
Joint Secretariat 2015	Research	Value of Information	no direct IPM parameters	Discuss various concerns and benefits from IK holders regarding scientific findings.	See Map 5	Lifetime (Pre-2013)	Semi-directed, Workshops	Aklavik, Inuvuk, Paulatuk, Sachs Harbor, Tuktoyaktuk, and Ulukhaktok views on scientific findings prior to 2013	
Voorhees 2019	Research	Value of Information	no direct IPM parameters	No Discussion Identified	Wainwright, Utqiagvik, Nuiqsut, and Kaktovik's Area of Observation within SB range	Last 15 Years (2003-2018)	Semi-directed	No IK identified	
Slavik 2013	Research	Value of Information	no direct IPM parameters	No Discussion Identified	Sach's Harbor Area of Observation within NB range, "western and southern coast and landfast ice of Banks Island."	Present Status (2010)	Semi-directed	No IK identified	