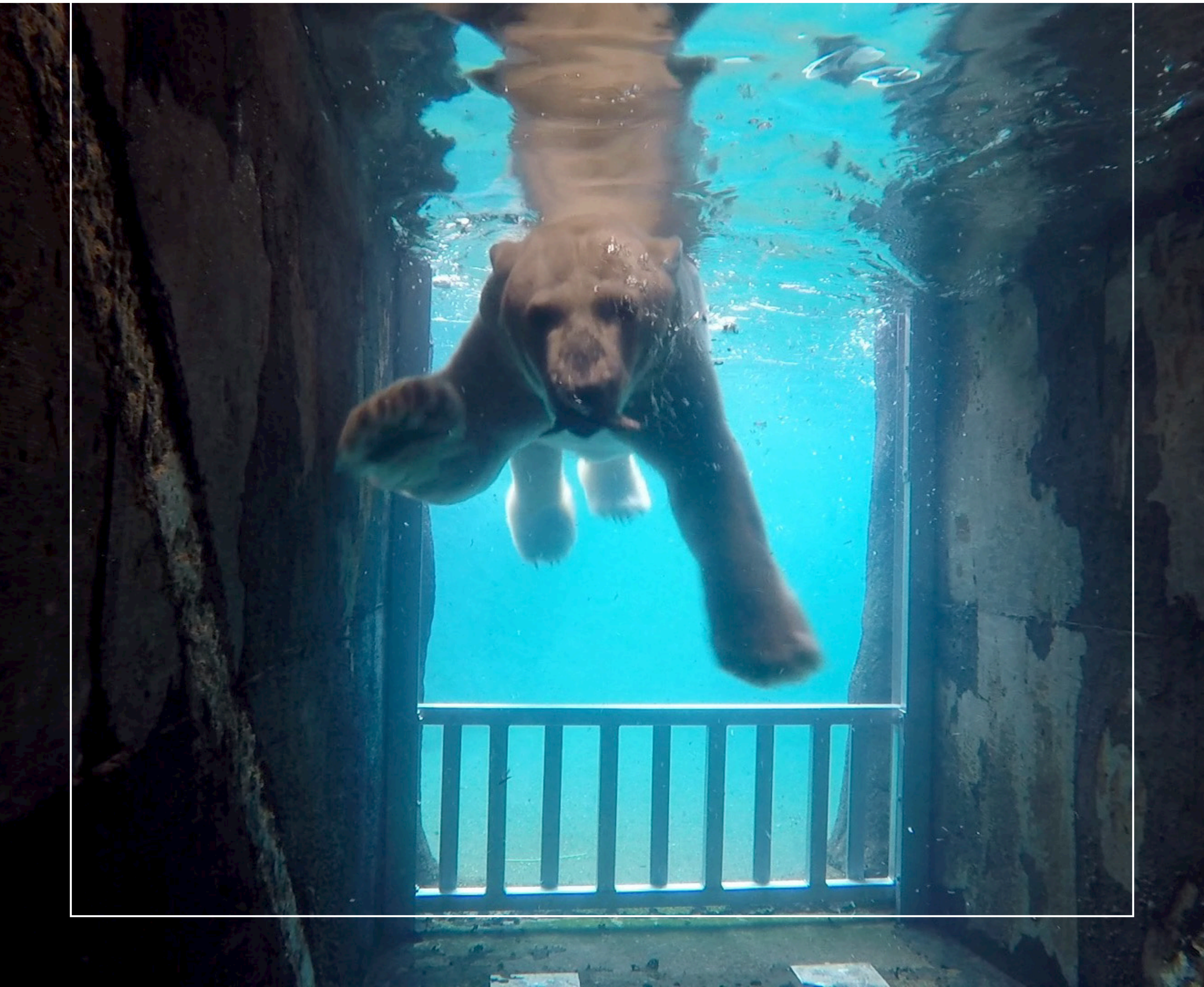
2022 POLAR BEAR RESEARCH MASTERPLAN

Polar Bear Research Council

Association of Zoos and Aquariums

Polar Bear Species Survival Plan



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On the cover: Polar bear Tasul swims into an underwater swim flume as part of a collaborative metabolic study at the Oregon Zoo. Photo by Michael Durham/Oregon Zoo.

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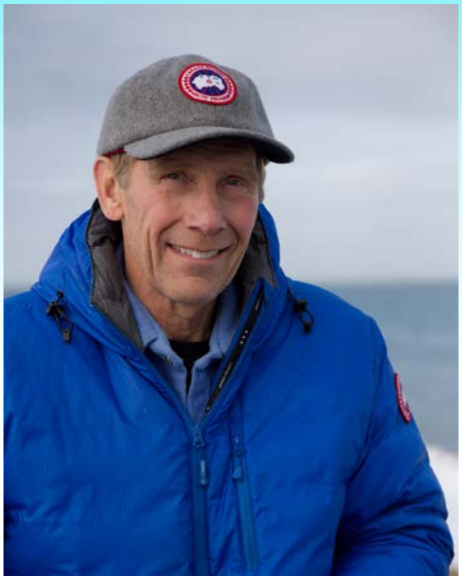
Dr. Anthony Pagano records behavior exhibited by Oregon Zoo polar bear Tasul, voluntarily sporting a research collar fitted with an accelerometer device. Photo by Michael Durham/Oregon Zoo.



Dr. Steven C. Amstrup

Over the past 40+ years, scientists have overcome tremendous logistical challenges to study wild polar bears, and I feel fortunate for the role I've played in that progress. Prior to joining Polar Bears International as chief scientist in 2010, I led polar bear research in Alaska for 30 years. My three decades of in situ fieldwork helped provide essential information on polar bear movements, distribution, population trends, life history traits, and basic biological needs—knowledge that has added greatly to our understanding of the bears and the actions needed to ensure their future.

This research culminated in the projection that, without action on human-caused climate warming, polar bears could all but disappear by the end of the century. As a result, polar bears became the first species listed under the U.S. Endangered Species Act due to the threat of global warming.

Continuing in situ research on wild polar bears across the Arctic has confirmed the threat of climate warming and provided the mechanistic underpinnings of polar bear life history needs. It also has shown that some vital studies simply cannot be conducted in the wild.

This is where zoos and aquariums can play a critical role. Bears in managed care can be repeatedly observed and sampled over long time periods—allowing sample size and replication not possible in the field. Such studies can fill critical knowledge gaps while testing and calibrating new research methods and technologies before they are deployed in the field.

Through projects supported by the Polar Bear Research Council, of the Association of Zoos and Aquariums, AZA member institutions have partnered with universities, government agencies, and Polar Bears International on research ranging from determining the polar bear's energy use when walking, running, and swimming to testing new devices for following the movements of bears in the wild. Ex situ research in zoo settings combined with in situ field research showed how polar bears use scent communication as they search for mates on broad expanses of pack ice. And studying polar bear hair and tissue samples from zoo animals have helped us understand wild bear diets.

The Polar Bear Research Masterplan is a living document that prioritizes ex situ research vital to polar bear conservation and management. It serves as a roadmap to the roles zoos and aquariums can fill in our understanding of polar bear life history needs. Presentation of ex situ research also can capture public attention and enhance the opportunities for zoos and aquariums to educate the public about the threats polar bears face—inspiring actions necessary to preserve them in the wild.

The combination of ex situ research opportunity with potential for outreach and education means zoos and aquariums can play a vital role in helping to assure future survival of polar bears throughout the Arctic. This document is a valuable resource for guiding, facilitating, and supporting this important work.

Sincerely,

Dr. Steven C. Amstrup
Chief Scientist, Polar Bears International

Mission: To ensure a robust, thriving zoo population of polar bears is involved in research that produces solutions to conservation and management challenges facing wild bears.

Description: The Polar Bear SSP's designation as a research population signals a shift toward requiring member participation in priority research projects with polar bears ex situ that can inform critical conservation and management questions that exist for polar bears in situ. For a research program to be successful, a diverse population of animals must be maintained, individual animal welfare must factor into decision-making and AZA facilities must work to ensure that viable candidates are available for research. Additionally, AZA facilities must ensure that staff are trained in sample collection and training techniques, and that facilities are designed to accommodate sample collection and/or research. Future polar bear SSP master-planning will center around maximizing our participation in meaningful conservation science.

Rationale: Polar bears in managed care can participate in valuable research that helps to conserve and understand polar bears in the wild. Zoo- and aquarium-housed polar bears can be trained via operant conditioning to voluntarily participate in hands-on procedures and longitudinal biological sampling. These bears have the added advantage in that their husbandry histories and medical records are available, environmental conditions are known and can be adjusted, and monitoring can be continuous during a study. Through multi-institutional collaborations, scientists can recruit a larger sample size of polar bears that ensure sufficient statistical power in studies on behavior, physiology, health, reproduction, and welfare. Polar bears in managed care can also contribute to the development and validation of new technologies and methodologies for use with wild bears, the true beneficiaries of this initiative.

The Polar Bear Research Council (PBRC)

The PBRC is composed of a Steering Committee that includes two PBRC Co-Chairs, the PBRC Facilitator and the Polar Bear SSP Chair. Additional members include advisors with expertise/experience in four priority research areas (see below). Priority research advisors are responsible for recruiting input from additional experts (typically 3-6) who can provide thoughtful reviews and unique perspectives to ensure the PBRC Masterplan is accomplished.

The PBRC's goals are to: 1) facilitate the use of the ex situ population to better characterize basic biology and to advance scientific methodologies for comparison and application to wild polar bears; 2) support research that is necessary for maintaining a viable, sustainable ex situ population for scientific research with application to the conservation of wild bears; and 3) build capacity within SSP member institutions to participate in priority scientific research efforts.

Purpose of the PBRC and the Research Masterplan

The purpose of the Polar Bear SSP Research Masterplan document is to: 1) guide research priorities for the Polar Bear SSP and participating institutions, 2) advise the Polar Bear SSP on proposal endorsement requests, 3) facilitate priority research efforts in SSP institutions, 4) keep current with emerging scientific questions regarding survival of polar bears in the wild, and 5) track progress made through the collaborative scientific studies of polar bears in managed care and of contributions made by zoos and aquaria to wild polar bear research. The masterplan is a living document that is intended to be updated every three to five years. This current masterplan is the 1st revised version of the original masterplan published in 2018.

Photo © Daniel J. Cox/NaturalExposures.com

AZA Polar Bear SSP Research Council

Co-Chairs

Dr. Terri Roth, Center for Conservation and Research of Endangered Wildlife (CREW), Cincinnati Zoo & Botanical Garden; email: terri.roth@cincinnatizoo.org

Dr. Megan Owen, San Diego Zoo Wildlife Alliance; email: mowen@sdzwa.org

Facilitator and Contact: Amy Cutting, Oregon Zoo; email (preferred) Amy.Cutting@oregonzoo.org; cell: 503-757-8163; Office: 503-220-2446

AZA Liaison: Steve Olson, Senior Vice President, Government Affairs, Association of Zoos and Aquariums (AZA); email: solson@aza.org

Polar Bear SSP Chair: Allison Jungheim, Como Park Zoo and Conservatory; email: allison.jungheim@ci.stpaul.mn.us

Priority research pillars and corresponding advisors

I. **Field Techniques Advisors**

Dr. Thea Bechshoft, Polar Bears International; email: thea@pbears.org

Dr. Stephen Petersen, Assiniboine Park Zoo; email: spetersen@assiniboinepark.ca

II. **Health and Welfare Advisor**

Dr. Randi Meyerson; email: randimeyerson61@gmail.com

III. **Physiological and Behavioral Ecology Advisors**

Dr. Karyn Rode, United States Geological Survey (USGS); email: krode@usgs.gov

Dr. Anthony Pagano, Washington State University; email: ampagano@ucsc.edu

IV. **Reproductive Physiology Advisor**

Dr. Erin Curry, CREW, Cincinnati Zoo & Botanical Garden; email: erin.curry@cincinnatizoo.org

List of PBRC endorsed, ongoing research projects *as of June 2021*

	Project title	PI and affiliation
1	*Macronutrient requirements and intake of polar bears*	Karyn Rode; USGS; krode@usgs.gov
2	*Comparative analyses of the expression of reproductive steroids and dehydroepiandrosterone sulfate (DHEAS) in captive and wild female polar bears.*	Shannon Atkinson and Monica Brandhuber; University Fairbanks; shannon.atkinson@alaska.edu
3	*Characterization of the gut microbiota in polar bears and a metabolic analysis*	Peko Tsuji and Maci Quintanilla; Towson University, MD; ptsuji@towson.edu
4	*Development of dynamic energy budget models in complex vertebrate mammals to understand past and future population dynamics.*	Stephanie Penk; University of Toronto; sr.penk@mail.utoronto.ca
5	*Validation and characterization of reproductive hormones and biomarkers in polar bear serum*	Erin Curry, Jessye Wojtusik, Terri Roth; Cincinnati Zoo/CREW; erin.curry@cincinnatizoo.org
6	*Analyzing hormone patterns of captive male polar bears housed under different social conditions*	Dylan McCart, Suzanne MacDonald; York University; dylanmccart@hotmail.com
7	*Assessing the timing and rate of fur growth in zoo polar bears*	Jennifer Stern, University of Washington and Karyn Rode, USGS; jhstern@uw.edu
8	*Polar bear ear measurements (for new ear tag tracking device)*	Elisabeth Kruger; World Wildlife Fund; Elisabeth.Kruger@wwfus.org
9	*Serum concentration comparisons of fatty acids, amino acids, vitamins, minerals, and cholesterol, between free-ranging and zoo polar bears*	Deb Schmidt, St. Louis Zoo and Karyn Rode, USGS; schmidt@stlzoo.org
10	*New attachment techniques for electronics to polar bears – Project "Burr on Fur"*	Geoff York, Polar Bears International; gyork@pbears.org

Field Techniques

(In-field monitoring and management techniques)

Advisors: Dr. Thea Bechshoft, Polar Bears International

Dr. Stephen Petersen, Assiniboine Park Zoo

Experts: BJ Kirschhoffer, Polar Bears International

Liz Larson, Utah's Hogle Zoo

Alysa McCall, Polar Bears International

Dr. Nicholas Pilfold, San Diego Zoo Wildlife Alliance

Dr. Tom Smith, Brigham Young University

Geoff York, Polar Bears International

Photo © Daniel J. Cox/NaturalExposures.com

Explanation of the research focus area in relation to polar bear conservation

The polar bear *(Ursus maritimus)* poses challenges for researchers and conservationists in that it is a large top predator that lives a primarily solitary life across vast expanses in a harsh and remote environment. Polar bear habitat also presents logistical difficulties and safety concerns for researchers as it consists of sea ice, marine waters, and terrestrial areas that experience a wide range of often unforgiving environmental conditions. When polar bears do occur near humans and their infrastructure successfully co-existing can present a significant risk and challenge. Together, these factors often hinder effective research and conservation efforts of polar bears across the Arctic. Technical and technological advances can play a vital role in overcoming this challenge, particularly those that have been developed in collaboration with institutions that have polar bears in their care. These bears can participate in scientific studies in a controlled environment, with subjects that can be repeatedly observed, monitored, or examined. Thus, applied monitoring and conservation tools that have been developed using ex situ bears can be nearly field-ready before being deployed in situ, reducing the chance of failure, and increasing the chances that field results will provide the desired data and results. An additional benefit is that the newly developed methods are often less invasive than the more traditional approaches to polar bear research.

The Field Techniques advisory group includes projects with direct in-field applications, in particular studies that test equipment for field deployment or validate new (or new applications of already existing) methods and technologies that directly inform in situ polar bear research and conservation. Meanwhile, projects focused on advances in laboratory analyses and techniques will sort under either the Physiological and Behavioral Ecology, the Reproductive Physiology, or the Health and Welfare advisory groups as deemed appropriate.

Recent examples of published work that has happened in zoo settings and how it has complemented or informed our understanding of polar bear biology and management

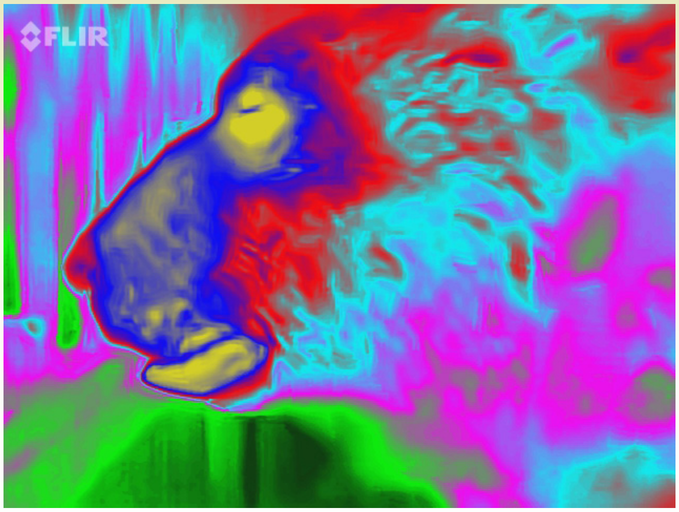
Identifying bear behavior from activity sensors
Pagano et al. (2017) and Ware et al. (2016) used activity sensor data on collars of zoo bears to relate collar activity to individual bear behaviors. Those relationships have then been used to be able to identify the behaviors of wild bears our on the sea ice based on historic and contemporary activity sensor data thereby better understanding the behavior of bears when and where they can rarely be observed.

Energetic costs of locomotion in bears
Pagano et al. (2018a) - Polar bears in human care were trained to voluntarily walk on a treadmill in a special chamber that could analyze the breath of the bear. This allowed scientists to record how the bear was moving at as well as the amount of energy they were expending. This information was then used to predict energy use in wild bears.

Identification of individual bears
Prop et al. (2020) - Sets of photographs of 15 polar bears from six AZA and EAZA zoos were used to develop a new method for individual recognition, based on distinguishing a set of physiognomic characteristics, which can be recognized from photographs taken in the field at distances of up to 400 m. Requiring less specific photos than the whisker spot recognition method (Anderson et al. 2010), this new method offers an additional method for identification of individual polar bears in the wild.

Validating thermal imagery tools
Bissonette (2020) - Polar bears in human care were filmed using an infrared camera while the bears sparred and played with each other. The change in the bear's temperature signal from beginning of the play session to the end of a session is related to the amount of energy the bear has spent on that activity. Thermal imagery has been used to detect polar bear dens (Smith et al. 2020) but may also have other applications to help understand polar bear biology and behaviour.

Improving diet estimates of wild polar bears inferred from hair and blood samples
Rode et al. (2016) worked with zoos to feed polar bears specific marine-based diets to trace how stable isotopes of carbon and nitrogen in food is reflected in



Infrared thermography image of a male polar bear. Image by Dylan McCart and Dr. Michelle Shero.

their blood and hair. Using this information, correction factors were identified that allow estimation of the prey species and macronutrient composition of wild polar bear diets from these same tissues. Further, this study determined the timeframe of diet represented in these tissues to improve interpretation of wild samples.

Priority areas that should take precedence within this research pillar

Given the unpredictable nature of methodological and technological advances, we have identified priority areas where new field techniques are likely to contribute significantly to our understanding and conservation of polar bears.

1. **Population assessment:** The key to managing populations is obtaining regular and timely population estimates to determine abundance and trends. For polar bears, this has been accomplished using capture-mark-recapture (hands-on and genetic) and via aerial surveys. All current methods are expensive, high risk, and time-consuming and therefore cannot be done with the regularity needed for a species in a changing habitat such as the Arctic. Examples of emerging technology likely to assist in counting polar bears include remote sensing tools that could help us accurately count bears using drones, aircraft, or satellites (e.g., LaRue et al. 2015, Barnas et al. 2018).

2. **Movement and dispersal:** Habitat use and requirements, movement, and dispersal studies all rely on the tracking of individual polar bears. This has been done primarily using satellite-

GPS ear tag on a tranquilized subadult polar bear. Photo by Dr. Andrew E. Derocher/ University of Alberta.

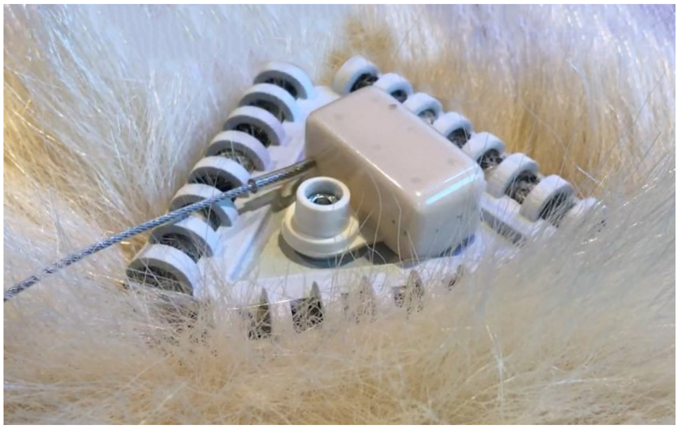
linked GPS collars, but there is an increasing need for redesign of these instruments to be smaller, lighter, and more efficient. There is also a need for them to be able to carry new sensors or be attached in different ways. Examples of emerging technology likely to assist in tracking polar bears include miniaturization and new battery technology as well as new tracking device attachment strategies like the one used in the 3M Burr on Fur adhesive tags.

3. **Minimally invasive monitoring:** Devices like camera traps, Doppler tracking radar, hair snags, photogrammetric or laser-based body condition measures, and opportunistic collection of fecal samples are good examples of non-invasive monitoring tools. Approaches like these can provide useful information on polar bears with minimal disturbance or effect on the animal. Non- or minimally invasive techniques should be pursued and used whenever possible over invasive techniques and can be tested and validated in zoological or aquarium settings.

4. **Polar bear/human coexistence:** Sea ice loss has led to an increase in polar bear sightings in northern coastal communities around the Arctic, a trend that is expected to continue as more polar bears are forced to spend longer periods of time onshore and as human activities in the Arctic increase, both in response to longer ice-free seasons (Wilder et al. 2017). To mitigate this, more information is needed on polar bear olfaction and vision in relation to potential deterrent tools and methods. Further, development and testing of early polar bear detection systems as well as non-harmful deterrent tools such as strobe lighting and specific sounds to examine their efficacy in potential use as a deterrent option.

5. **Polar bear awareness:** Human perceptions of polar bears and their actions can significantly influence chances of human/bear conflict when working, living, or recreating in the north. Social science research that probes this relationship and explores ways to minimize conflict is needed.

A prototype of one of the Burr on Fur adhesive GPS tags. As with the ear tags, these smaller tags allow us to study not just adult females, but also males and younger bears, collecting valuable information on the habitat use of these little-studied groups. Photo by 3M and Polar Bears International.



Work currently underway or not yet published

1. **Population assessment**
    - Collection of aerial thermal images of polar bears to train machine learning algorithms to detect polar bears in seal surveys.
2. **Movement and dispersal**
    - Testing of adhesive satellite tags that attach to the bear's fur while providing movement data.
    - Ear tag redesign for a smaller more ergonomic tag to replace the current bulkier design.
3. **Minimally invasive monitoring**
    - SAR (synthetic aperture radar); a device used to detect polar bear maternity dens under the snow while flying overhead.
    - Maternal den studies; monitoring polar bear dens with remote camera systems to record data on the activity of emerging polar bear moms and cubs.
    - Body condition; developing an algorithm that allows body condition to be inferred from photographs or laser-based three-dimensional imagery.
    - Individual recognition; further development of the automated system developed by the Waterman group (Anderson et al. 2010) that uses whisker spot patterns to identify bears.
4. **Polar bear/human coexistence**
    - Early warning polar bear detection; developing a radar technology based system to reduce human-polar bear conflict in remote locations.
    - Polar bear olfactory preferences; assessing a range of scents for their properties as potential attractants/deterrents.
5. **Improving methods for studying polar bear ecology from tissue samples**
    - Assessing the timing and rate of fur growth in zoo polar bears to improve interpretation of studies of diet, contaminants, and stress hormones in fur.

Polar bear Nora swims in a metabolic chamber as part of an energetics study at the Oregon Zoo. Photo by Michael Durham/Oregon Zoo.

Health and Welfare

Advisor: Dr. Randi Meyerson

Experts: Dr. Dalen Agnew, Michigan State University

Dr. Todd Atwood, USGS

Dr. Jonathon Cracknell, European Association of Zoos and Aquaria

Dr. Wynona Shellabarger, Detroit Zoological Society

Dr. Patricia Pesavento, University of California, Davis

Photo © Daniel J. Cox/NaturalExposures.com

Explanation of the research focus area in relation to polar bear conservation

The Veterinary Medicine Research subcommittee identified health and welfare concerns of wild and zoo managed polar bears, trends in pathology, and the threat of emerging diseases in a warming Arctic as their top priorities. Though the greatest threat to polar bears is loss of sea ice, disease related factors were identified as important criteria both for their 2008 listing under the Endangered Species Act (USFWS, 2008) and for recovery in the 2016 USFWS Polar Bear Conservation Management Plan (USFWS, 2016).

A warming and changing Arctic environment is having significant effects on wild polar bears. Shorter annual periods of sea ice availability, with corresponding shorter periods of time for bears to hunt ice seals, has been associated with declines in body condition, reproductive success, survival, and abundance. Poor body condition decreases immune function, making the bears more susceptible to pathogens, as well as the effects of fat-soluble contaminants, as their fat supplies become depleted. Additionally, a warming environment, with a greater ice-free period, increases exposure to infectious diseases, both through increased concentration of conspecifics and other species affiliated with human settlements, as well as northern migration of novel pathogens and vectors (Fagre et al., 2015). As the loss of sea ice continues unabated, greater exposure to pathogens and parasites has the potential to adversely affect the health of the polar bear populations.

While types of impact, such as starvation, decreased reproduction and immune function, and increased susceptibility to disease are easy to predict; studies of the S. Beaufort Sea polar bears demonstrate that the specific effects on the differing subpopulations are not. Differing lengths of time on shore, types and levels of food source availability, and prior exposure to pathogens were all shown to have significant effect on the health status of individual bears (Atwood et.al 2017; Neuman-Lee et. al 2017).

While a major focus of the polar bear research masterplan is to facilitate ex situ research to help answer in situ questions, the plan also prioritizes the need to continue addressing the health and welfare concerns of the zoo managed polar bear population.

Male polar bear anesthetized for physical examination. Photo by Louisville Zoo.

Examples of work that has happened in zoo settings and how it has complemented or informed our understanding of polar bear biology and management

Gene transcription studies
Studies of gene transcription have been conducted to assess ecological and anthropological stressors (Bowen et.al, 2015). Results revealed immune function impairment in polar bears from the Beaufort Sea, when compared with Chukchi and captive polar bears.

Feeding trials
Studies involving closely monitored feeding trials have been performed to quantify dietary lipid and protein preference in zoo bears, and data have been compared with that from studies of wild bear diets to infer optimal macronutrient intake (Rode et al., 2021). Results indicate that bears should consume more lipid and less protein than previously thought.

Pathogenic studies
Bears in our care, with known health histories, exposure locations and the ability to provide sequential blood samples can provide information related to pathogenic titers (Neuman-Lee et al., 2017; Dutton et al., 2009). Study results have shined a light on the large number of factors that must be considered in interpreting results.

Research Priority Areas

Given the expanse of the study of polar bear health, many of the issues identified in this section of the document will also be included in other areas of the Polar Bear Research Masterplan.

Additionally, this section not only looks at veterinary issues involving wild polar bears, but the health and welfare of bears in human care as well. It is essential that zoo bears are healthy both mentally and physically and display many natural behaviors so that research results are transferable to wild bears.

1. **Veterinary health and welfare:** Although zoos have greatly improved their facilities and care of bears over the years, managed polar bears continue to face several challenges that may have an impact on their welfare. The success of the managed population depends on each individual bear's ability to thrive. Therefore, identifying factors in the physical and social environments that contribute to positive welfare is critical. In addition to being an important conservation education ambassador for climate change, these bears, as participants in conservation relevant research, afford the opportunity to better understand how current and future environmental changes and challenges are affecting or will affect their wild populations as well. Whereas, some areas of study are specific to their wild or captive status, other studies have relevance to both populations.
    - Investigate poor captive reproductive success.
    - Develop effective hand-rearing protocols.
    - Define effective care and management for geriatric bears.
    - Identify common dermatological issues and possible relationships to nutritional status, immune function, reproductive status, and/or water quality.
    - Investigate the polar bears' ability to adapt to higher thermal temperatures.
    - Identify and address behavioral and physiological causative and indicators of stress.
2. **Pathology**
    - Establish/centralize tissue and plasma banks in US and Canada
    - Establish consistent necropsy protocols for field and zoo use which facilitate collaborations and comparisons between zoo managed and wild polar bears. Including "how to" photographic documentation, morphometrics, and the creation of a brief instructional video for necropsy procedures for field biologists.
    - Coordinate retrospective and prospective necropsy data.
    - Standardize sampling techniques in the field and zoos in relation to histology, cytology, virology, toxicology, parasitology, biotoxins, and genetics studies.

Voluntary blood collection from a polar bear. Photo by Como Park Zoo & Conservatory.

Polar bear cub CT scan as part of neurological exam. Photo by Wynona Shellabarger/Detroit Zoological Society.

3. **Emerging diseases**
   - Evaluate potential emerging diseases from vector migration northward as habitat warms- i.e. mosquitoes and West Nile Virus
   - Evaluate disease concerns in their prey species; both availability and possible cross-species transmission.
   - Evaluate increased exposure at the human interface to infectious disease carriers, such as domestic dogs and cats, as polar bears seek out human food caches, and humans move into or spend greater amounts of time in more northern latitudes
   - Evaluate increased exposure to novel species as a sequela to warming (isolation, migration) or translocation (zoos)
   - Establish baseline assessment of infectious disease burden.
   - Establish baseline characterizations of the microbiome and virome.
4. **Technological Advancements for Healthcare**
   - Establish a protocol for indicators/measures of stress- i.e. voluntary blood draw sampling of consecutive cortisol levels after periods of stress to help determine delay period between stressor and blood/fecal/hair cortisol level changes.
   - Development of techniques that permit oiled/ill/injured bears to be treated in situ and/or in close proximity to their natural territory and associated sub-populations.
   - Optimize techniques and training of polar bears for minimally invasive sampling and veterinary treatments.

Studies currently underway or not yet published

1. Evaluation and comparison of Toxoplasmosis gondii titers in wild and zoo polar bears and implications to the health of the polar bears and the Inupiat communities that harvest them. R. Meyerson and W. Shellabarger, Detroit Zoological Society.
2. Investigating the relationship between ambient conditions and thermoregulatory responses in polar bears. L. Graham, WRG Conservation Foundation and Ryerson University.
3. Multi-institutional evaluation of peri-vulvar dermatitis in female polar bears and implications to welfare and health concerns in both zoo and wild bears. E. Curry, Center for Conservation and Research of Endangered Wildlife, W. Shellabarger, Detroit Zoological Society.
4. West Nile titers in zoo polar bears as indicators of threat to wild polar bears in a warming Arctic. R. Meyerson and W. Shellabarger, Detroit Zoological Society.

Physiological and Behavioral Ecology

Advisors: Dr. Karyn Rode, USGS

Dr. Anthony Pagano, Washington State University

Experts: Dr. Thea Bechshoft, Polar Bears International

Dr. John Whiteman, Old Dominion University

Dr. Tom Smith, Brigham Young University

Photo © Daniel J. Cox/NaturalExposures.com

Explanation of the research focus area in relation to polar bear conservation

Understanding the mechanisms by which the current and near-future status of polar bears will be affected by sea ice loss and other ecosystem changes associated with climate change is important for informing management decisions and improving the accuracy of long-term projections. Although information on population abundance and trends are critical, for most polar bear populations the logistical limitations of gathering data from a species that occupies a very large home range throughout remote regions of the Arctic precludes estimation of population parameters. Thus, management decisions often must be made based on inference of population dynamics based on bear health, nutritional condition, behavior, and ecology. Further, as sea ice loss has become the primary threat facing polar bears, there is an increased need to understand mechanistic relationships between sea ice loss and polar bear population dynamics to improve short-term and long-term projections. Thus, increasingly polar bear studies have focused on understanding behavioral responses to sea ice loss and physiological limitations in their ability to adapt. To accommodate those studies, new methods are needed. Polar bears in zoos provide an excellent opportunity for development of new methods to monitor polar bear behavior and physiology in the wild and to better understand the physiological limitations of the species.

Examples of work that has happened in zoo settings and how it has complemented or informed our understanding of polar bear biology and management

In recent years, a number of studies of polar bear physiological and behavioral ecology have been conducted in zoos, with findings being applied to better understanding polar bears in the wild. These include:

Validation of activity sensors

Validation of activity sensors in collars for identifying polar bear behavior including differentiating resting versus active behavior from archived polar bear activity sensor data (Ware et al. 2015; 2017) and classifying swimming, walking, and resting behavior using more recently developed tri-axial accelerometers (Pagano et al. 2017).

Quantifying stable isotopes

Quantifying routing of stable isotopes in polar bear diets into tissues to use samples of polar bear blood and hair from wild polar bears to estimate diets (Rode et al.

2016). This information will allow detection of dietary changes over time that may be associated with sea ice loss or other environmental changes. Because diet can affect exposure to contaminants and pathogens (McKinney et al. 2009, 2017), dietary change is an important component of understanding potential cumulative effects of ecological change.

Measuring metabolic rates

Measuring metabolic rates of polar bears while walking and swimming (Pagano et al. 2018 b, c). This information is important to understanding the energetic costs of behavioral changes and variation in polar bears. For example, polar bears have been documented to increasingly swim long distances in the southern Beaufort Sea during the annual sea ice minimum (Pagano et al. 2012). Additionally, changes in patterns of sea ice drift have been shown to increase the rate of walking polar bears must maintain to travel (Durner et al. 2017). Data on metabolic rates will allow quantification of the impacts of such changes.

Chemical communication

Studying polar bear chemical communication to better understand social behavior, including breeding (Owen et al. 2015). Little has been known about how polar bears communicate and maintain social relationships out on the sea ice. Habitat fragmentation associated with sea ice has been identified as a potential factor that could disrupt breeding behavior in the spring. This study provided baseline information needed in better understanding potential implications of changing habitat conditions on social interactions.

Hearing sensitivity in polar bears

Concerns regarding the spatial and temporal overlap of oil and gas activities and maternal denning on Alaska's North Slope led to initiation of a studying of hearing sensitivity in polar bears. These baseline data (Owen & Bowles 2011) can be used to develop biologically relevant protective guidelines for industrial/human activity in sensitive polar bear habitat (Owen et al. 2021)

Female polar bear Tatqiq swimming in her pool at the San Diego Zoo while participating in a study designed to validate collar-mounted activity sensor data. This study, co-led by USGS and the UCSC, contributed to the behavioral classification of data generated by both tri-axial accelerometers and mercury tip-switch sensors. Photo by San Diego Wildlife Alliance.

Priority areas that should take precedence within this research area

While it is difficult to foresee the variety of ways polar bears in zoos could help to better understand the behavioral and physiological ecology of polar bears, some recent themes have emerged as important contributions that could be made in the coming years.

1. Improve and validate methods for monitoring exposure to stressors and the state of chronic stress via cortisol in hair and urine or other metrics from blood.
2. Identify the seasonal timing of hair growth and rates of growth and the factors that affect these metrics, such as food intake, nutritional condition, size, age, sex, and environmental conditions in order to improve use of hair as an ecological monitoring tool for wild polar bears.
3. Continue to improve estimation of energetic costs in polar bears including identifying the primary factors affecting these costs, such as sex, age, and environmental conditions. These efforts should include quantification of the energetic costs of reproduction, lactation, and growth.
4. Develop a detailed understanding of social communication in polar bears and determine how rapid environmental change may compromise mate search, courtship, social spacing and maternal care.
5. Identifying stimuli to both attract and deter polar bears. Attractants would be invaluable for improving capture rates for hair sampling devices. Studies of deterrents may be invaluable for improving co-existence for human activities in polar bear habitat.
6. Better understand macro and micronutrient requirements, including relationships between intake and weight gain, in order to better understand implications of changing diets.

Columbus Zoo bear sniffing meat in feeding trial. Photo by Devon Sabo.

7. Describe the range of maternal care behaviors that are correlated with successful cub rearing.

Work currently proposed, underway or not yet published

Several studies are currently underway, including a study of hair growth rates, a comparison of micronutrients in polar bear serum between wild and zoo bears, an evaluation of optimal dietary macronutrient ratios, estimation of stable isotope discrimination in the lipid and protein components of blood serum, and a study of bear behavior for improving hair collection.

Reproduction

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Explanation of the research focus area in relation to polar bear conservation

A reduction in the availability of Arctic sea ice upon which polar bears hunt is resulting in decreased female body weights (Stirling et al. 1999; Rode et al. 2010; Obbard et al. 2016), is predicted to result in increased reproductive intervals (Derocher and Stirling, 1994), and to negatively impact litter sizes (Molnar et al. 2011). Reproductive success is essential to species survival, and reduced fecundity is often a precursor to a population's decline. Given the impending crisis facing wild bears, the advancement of reproductive monitoring techniques will provide enhanced methodologies necessary to better determine how the species is coping with the changing environment.

Anthropogenic impact, such as human-induced climate change and environmental contaminants, may impact fertility of polar bears, but the ability to assess the intricacies of reproduction in this species is hindered by a lack of monitoring methods. In females, there is no established technique for diagnosing pregnancy or distinguishing true pregnancy from pseudo-pregnancy; therefore, frequency of pregnancy loss cannot be determined. In males, there are challenges associated with the collection of semen, so knowledge of baseline gamete biology is deficient. The zoo managed population of polar bears provides valuable opportunities to develop improved monitoring approaches that may enhance our understanding of how various factors impact the reproductive physiology of wild bears. Because samples can be collected regularly from the ex situ population, the concentrations and fluctuations of specific hormones and biomarkers can be characterized in controlled settings and throughout the lifetime of an individual, an impossible endeavor when considering the wild population. Information gained from studying zoo bears may allow for more accurate assessments of the reproductive physiology of wild populations and may provide insights into how variables such as body condition, environmental contaminants, and human disturbances may impact reproductive processes of in situ populations.

Examples of work that has happened in zoo settings and how it has complemented or informed our understanding of polar bear biology and management

A growing number of reports have stemmed from research of the ex situ population and have provided insight into the medley of reproductive phenomena experienced by this species:

Non-invasive monitoring methods to better characterize reproductive processes

Fecal and urine progesterone and testosterone metabolite analyses have yielded understanding of ovarian activity, including timing of ovulation and re-activation of the corpus luteum in females

An ultrasound examination is conducted on an anesthetized female polar bear. Photo by Seneca Park Zoo.

that have bred. Progestogen analysis of females which were housed without males or with non-intact males has provided verification that true pseudopregnancy does exist in this species (Stoops et al., 2012, Steinman et al., 2017, Knott et al., 2017) and indicates that progesterone concentrations alone cannot be used to infer pregnancy status. Seasonal and reproductive impact on fecal glucocorticoid (FGC) excretion was studied in a small group of pregnant and pseudopregnant bears (Bryant and Roth, 2018). Glucocorticoid patterns varied among individuals and were not consistent within pregnancy status or across seasons. Fecal protein analyses indicated that the concentrations of specific proteins and protein fragments may be significantly higher in pregnant versus pseudo-pregnant females (Curry et al., 2012); however, additional research is needed to determine if fecal proteins may provide an accurate, reliable pregnancy test. Similarly, in a study aimed to determine if odor detection dogs could distinguish fecal samples originating from pregnant versus non-pregnant polar bears (Curry et al., 2021), the dog alerted on novel samples collected from pregnancies on which he was trained, but he failed to generalize to novel pregnancies. Fecal testosterone analysis showed that testosterone concentrations are significantly higher during the breeding season and that males housed with females exhibit higher testosterone than those housed without females, indicating that testosterone concentrations may be influenced by the presence of sexually mature females (Curry et al., 2012).

Defining breeding season and assessing reproductive behaviors

An investigation of multi-institutional records has defined the polar bear breeding and cubbing seasons: 85% of matings occurs between 12 February and 8 April (Curry et al., 2012) and 74% of litters were born between 13 November and 15 December, with mean and median litter birth dates of 29 November (Curry et al., 2015). Because entire mating bouts are difficult to observe, and the precise day of parturition is unknown in wild bears, detailed descriptions of breeding and parturition dates in zoos may be useful in characterizing the reproductive seasonality of this species.

Semen collection and cryopreservation

Performing urethral catheterization in males anesthetized with medetomidine results in a sperm recovery rate of 87% in the breeding season and 30% in the non-breeding season (Wojtusik (in prep), Curry 2016 and 2017). These methods are field-friendly and potentially could be used to assess sperm parameters of wild bears while also providing valuable genetic material for long-term storage. The effects of various semen extenders and sperm cryopreservation methods are being studied, and a polar bear sperm bank has been established. Current cryopreservation methodologies result in a post-thaw sperm motility rate of up to 60% (unpublished; CREW).

Polar bear sperm. Photo by Cincinnati Zoo & Botanical Garden.

Priority areas that should take precedence within this research pillar

The reproduction research priorities are focused on three strategies which are in alignment with the Polar Bear Research Council's mission: 1) Use the ex situ population to better characterize basic reproductive physiology and improve monitoring techniques for comparison and application to in situ polar bears; 2) conduct research that is necessary for maintaining a viable, sustainable ex situ population for scientific research with application to wild bears; and 3) preserve the extant gene pool to prevent loss of genetic diversity that could occur due to environmental changes.

1. **Improve and expand reproductive monitoring capabilities:** Although fecal steroid metabolite analysis provides insight into reproductive processes, no definitive diagnostic indicators of ovarian activity and pregnancy have been validated. Efforts should be made to further investigate non-invasive (feces, urine, saliva, other) and minimally invasive (serum) biological matrices and novel approaches to expand and improve the ability to monitor reproductive processes. Specific areas that warrant research are: methods to diagnose and monitor pregnancy, including points of pregnancy failure; characterization of ovarian dynamics, including the stimulus required for ovulation; evaluation of steroid hormones and biosynthesis pathways; investigation of temporal trends in non-steroid hormones, and; examination of biomarkers of metabolism and their relationships to reproduction.

2. **Identify factors impacting reproductive success:** It is generally unknown why some zoo managed bears produce cubs and others do not, despite exhibiting seemingly normal copulatory behaviors. Identifying factors or management strategies among individuals and institutions that experience reproductive success may allow predictions to be made on potential causes of reproductive failure in wild bears. Maintaining a viable ex situ population is essential in serving a wide range of conservation-relevant research needs, but currently, the ex situ population is not self-sustaining due to low reproductive success in recent years. Research needs include: understanding optimal body condition and nutritional needs for cub production; determining the influence of environmental contaminants on reproductive processes; identifying exogenous and/or endogenous cues for regulation of emergence from embryonic diapause; evaluating housing and/or management strategies, including light and noise pollution, on reproductive behavior and cub production; evaluating the genetic relatedness of individuals in zoos, and; developing and utilizing assisted reproductive technologies (ART) to maintain a research population and to preserve valuable genetics.

3. **Assess reproductive anatomy and gamete biology:** There is limited data on the basic anatomy of polar bear reproductive systems and pathologies that may impact reproductive processes. Immobilizations and necropsies provide opportunities to visualize and evaluate reproductive tracts, assess pathologies, collect and cryopreserve gametes to preserve valuable genetic material, and preserve tissues collected post-mortem.

Reproductive studies currently underway or not yet published

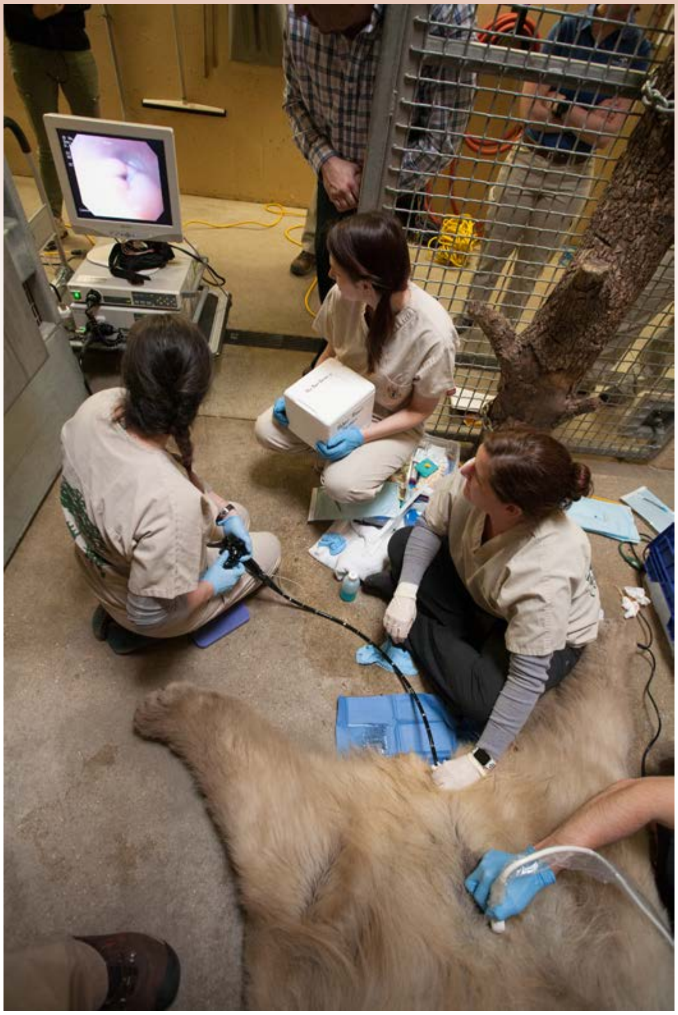
Non-invasive monitoring: Fecal steroid metabolite changes associated with sexual maturation (CREW, manuscript in prep); Dehydroepiandrosterone (DHEAS) quantification in feces collected from both zoo and wild bears (Brandhuber, U of Alaska Fairbanks); quantification of testosterone concentrations in group-housed vs. solo housed male polar bears (McCart, York University); PGFM quantification in parturient vs. non-parturient bears (CREW).

Pregnancy diagnosis: Investigation into specific fecal proteins as biomarkers of pregnancy using sequential window acquisition of all theoretical ion fragments (SWATH; CREW); fecal volatile organic compound (VOC) analysis (collaboration between CREW and Dr. Wilson at University of Saskatchewan); fecal metabolomics profiling (collaboration between CREW and Cincinnati Children's Hospital Medical Center)

Serum hormone analysis: Quantification of Anti-Mullerian hormone (AMH) concentrations by sex, season, age, and fertility status (Tompros/CREW); development of a multi-plex serum panel to measure leptin, prolactin, FSH, LH, kisspeptin, melatonin, and Vitamin D in serum banked from zoo bears (Wojtusik/CREW).

Identifying factors impacting reproduction: Long-term effects of contraception on reproduction in polar bears (CREW, manuscript under review); nutrition and body weight during pregnancy (Toronto Zoo, in process).

Physiological assessments of reproductive systems: Semen collection and cryopreservation, both at physical examinations and post-mortem/post-castration (CREW, Toronto Zoo); evaluation of semen extenders (CREW, Toronto Zoo); laparoscopy and ultrasonography of the female polar bear (Justine O'Brien, SeaWorld & Busch Gardens Reproductive Research Center (SWBGRRC), Todd Robeck (SWBGRRC), and Dean Hendrickson (Colorado State); vaginal endoscopy, endocrine data (paired fecal and urine), and AI (Justine O'Brien, Karen Steinman (SWBGRRC), and CREW); histopathology of reproductive tracts collected post-mortem (Agnew & Shellabarger); assessment of prevalence of perivulvar dermatitis in zoo bears (Shellabarger).



Researchers perform a fertility exam and artificial insemination procedure. Vaginal endoscopy allows visualization of the cervix. Photo by Henry Vilas Zoo.

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Back cover: Polar bear at the Cincinnati Zoo & Botanical Garden. Photo by Tom Uhlman.