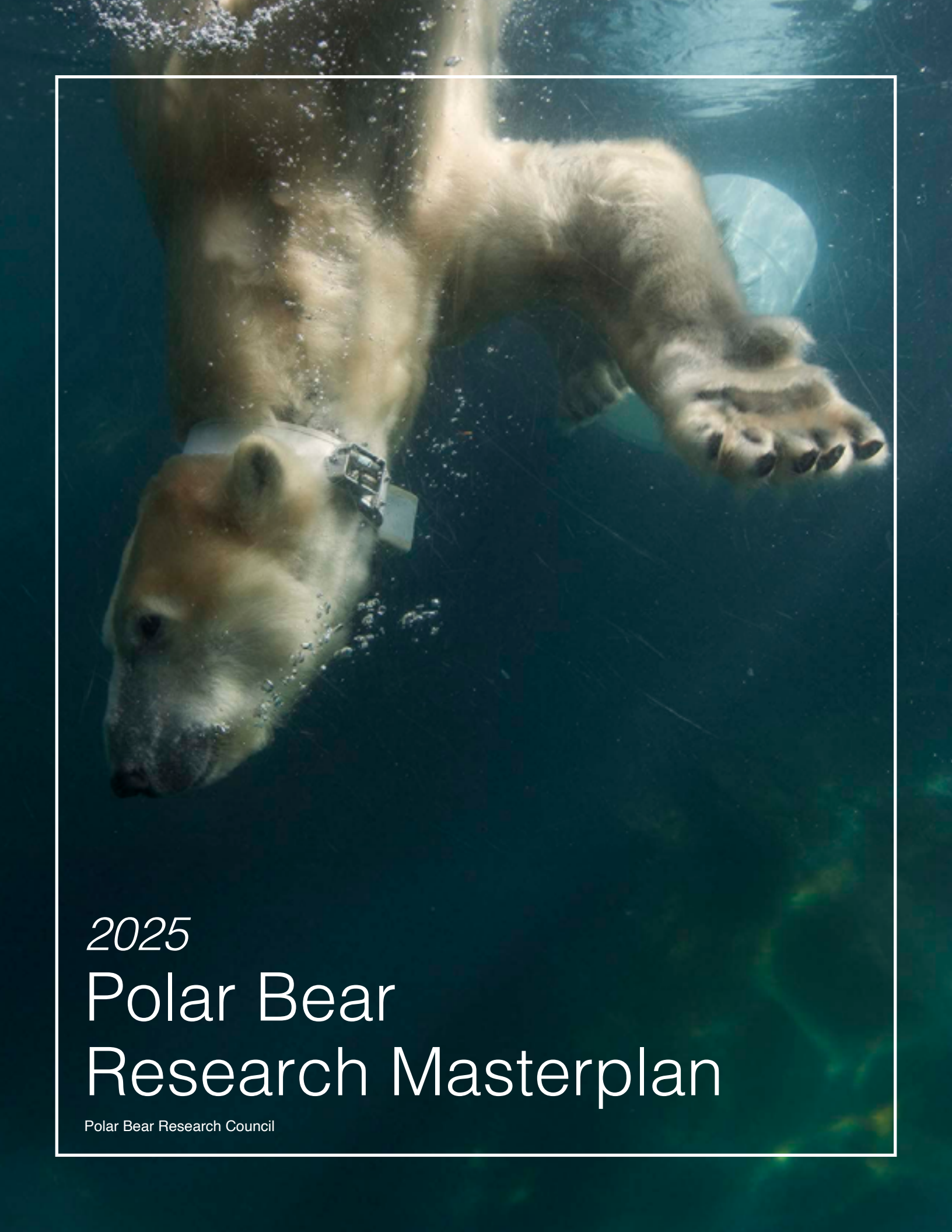

2025

Polar Bear Research Masterplan

Polar Bear Research Council

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Cover photo: One of three zoo bears that participated in a project to validate accelerometer data collected by satellite linked collars. This enabled USGS researchers in Alaska to confidently decode the behavior of wild bears wearing similar collar sensors.
Photo: San Diego Zoo

Left: a polar bear, trained to wear a research collar, helps calibrate collar-mounted accelerometer device.
Photo: Oregon Zoo

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Masterplan Design By: Jenna Beckley; Polar Bears International

Introduction

By Dr. Karyn Rode

Polar bears range over some of the most remote places in the world, traveling on sea ice that floats over the Arctic Ocean and associated seas and bays. They have the largest home range of any terrestrial carnivore. Thus, it is not surprising that studying these animals and knowing how their populations are faring in response to Arctic sea ice loss is a tremendous challenge. In the past 15 years, zoos have stepped up to the plate to partner in dramatically improving our understanding of this species. In doing so, they have helped provide information on polar bears that has been key to long-term management and conservation.

I know these challenges and the tremendous value of studies with polar bears in zoos because it's my job as a research wildlife biologist with the US Geological Survey to answer questions about polar bears that are needed to inform their management and conservation. In 2008, in partnership with the US Fish and Wildlife Service we began a study of polar bears in the Chukchi Sea, a population that ranges between the northwest coast of Alaska and eastern Russia. At best we hoped to be able to find, sedate, and measure enough bears to get a sense for how the population might be coping with substantial declines in summer sea ice since the 1970s. Simultaneously, we began a partnership with the Oregon Zoo, who had begun training their polar bears for blood draws. This effort opened the door to a variety of studies that allowed us to obtain more specific information about polar bear health and diet from blood samples we collected from wild polar bears. As conversations between research scientists and zoo staff increased, there was the realization that there was a whole lot more that could be done in studies with bears at zoos to improve methods for studying bears in the wild, thereby improving the information available to support their conservation and management.

Since that time, a large suite of studies has been conducted at zoos that have helped us better understand their requirements and improve our ability to monitor them in the wild. Many of those studies are captured here in the Polar Bear Research Council's Master Plan. In the Chukchi Sea, spring sea ice has reached new record lows. We no longer have the ability to monitor this population as we have since 2008. Unstable and unpredictable sea ice make it unsafe to sedate, collar, and sample bears on the sea ice. Here again, we have turned to zoos to help develop a new approach and adapt to changes in our ability to access and study polar bears. Zoos throughout the US have partnered to develop a method for using aerial and ground-based imagery to estimate polar bear body condition and size, key indicators of reproduction and cub survival.

The AZA Polar Bear Research Council plays a key role in building the capacity of zoos to maintain staffing and capability to support research and prioritizing research efforts to maximize their impact in support of management and conservation of polar bears in the wild. They have committed to a consistent, organized effort partnering closely with scientists and management agencies to ensure that their efforts have the greatest possible impact. This updated Masterplan exemplifies this commitment.

Dr. Karyn Rode
Research Wildlife Biologist,
U.S. Geological Survey
Alaska Science Center

The Polar Bear Research Council

The Polar Bear Research Council (PBRC) is an ad hoc group dedicated to advancing polar bear research in North American zoos and aquariums. Established in 2018, the PBRC brings together zoological professionals, veterinarians, agency and zoo scientists, academic researchers, and a facilitator from Polar Bears International. This diverse collaboration aims to enhance the coordination of research efforts in managed care settings, ultimately supporting the conservation and management of wild polar bear populations.

The PBRC is composed of a Steering Committee that includes two Co-Chairs, a Facilitator and the Association of Zoos and Aquariums' (AZA) Polar Bear Program Leader. Additional members include advisors who coordinate activities within priority research areas. These advisors are responsible for recruiting input from additional expert consultants (typically 3-6) in their field who can provide additional unique perspectives.

Mission

To encourage and contribute to the coordination of research efforts with polar bears in zoological facilities that inform in situ conservation and enhance the health and welfare of the species.

Rationale

Studying polar bears in their natural habitat poses significant challenges. Factors such as high cost, geopolitical issues and regulations, harsh environments, limited accessibility, and the bears' wide-ranging distribution create logistical barriers. Additionally, a growing emphasis on less invasive research methods further complicates data collection. While understanding population abundance and trends is essential for conservation, these challenges often make traditional population assessments impractical. Consequently, management decisions are often made based on inference of population dynamics based on bear health, nutritional condition, behavior, genomics, and ecology. Further, as sea ice loss continues to be the most pressing threat to polar bears, there is an urgent need to understand the mechanistic relationships between sea ice changes to population dynamics. Strengthening these connections is crucial for improving both short- and long-term population projections and guiding effective conservation strategies.

A polar bear voluntarily offers its paw for a trained blood collection behavior.
Photo: Como Park Zoo and Conservatory.

Ex situ polar bears provide a valuable and unique alternative to advance polar bear conservation science. Zoo- and aquarium-housed polar bears can be trained via operant conditioning to voluntarily participate in hands-on procedures, facilitating longitudinal biological sampling. Through multi-institutional collaborations, scientists can recruit larger sample sizes that ensure statistical significance in studies on behavior, physiology, health, reproduction and welfare, and new technologies/methodologies can be trialed and validated prior to their use on wild bears. Appendix B details the types of samples and data regularly collected from zoo-housed polar bears as part of routine health monitoring and husbandry; for these activities, additional research permitting by USFWS is not required.

Over the past 25 years, the zoological community has steadily increased participation in priority research projects that inform critical conservation and management questions that exist for polar bears in situ. To maintain a robust research program, institutions must support a viable ex situ population, prioritize individual animal welfare, and ensure suitable candidates are available for scientific studies. Additionally, institutions must ensure that staff are trained in sample collection and animal training techniques, and that facilities are designed to accommodate sample collection and/or research.

Purpose of the PBRC

The specific objectives of the PBRC are to:

- Evaluate, critique, endorse, and promote research proposals utilizing polar bears in zoos and aquariums;
- Support researchers in working with the zoo and aquarium community;
- Compile and share peer-reviewed publications resulting from studies with polar bears in zoos and aquariums;
- Increase capacity for, and remove barriers to, polar bear conservation science in zoos and aquariums, and;
- Demonstrate the significant contributions of zoological-based science to polar bear recovery efforts.

The PBRC aims to focus research efforts on those most feasible in zoological institutions and that meaningfully contribute to polar bear conservation and management. Many of the completed studies in these disciplines would not be possible in the wild. The three research pillars selected are those where information gaps exist that can be addressed through ex situ activity and are feasible in the zoo and aquarium context:

- Physiological and behavioral ecology
- Health, reproduction and welfare
- Field techniques

The purpose of the PBRC Research Masterplan document is to:

- Guide research priorities for the AZA population of polar bears and participating institutions, providing a clear framework for future studies;
- Communicate research opportunities to potential investigators, encouraging collaboration; and
- Highlight the progress achieved through scientific studies of managed polar bears, showcasing the valuable contributions these efforts make to conservation.

The Masterplan is a living document that will be formally updated every three to five years. This masterplan is the 3rd revised version of the original masterplan published in 2018.

AZA Polar Bear Research Council

PBRC Co-Chairs:

Dr. Erin Curry, Center for Conservation and Research of Endangered Wildlife (CREW), Cincinnati Zoo & Botanical Garden; *email: erin.curry@cincinnatizoo.org*
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AZA Polar Bear Coordinator:

Allison Jungheim, Como Park Zoo and Conservatory; *email: allison.jungheim@ ci.stpaul.mn.us*

Priority research pillars and corresponding advisors and consultants:

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Health, Reproduction, and Welfare Advisors

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

Physiological and Behavioral Ecology Advisor

Dr. Anthony Pagano, US Geological Survey; *email: apagano@usgs.gov*

Graduate Student Member

Sarah Teman, PhD Candidate, University of Washington, *email: steman@uw.edu*

Male polar bear in Churchill, Manitoba.
Photo: BJ Kirschhoffer

Field Techniques

In-field monitoring and management techniques

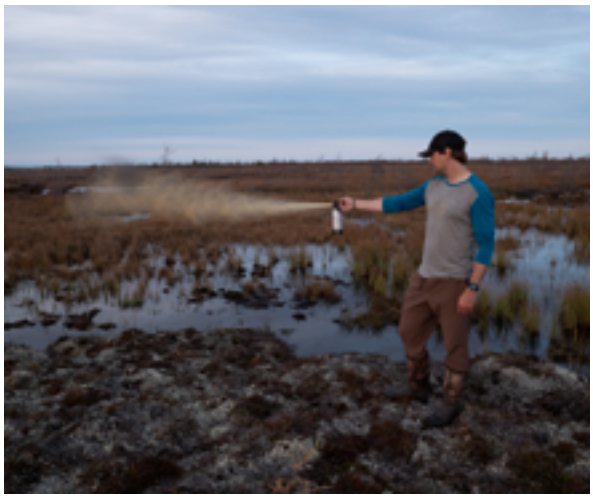
Advisor	**Dr. Stephen Petersen, Assiniboine Park Zoo**
Experts	**Liz Larson, Utah's Hogle Zoo** **Alysa McCall, Polar Bears International** **Dr. Nicholas Pilfold, San Diego Zoo Wildlife Alliance** **Dr. Tom Smith, Brigham Young University** **Lindsey Mangipane, US Fish and Wildlife Service**

Scientists collect data to develop laser photogrammetry body condition assessments at the Memphis Zoo.
Photo: Lindsey Mangipane, USFWS

Relation of the research focus area to polar bear conservation

Studying polar bears in the wild poses logistical and safety challenges for both polar bears and researchers. These factors often hinder effective research and conservation efforts but technical and technological advances can play a vital role in overcoming these challenges. New, safer methods can be implemented in the field with greater confidence when they have been developed in collaboration with institutions that have polar bears in their care. Polar bears who participate in scientific studies in a controlled environment, and can be repeatedly observed, monitored, or examined to ensure safety. 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 groups is also interested in methods that solve challenges where humans and polar bears overlap in their activities. Polar bear interaction with human settlements presents considerable challenges related to coexistence and work with polar bears in human care on methods to detect, deter, and protect polar bears can be developed and be nearly field-ready before being deployed. This will reduce the chance of failure, and increase the chances that field methods are effective.

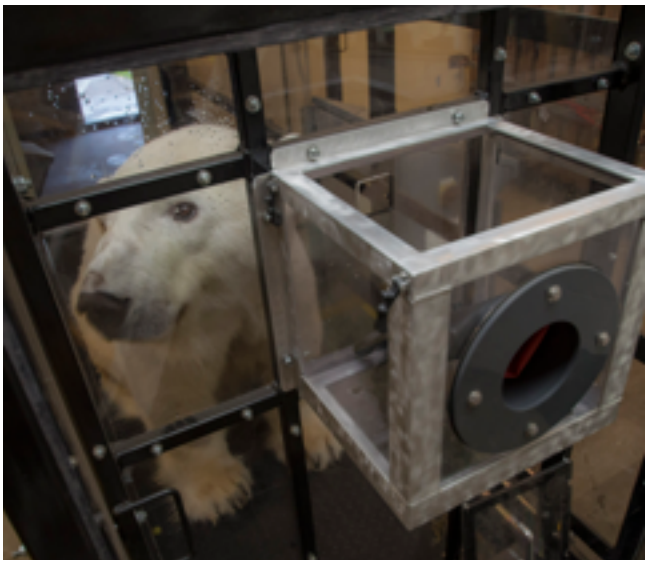


A person testing bear spray in Churchill, Manitoba.
Photo: Kt Miller

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.



A polar bear learns to walk on a treadmill in an enclosed space to measure the metabolic costs of locomotion.
Photo: Oregon Zoo

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.

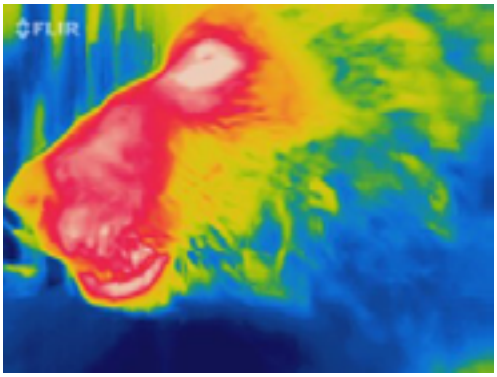
This allowed scientists to record how the bear was moving at as well as the amount of energy they were expending. This information was then used to predict energy use in wild bears.

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

A method to accurately measure the heart rate and respiration rate of polar bears via infrared thermography video analyses was validated in zoo bears. This new tool provides a non-invasive means of monitoring health of wild populations (Rzucidlo et al., 2023). Additionally, 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



Infrared thermography image of a male polar bear. Photo: Dylan McCart and Dr. Michelle Shero

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 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 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.

- **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 shifting 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).

- **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-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.

- **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.

Left: Burr-On-Fur Tracker on a bear at the Point Defiance Zoo. Photo: Emily Ringer

Right: Ear Tag on a wild polar bear. Photo: Andrew Derocher

- **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.

- **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.

Work currently underway or not yet published:

Population assessment

- Collection of aerial thermal images of polar bears to train machine learning algorithms to detect polar bears in seal surveys.

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.

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.

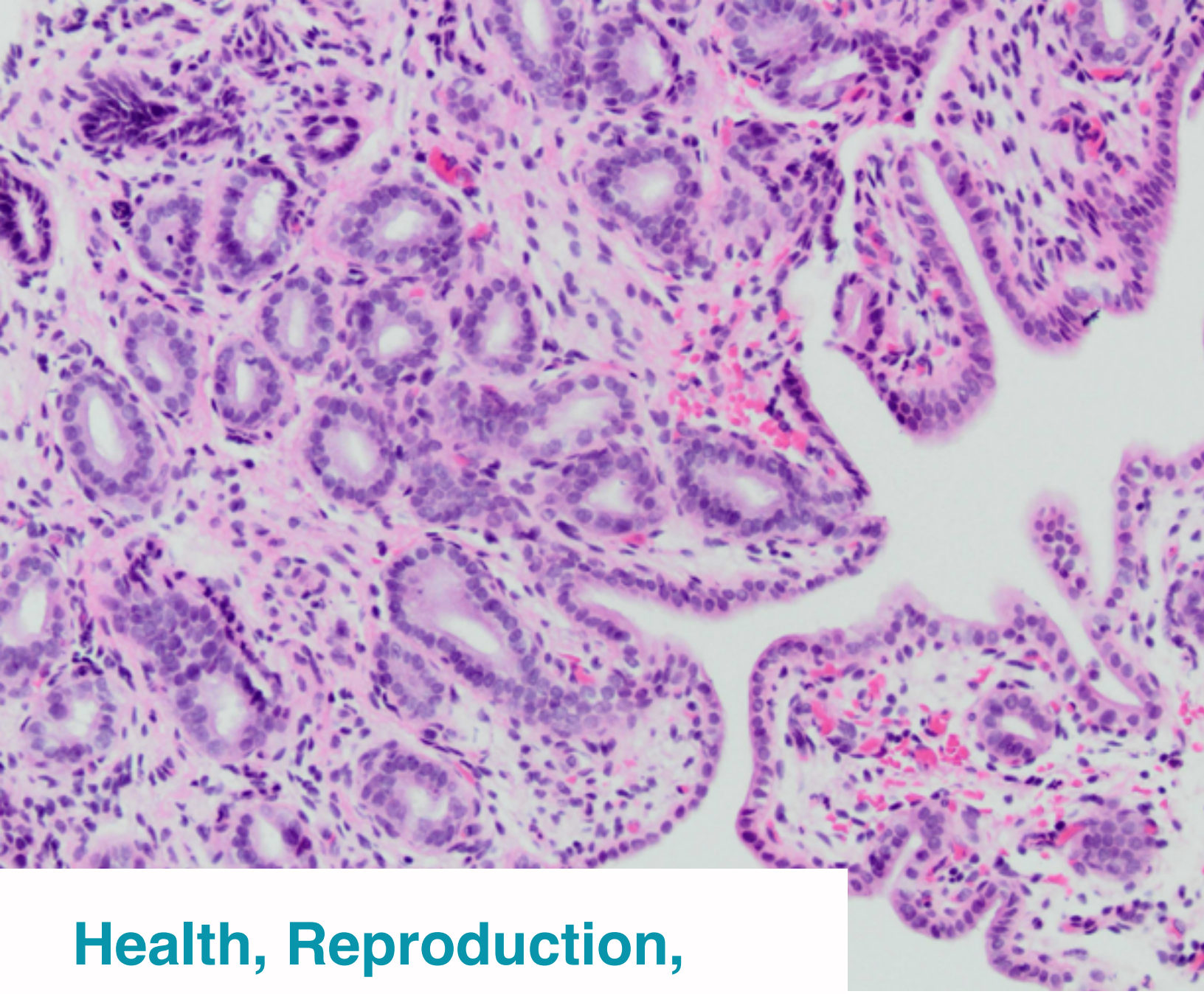
Polar bear/human coexistence

- 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.

PBI Beardar tower collecting data points at the Assiniboine Park Zoo.
Photo: Handcraft Creative

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.



Health, Reproduction, and Welfare

Advisors	**Dr. Hendrik Nolleson, San Diego Zoo Wildlife Alliance** **Dr. Erin Curry, CREW/Cincinnati Zoo & Botanical Garden**
Experts	**Dr. Dalen Agnew, Michigan State University** **Dr. Todd Atwood, USGS** **Dr. Karyn Rode, Research Wildlife Biologist, USGS, Alaska Science Center** **Dr. Patricia Pesavento, University of California, Davis** **Dr. Wynona Shellabarger, Detroit Zoological Society**

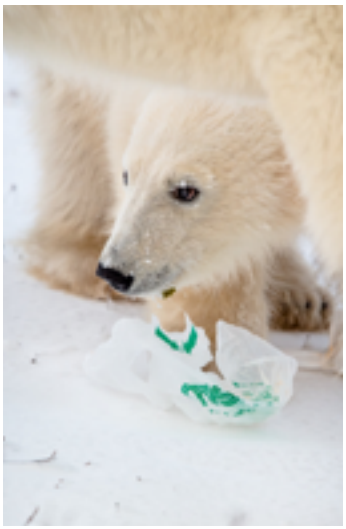
Endometrial biopsies help diagnose and understand reproductive pathologies. Photo: Cincinnati Zoo's CREW

Relation of the research focus area to polar bear conservation

Polar bear health is affected by a warming and changing Arctic environment. Polar bears rely on sea ice as a platform to hunt their prey, raise their young, mate, den, travel, and rest. However, the warming climate and accompanying loss of sea ice has affected the ability for polar bears to carry out these necessary life functions. Multiple stressors, arising from or worsened by the loss of sea ice, significantly affect polar bear health at both the individual and population levels.

There have been many scientific studies documenting these impacts. For instance, shorter annual periods of sea ice availability, with corresponding shorter periods for bears to hunt ice seals, have been associated with declines in population vital rates, including nutritional condition (Rode et al. 2010), recruitment (Rode et al. 2010), and survival (Regehr et al. 2009). Reduced foraging opportunities on the sea ice have caused some polar bears to spend more time on land in search of human-provisioned resources (Atwood et al. 2016a). Moreover, land-based food resources are likely insufficient for supporting polar bears' energetic needs (Rode et al. 2015, Pagano et al. 2024). In addition, land use can increase bear's risk of exposure to terrestrial zoonotic pathogens and developing disease (Atwood et al. 2017).

Yet, bears that remain on the sea ice are also at risk of pathogen exposure as the changing climate drives the expansion of pathogens into the Arctic (Atwood et al. 2017). The impact of immune and nutritional stress on polar bear health may be intensified by exposure to high levels of bioaccumulating contaminants, with polar bears carrying some of the highest concentrations (Routti et al. 2019). In fact, such contaminants may cause endocrine disruption and reproductive pathology (Routti et al. 2019). Further, a growing industrial presence in the Arctic has the potential to disturb bears' natural behaviors and cause physiological stress, contributing to poor health (Atwood et al. 2016b).



A polar bear cub with a plastic bag.
Photo: Meril Darees

A holistic approach towards understanding polar bear health is needed to support conservation goals (Patyk et al. 2015). Monitoring polar bear health is crucial for forecasting how bears will respond to the challenges posed by climate change. Increasingly, information on wildlife health is being incorporated into management and decision making (Deem et al. 2008). Knowledge of polar bear health is important for government management agencies and Indigenous co-managers, the latter of whom depend on polar bears for subsistence hunting and cultural traditions.

Based on a 2024 survey conducted by PBRC of 13 biologists or veterinarians whose in situ and ex situ work aims to conserve polar bears, the top three direct threats to in situ polar bear health are:

1. Reduced food intake interacting with increased energy requirements;
2. Disturbance from increased industrial activities in the Arctic; and
3. Exposure to pathogens and contaminants, and subsequent diseases.

Examples of work that have occurred in zoo settings and how these have informed our understanding of polar bear health:

Reproduction

Scientists and veterinarians routinely perform reproductive health assessments on captive polar bears to understand reproductive status, anatomy, and physiology (Curry et al. 2024, Aldrich et al. 2024, Wojtusik et al., 2022). Longitudinal, non-invasive monitoring of zoo bears has provided insight into temporal trends of reproductive hormones and their seasonal changes (Stoops et al. 2012, Curry et al. 2012), how they fluctuate at sexual maturation (Wojtusik et al., 2024), and during pregnancy or pseudopregnancy (Stoops et al., 2012; Brandhuber et al. 2023). Additionally, the review of zoological records has helped to define the breeding season (Curry et al., 2012) and cubbing season (Curry et al. 2015). The findings from this research may help inform studies of reproductive success in wild polar bears.

Zoo veterinary staff examine a polar bear during a routine medical exam.
Photo: Katie G. Cotterill/Point Defiance Zoo and Aquarium

Genetics

Studies of gene transcription have been conducted to assess the physiological effects of ecological and anthropogenic stressors (Bowen et al. 2015). Results revealed immune function impairment in polar bears from the Southern Beaufort Sea, when compared with Chukchi and captive polar bears. This study highlights the importance of developing population- and region-specific conservation efforts to mitigate health impacts.

Nutrition

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. This study emphasizes the importance of wild polar bears having access to abundant, fatty seals to support their overall health.

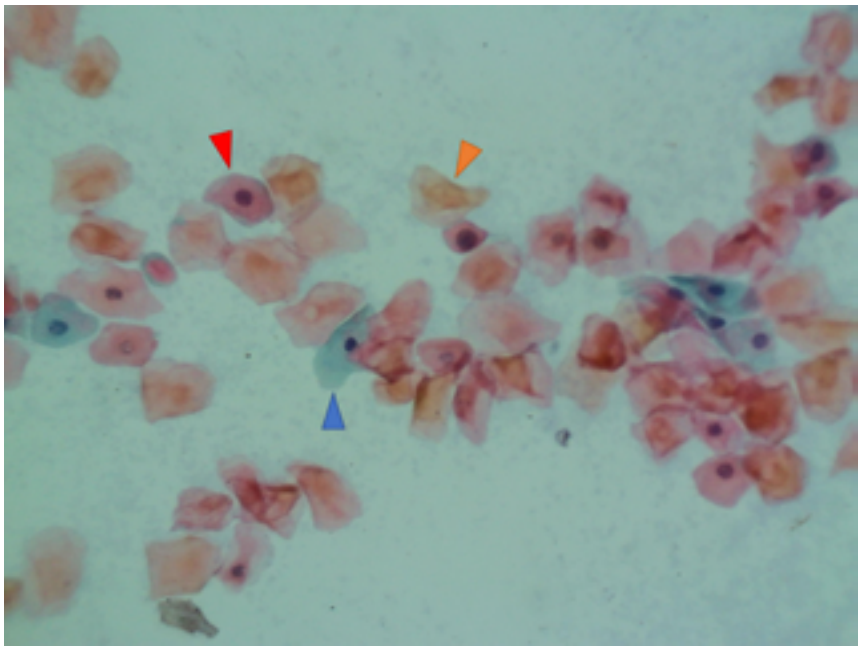
Pathogen studies

Bears in human care, with known health histories and the ability to provide routine blood samples, can aid in studies examining pathogen titers and seroprevalence (Neuman-Lee et al.)

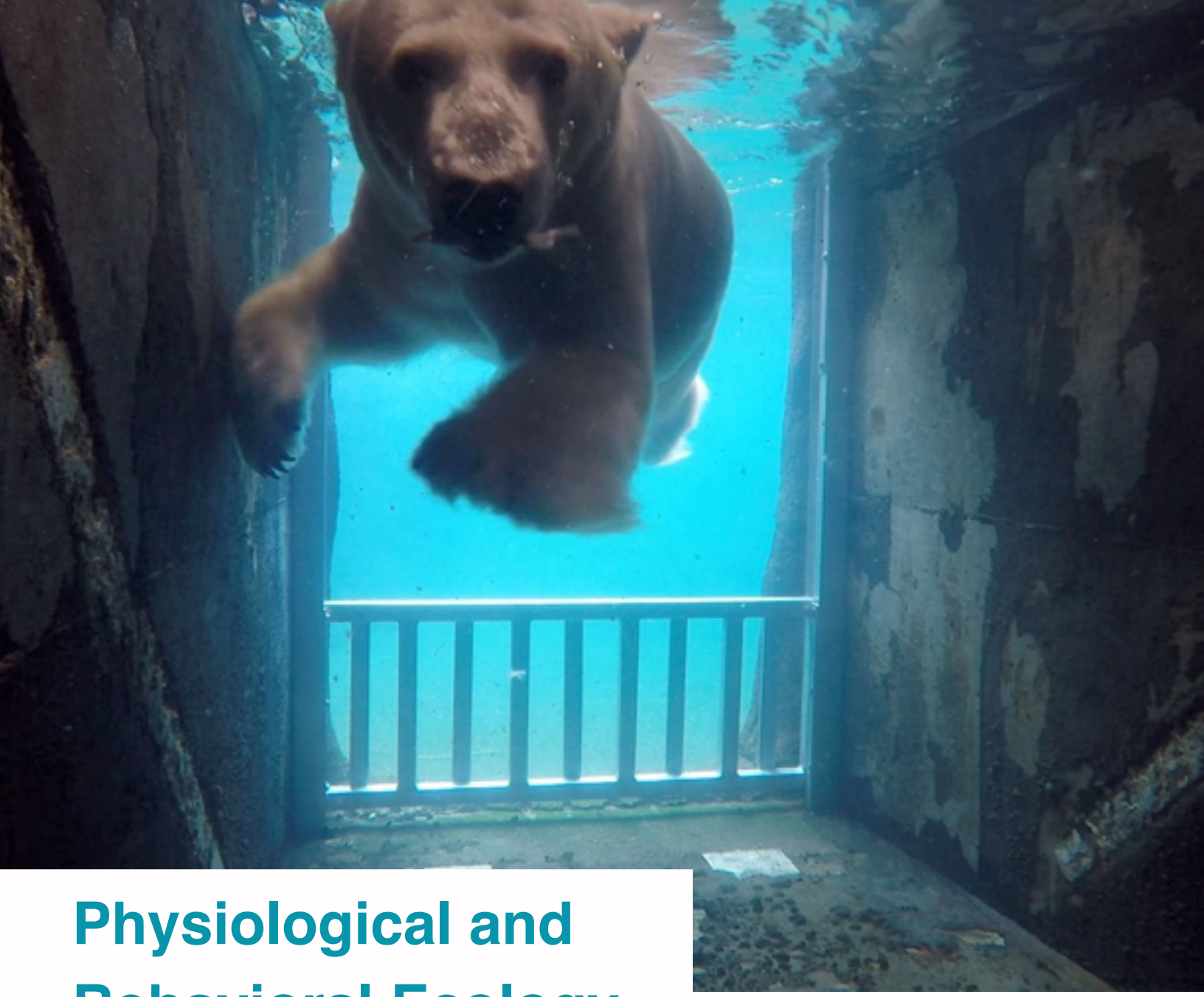
A polar bear is given the opportunity to self-select high protein or high fat items in a macronutrient diet trial
Photo: Devon Sabo, Columbus Zoo and Aquarium

Studies currently underway and not yet published:

- The Center for Conservation and Research of Endangered Wildlife (CREW) at the Cincinnati Zoo & Botanical Garden has validated and quantified ~25 hormones that signal nutritional, immune, endocrine, and reproductive status, using serum samples collected from zoo-housed polar bears. The next phase of this project will uncover associations between hormone signatures and specific disease states (PIs: E. Curry, E. Virgin, J. Wojtusik)
- Oregon Zoo is validating a point-of-care analyzer for measuring thyroid hormones in polar bears (PI: G. Huckins). This will help to establish reference ranges of thyroid hormones and will enhance our understanding of seasonal fluctuations of hormones.
- The University of Washington and Cincinnati Zoo CREW are investigating hemoglobin A1c, a measure of long-term blood sugar, in polar bears (PIs: S. Teman and E. Curry). This project explores the potential use of hemoglobin A1c as a biomarker of nutrition and recent reproduction.
- Point Defiance Zoo & Aquarium is investigating rates of hepatocellular carcinoma in zoo polar bears in relation to demographic factors, clinical signs, and survival (PI: C. Soehnlein). Maryland Zoo is examining serum biomarkers to aid in determining early-stage renal disease in zoo polar bears (PI: J. Sohl). A better understanding of disease progression in zoo polar bears could enhance our understanding of disease in their wild counterparts.
- San Diego Zoo Wildlife Alliance (SDZWA), in collaboration with the Brookfield Zoo is examining polar bear maternal care and cub development. (PIs: M. Owen and D. James)
- The Detroit Zoological Society (DZS) is working to evaluate nutrition, growth trends, developmental milesont and mortality in zoo-born polar be cubs (PIs: K. Garland and W. Shellabarger).
- CREW/Cincinnati Zoo are leading efforts to develop a pregnancy test that would enable accurate pregnancy diagnosis (PI: E. Curry).



Stained polar bear vaginal cells enable accurate staging of estrous cycle.
Photo: Erin Curry, Cincinnati Zoo's CREW



Physiological and Behavioral Ecology

Advisor	**Dr. Anthony Pagano, US Geological Survey**
Experts	**Dr. Thea Bechshoft, Polar Bears International** **Dr. John Whiteman, Old Dominion University** **Dr. Tom Smith, Brigham Young University** **Dr. Karyn Rode, US Geological Survey**

A polar bear swims in an aquatic treadmill, allowing researchers to measure energetic costs of locomotion.
Photo: Oregon Zoo

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

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 applied to better understanding polar bears in the wild. These include:

Validation of activity sensors

Utilizing advanced activity sensors, including tri-axial accelerometers, has been validated for use on wild bears to discriminate resting, active, swimming, and walking behaviors (Ware et al. 2015; Pagano et al. 2017). This technology enhances our understanding of polar bear activity and behavior and allows more accurate modeling of behavioral changes in response to ongoing sea ice loss (Ware et al. 2017, Pagano et al. 2020).

Improving methods for estimating energy intake and diet

Chemical components of polar bear tissues, such as blood and hair, can provide information on the feeding behavior of polar bears that is difficult, if not impossible, to assess otherwise. Stable isotopes, naturally occurring variations of elements in the environment, can provide information on the types of prey polar bears consume and the energy content of their diet. But applying these tools requires understanding how the foods that polar bears consume get incorporated into their tissues – something that has only been possible with polar bears in zoos (Rode et al. 2016). 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 changeWith this new tool, studies have been able to identify changes in energy intake that are important in affecting polar bear survival and population dynamics (Rode et al. 2023). Further, because diet can affect exposure to contaminants and pathogens (McKinney et al. 2009, 2017), improved information on polar bear dietsis an important component of understanding potential cumulative effects of dietary change.

Measuring changes in energy expenditure

Measuring energy expenditure via metabolic rates of polar bears while walking and swimming () has provided critical information necessary to understanding the energetic costs of behavioral changes and variation in polar bears (Pagano et al. 2018. 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 allow quantification of the impacts of such changes.

Chemical communication

Studying polar bear chemical communication has been important for better understanding 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).

Priority areas that should take precedence within this 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 in order to improve use of hair as an ecological monitoring tool for wild polar bears.

3. Estimate energetic costs of reproduction, lactation and growth in polar bears including identifying the primary factors affecting these costs, such as sex, age, and environmental conditions.

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. Identify stimuli to both attract and deter polar bears. Attractants would be invaluable for improving capture rates for hair sampling devices. Studies of deterrents are critical to improving co-existence for human activities in polar bear habitat.

Polar bear fur.
Photo: Simon Gee

6. Better understand macro and micronutrient requirements, including relationships between intake and weight gain, in order to better understand implications of changing diets.

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 seasonal variation in hair growth rates, further work investigating the metabolic costs of swimming, and a study of the factors influencing rates of bear food intake to aid in estimating energy intake of bears in the wild

References

Anderson, C.J.R., Lobo, N.D.V., Roth, J.D., and Waterman, J.M. (2010). Computer-aided photo-identification system with an application to polar bears based on whisker spot patterns. Journal of Mammalogy 91(6):1350–1359.

Aldrich, E. D., Hendrickson, D. A., Schmitt, T. L., Nollens, H. H., Montano, G., Steinman, K. J., O'Brien, J. K., & Robeck, T. R. (2024). Laparoscopic Evaluation of the Reproductive Tract in Two Female Polar Bears (Three Procedures) (Ursus maritimus). Life, 14(1), 105.

Atwood, T.C., Colleen Duncan, C., Patyk, K.A., Nol, P., Rhyan, J., McCollum, M., McKinne, M.A., Ramey, A.M., Cerqueira-Cézar, C.K., Kwok, O.C.H., Dubey, J.P., and Hennage, S. (2017). Environmental and behavioral changes may influence the exposure of an Arctic apex predator to pathogens and contaminants. Scientific Reports 7:13193.

Atwood TC, Peacock E, McKinney MA, Lillie K, Wilson R, et al. (2016a) Rapid Environmental Change Drives Increased Land Use by an Arctic Marine Predator. PLOS ONE 11(6): e0155932.

Atwood TC, Marcot BC, Douglas DC, Amstrup SC, Rode KD, Durner GM, Bromaghin JF. (2016b). Forecasting the relative influence of environmental and anthropogenic stressors on polar bears. Ecosphere 7:6, e01370.

Barnas, A.F., Felege, C.J., Rockwell, R.F., and Ellis-Felege, S.N. (2018). A pilot (less) study on the use of an unmanned aircraft system for studying polar bears (Ursus maritimus). Polar Biology 41(5):1055-1062.

Bissonnette, P.B., J.M. Waterman, & S.D. Petersen. (2023) The use of infrared thermography to non-invasively measure the surface temperature of polar bears during bouts of social play. Zoo Biology 41(1): 38-44.

Bowen, L., Miles, A.K., Waters, S., Meyerson, R., Rode, K., and Atwood, T. (2015). Gene transcription in polar bears (Ursus maritimus) from disparate populations. Polar Biology DOI 10.1007/s00300-015-1705-0.

Brandhuber, M., Atkinson, S., Cunningham, C., Roth, T., & Curry, E. (2023). Assessing Dehydroepiandrosterone Sulfate (DHEAS) as a novel biomarker for monitoring estrus and successful reproduction in polar bears. General and comparative endocrinology, 338, 114276.

Bryant, J., and Roth, T.L. (2018). Annual faecal glucocorticoid metabolite concentrations in pregnant and pseudopregnant polar bears (Ursus maritimus) in North American zoos. Journal of Zoo and Aquarium Research 6(1):6–11.

Curry E, Barnes J, Donelan E, Wojtusik J, Kennedy V, Virgin E, Philpott M, Roth T. 2024. Reproductive health assessments in female polar bears: Anatomy, pathology, and diagnostic techniques. Theriogenology Wild 5:100105.

Curry, E., Roth T.L., MacKinnon K.M., and Stoops, M.A. (2012). Factors influencing annual fecal testosterone metabolite profiles in captive male polar bears (Ursus maritimus). Reproduction of Domestic Animals 47:222-225.

Curry, E., Safayi, S., Meyerson, R., and Roth, T.L. (2015). Reproductive trends of captive polar bears (Ursus maritimus) in North American zoos: a historical analysis. Journal of Zoo and Aquarium Research 3:99-106.

Curry, E., Skogen, M., and Roth, T.L. (2021). Evaluation of an odour-detection dog for non-invasive pregnancy diagnosis in polar bears (Ursus maritimus): Considerations for training sniffer dogs for biomedical investigations in wildlife species. Journal of Zoo and Aquarium Research 9:1-7.

Curry, E., Stoops, M.A., and Roth, T.L. (2012). Non- invasive detection of candidate pregnancy protein biomarkers in the feces of captive polar bears (Ursus maritimus). Theriogenology 78:308-314.

Deem SL, Karesh WB, Weisman W. 2008. Putting theory into practice: Wildlife health in conservation. Conservation Biology, 15(5), 1224-1233.

Derocher, A.E., and Stirling, I. (1994). Age-specific reproductive performance of female polar bears (Ursus maritimus). Journal of Zoology 234:527–536.

DiVincenti, L., Garner, M., Thomas, B., & Birkenheuer, A. (2019). Babesia sp. infection in a zoo-housed polar bear (Ursus maritimus). Veterinary parasitology, regional studies and reports, 18, 100350.

Durner, G.M., Douglas, D.C, Albeke, S.E., Whiteman, J.P., Amstrup, S.C., Richardson, E.S., Wilson, R.R., and Ben- David, M. (2017). Increased Arctic sea ice drift alters adult female polar bear movements and energetics. Global Change Biology 23:3460-3473.

Dutton, C.J. , Quinnell, M., Lindsay, R., DeLay, J., and Barker, I.K. (2009). Paraparesis in a polar bear (Ursus maritimus) associated with West Nile virus infection. Journal of Zoo and Wildlife Medicine 40(3):568-71.

Fagre, A.C., Patyk, K.A., Nol, P., Atwood, T., Hueffer, K., and Duncan, C. (2015). A review of infectious agents in polar bears (Ursus maritimus) and their long- term ecological relevance EcoHealth DOI: 10.1007/ s10393-015-1023-6.

Knott, K.K., Mastromonaco, G.F., Owen, M.A., and Kouba, A.J. (2017). Urinary profiles of progestin and androgen metabolites in female polar bears during parturient and non-parturient cycles. Conservation Physiology 5:1-12.

LaRue, M.A., Stapleton, S., Porter, C., Atkinson, S., Atwood, T., Dyck, M., and Lecomte, N. (2015). Testing methods for using high☒resolution satellite imagery to monitor polar bear abundance and distribution. Wildlife Society Bulletin 39(4):772-779.

McKinney, M.A., Atwood, T.C., Pedro, S., and Peacock, E. (2017). Ecological change drives a decline in mercury concentrations in Southern Beaufort Sea polar bears. Environmental Science and Technology 51:7814-7822.

McKinney, M.A., Peacock, E., and Letcher, R.J. (2009). Sea ice-associated diet change increases the levels of chlorinated and brominated contaminants in polar bears. Environmental Science and Technology 43:4334-4339.

Molnár, P. K., C. M. Bitz, M. M. Holland, J. E. Kay, S. R. Penk, and S. C. Amstrup (2020). Fasting season length sets temporal limits for global polar bear persistence. Nature Climate Change 10:732–738.

Molnár P.K., Derocher, A.E., Klanjscek, T., and Lewis, M.A. (2011). Predicting climate change impacts on polar bear litter size. Nature Communications 2:186.

Neuman-Lee, L.A., Terletzky, P.A., Atwood, T.C., Gese, E.M., Smith, G.D., Greenfield, S., Pettit, J., and French, S.S. (2017). Demographic and temporal variations in immunity and condition of polar bears (Ursus maritimus) from the southern Beaufort Sea. Journal of Experimental Zoology: 327(5):333-346.

Obbard, M.E., Cattet, M.R.L., Howe, E.J., Middel, K.R., Newton, E.J., Kolenosky, G.B., et al. (2016). Trends in body condition in polar bears (Ursus maritimus) from the Southern Hudson Bay subpopulation in relation to changes in sea ice. Arctic Science 2:15-32.

Owen, M.A., and A. E. Bowles. (2011). In-air auditory psychophysics and the management of a threatened carnivore, the polar bear (Ursus maritimus). International Journal of Comparative Psychology 24:244-254.

Owen, M.A., Swaisgood, R.R., Slocomb, C., Amstrup, S.C., Durner, G.M., Simac, K., and Pessier, A.P. (2015). An experimental investigation of chemical communication in the polar bear. Journal of Zoology 295:36-43.

Owen, M.A., Pagano A.M., Wisdom, S.S., Kirschhoffer, B., Bowles, A.E. and O'Neill, C. (2021). Estimating the audibility of industrial noise to denning polar bears. The Journal of Wildlife Management 85(2):384-396.

Pagano, A.M., T.C. Atwood, G.M. Durner, and T.M. Williams (2020). The seasonal energetic landscape of an apex marine carnivore, the polar bear. Ecology 101:e02959.

Pagano, A.M., Carnahan, A.M., Robbins, C.T., Owen, M.A., Batson, T., Wagner, N., Cutting, A., Nicassio-Hiskey, N., Hash, A., and Williams, T.M. (2018a). Energetic costs of locomotion in bears: is plantigrade locomotion energetically economical? Journal of Experimental Biology 221(12), DOI:p.jeb175372.

Pagano, A.M., Cutting, A., Nicassio-Hiskey, N., Hash, A., and Williams, T.M. (2018b). Energetic costs of aquatic locomotion in a subadult polar bear. Society for Marine Mammalogy DOI: 10.1111/MMS.12556.

Pagano, A.M., Durner, G.M., Amstrup, S.C., Simac, K.S., and York, G.S. (2012). Long-distance swimming by polar bears (Ursus maritimus) of the southern Beaufort Sea during years of extensive open water. Canadian Journal of Zoology 90:663-676.s

Pagano, A. M., G. M. Durner, K. D. Rode, T. C. Atwood, S.N. Atkinson, E. Peacock, D. P. Costa, M. A. Owen, and T. M. Williams (2018c). High-energy, high-fat lifestyle challenges an Arctic apex predator, the polar bear. Science 359:568–572.

Pagano, A.M., Robbins, C.T., Carnahan, T., Owen, M.A., Batson, T., Wagner, N., Hash, A., Williams, T.M. (2018c). Costs of locomotion in two large plantigrade carnivores: polar bears and grizzly bears. Journal of Experimental Biology 221(12): https://doi.org/10.1242/jeb.175372.

Pagano, A.M., Rode, K.D., Cutting, A., Owen, M.A., Jensen, S., Ware, J.V., Robbins, C.T., Durner, G.M., Atwood, T.C., Obbard, M.E., Middel, K.R., Thiemann, G.W., and Williams, T.M. (2017). Using tri-axial accelerometers to identify wild polar bear behaviors. Endangered Species Research 32:19-33.

Patyk KA, Duncan C, Nol P, Sonne C, Laidre K, Obbard M, Wiig Ø, Aars J, Regehr E, Gustafson LL, Atwood T. Establishing a definition of polar bear (Ursus maritimus) health: a guide to research and management activities. Sci Total Environ. 2015 May 1;514:371-8.

Pilfold, N. W., Richardson, E. S., Ellis, J., Jenkins, E., Scandrett, W. B., Hernández⊠Ortiz, A., ... & Lunn, N. J. (2021). Long⊠term increases in pathogen seroprevalence in polar bears (Ursus maritimus) influenced by climate change. Global change biology, 27(19), 4481-4497.

Prop, J., Staverlokk, A., and Moe, B. (2020). Identifying individual polar bears at safe distances: A test with captive animals. PLoS ONE 15(2): e0228991

Regehr, EV, Hunter, CM, Caswell, H, Amstrup, SC, & Stirling, I. (2009). Survival and breeding of polar bears in the southern Beaufort Sea in relation to sea ice. Journal of Animal Ecology 79:1, 117-127.

Robbins CT, Lopez-Alfaro C, Rode KD, Toien O, Nelson OL. 2012. Hibernation and seasonal fasting in bears: the energetic costs and consequences for polar bears. Journal of Mammalogy 93(6):1493-1503.

Rode KD, Robbins CT, Nelson L, & Amstrup SC. (2015). Can polar bears use terrestrial foods to offset lost ice-based hunting opportunities? Frontiers in Ecology and the Environment 13(3):138-145.

Rode, K.D., Amstrup, S.C., and Regehr, E.V. (2010). Reduced body size and cub recruitment in polar bears associated with sea ice decline. Ecological Applications 20:768-782.

Rode, K. D., C. T. Robbins, C. A. Stricker, B. D. Taras, and T. N. Tollefson (2021). Energetic and health effects of protein overconsumption constrain dietary adaptation in an apex predator. Scientific Reports 11:15309.

Rode, K.D., Robbins, C.T., Stricker, C.A., Taras, B.D., and Tollefson, T.N. (2021). Energetic and health effects of protein overconsumption constrain dietary adaptation in an apex predator. Scientific Reports: in press.

Rode, K.D., Stricker, C.A., Erlenbach, J., Robbins, C.T., Cherry, S.G., Newsome, S.D., Cutting,

A., Jensen, S., Stenhouse, G., Brooks, M., Hash, A., and Nicassio, N. (2016). Isotopic Incorporation and the Effects of Fasting and Dietary Lipid Content on Isotopic Discrimination in Large Carnivorous Mammals. Physiological and Biochemical Zoology 89(3):182-197. DOI: 10.1086/686490.

Routti H, Atwood TC, Bechshoft T, Boltunov A, Ciesielski TM, Desforges JP, Dietz R, Gabrielsen GW, Jenssen BM, Letcher RJ, McKinney MA, Morris AD, Rigét FF, Sonne C, Styrishave B, Tartu S. State of knowledge on current exposure, fate and potential health effects of contaminants in polar bears from the circumpolar Arctic. Sci Total Environ. 2019 May 10;664:1063-1083.

Rzucidlo, C., Curry, E., Shero, M. (2023). Non-invasive measurements of respiration and heart rate across wildlife species using Eulerian video magnification of infrared thermal imagery. BMC Biology 21:61. doi: 10.1186/s12915-023-01555-9.

Smith, T.S., Amstrup, S.C., Kirschhoffer, B.J., and York, G. (2020). Efficacy of aerial forward-looking infrared surveys for detecting polar bear maternal dens. PLoS ONE 15(2):e0222744.

Steinman, K.J., O'Brien, J.K., Fetter, G.A., Curry, E., Roth, T.L., Owen, M.A., and Robeck, T.R. (2017). Enzyme immunoassay analysis for androgens in polar bear (Ursus maritimus) urine using enzyme hydrolysis. Aquatic Mammals 43:245-253.

Stirling, I., Lunn, N.J., and Lacozza, J. (1999). Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294-306.

Stoops, M.A., MacKinnon, K.M., and Roth, T.L. (2012). Longitudinal fecal hormone analysis for monitoring reproductive activity in the female polar bear (Ursus maritimus). Theriogenology 78:1977–1986.

U.S. Fish and Wildlife Service. (2008). Endangered and threatened wildlife and plants; determination of threatened status for the polar bear (Ursus maritimus) throughout its range; final rule. Federal Register 73(28):212-228, 303.

U.S. Fish and Wildlife. (2016). Polar Bear (Ursus maritimus) Conservation Management Plan, U.S. Fish and Wildlife, Region 7, Anchorage, Alaska.

Ware, J.V., Rode, K.D., Bromaghin, J.F., Douglas, D.C.,

Wilson, R.R., Regehr, E.V., Amstrup, S.C., Durner, G., Pagano, A.M., Olson, J., Robbins, C.T., and Jansen, H.T. (2017). Habitat degradation affects the summer activity of polar bears. Oecologia 184:87-99.

Ware, J.V., Rode, K.D., Pagano, A.M., Bromaghin, J., Robbins, C.T., Erlenbach, J., Jensen, S., Cutting, A., Nicassio-Hiskey, N., Hash, A., Owen, M., and Jansen, H.T. (2015). Validation of mercury tip-switch and accelerometer activity sensors for identifying resting and active behavior in bears. Ursus:26(2):86-96, doi 10.2192/URSUS-D-14-00031.1.

Wilder, J.M., Vongraven, D., Atwood, T., Hansen, B., Jessen, A., Kochnev, A., York, G., Vallender, R., Hedman, D., and Gibbons, M. (2017). Polar bear attacks on humans: implications of a changing climate. Wildlife Society Bulletin 41:537-547.

Whiteman, J. P., Harlow, H. J., Durner, G. M., Anderson-Sprecher, R., Albeke, S. E., Regehr, E. V., Amstrup, S. C., & Ben-David, M. (2015). Animal physiology. Summer declines in activity and body temperature offer polar bears limited energy savings. Science (New York, N.Y.), 349(6245), 295–298.

Wojtusik J, Philpott M, Donelan D, Stoops M, Roth T, Curry E. 2024. Testosterone concentrations in juvenile male polar bears (Ursus maritimus). Theriogenology Wild 5:100104.

Wojtusik, J., Roth, T.L., Curry, E. (2022). Case studies in polar bear (Ursus maritimus) sperm collection and cryopreservation techniques. Animals 12:430.

Woodruff SP, Andersen EM, Wilson RR, Mangipane LS, Miller SB, Klein KJ, Lemons PR (2022) Classifying the effects of human disturbance on denning polar bears. Endang Species Res 49:43-56.

APPENDIX A

Zoo Conservation Science Collaboration Best Practices Adapted from Appendix A to EAZA prospectus (with permission)

Research collaborations between scientists and zoos and aquariums hold immense value for our improved understanding of the challenges faced by wild polar bears in a warming Arctic and can inform conservation management efforts. However, as part of creating a robust partnership, it is highly recommended that both parties become familiar with the norms and expectations of their potential research partner(s). Proactive thoughtful communication can prevent avoidable obstacles and miscommunications throughout the research process. The following considerations - listed here for both primary investigators (PIs) and zoo professionals (staff) - can serve as a useful foundation for initiating these conversations and partnerships.

Considerations for Principal Investigators:

Crafting a successful proposal

- **Note:** The PBRC is available to review and provide feedback on proposals at any stage of the process. They can also connect potential PI's with appropriate facilities.
- PI's should create a detailed proposal delineating critical success factors and negotiable aspects, while respecting keepers' schedules (clearly outline time commitments and distribution of responsibilities during the project).
- Clearly communicate the conservation applications of your proposal.
- Allow 2-4 months of planning to obtain the necessary permissions. The PBRC can help with this process!

Relationship building

- Meet with staff (virtually or in person) and be prepared to consider adapting your methodology based on staff feedback.
- If possible, consider adding to your project budget expenses for resources such as financial support, labour, or equipment for the zoo.
- Respect concerns about animal welfare, health, and public perception and assist in problem solving.
- Once project is approved, meet with front line keeper staff to answer questions abut the details.
- Provide regular progress updates and build strong relationships with the staff through regular, personal interactions and express appreciation for contributions.
- Future project implications: Even if this is your last or only collaboration, consider your project's impact on future work. Aim to create a path for successful partnerships in future research endeavours.

Acknowledgement

- Establish a fair credit allocation system, emphasizing co-authorship and contribution acknowledgment.
- At the project's outset, clarify data and sample ownership, including control and usage of collected information.

Public engagement

- Be prepared for participation in public and popular media events showcasing the project.
- Contribute to zoo newsletters, social media, and other public-facing material

Considerations for Zoo Professionals and Institutions

Prepare your team for research collaborations

- Prioritize husbandry behavior training and general desensitization of bears for their health and welfare, and to facilitate research collaborations.
- Emphasize for your animal care and veterinary teams the critical role bears in human care are playing in conservation science. Share the PBRC Masterplan and discuss how your team might support such initiatives.
- Demonstrate enthusiasm for research collaborations and use creative problem solving to work through concerns and challenges.

Permitting and approval considerations

- Appendix B in this Masterplan articulates the interpretation, by the USFWS, of activities not requiring a permit. If a permit is required, it is the responsibility of the PI to obtain one prior to beginning any work.
- The PBRC will review any proposals and provide feedback to the PI.
- The PBRC will endorse proposals that are deemed well designed and to have significant implications for conservation or management.
- Each institution has an obligation to review all incoming research proposals and determine for themselves whether to proceed.
- The PBRC is available to help facilitate collecting additional information from PI's who may be receiving a large number of inquiries from multiple institutions to reduce the overall burden of collaborating with zoological institutions.

Designate a primary point of contact (POC) for the PI

- The selected POC should be invested in conservation science, have some authority for decision-making and be a problem solver and skilled communicator.
- The POC should have sufficient capacity to meet with all parties involved in the collaboration to discuss ideas and concerns.
- The POC should be prepared to help the PI navigate the complexities of the zoo environment.
- The POC can help staff articulate how a seemingly small research question is typically a small part of a larger puzzle or a variable in a complex model that researchers are trying to decipher.
- The POC should share project updates widely and liaise with marketing and comms teams who may wish to share accomplishments publicly.
- Note: the PBRC is available to assist POC's in navigating these challenges.

Practicalities

- Safety procedures: Institutions must provide a thorough safety briefing and essential guidelines for working onsite to ensure the safety of all involved.
- Inform researchers promptly about events that could impact data collection, including relocation, medication changes, veterinary procedures, bear behavioural dynamics, changes in husbandry practices, construction activities, and observed

Other considerations

- Research studies often bring benefits beyond their primary purpose, such as enhancing animal welfare ex situ (e.g., Puppe et al., 2007; Hopper et al., 2016; Rode et al 2021).

- Research collaborations have generated significant public interest and support when communicated through on-grounds messaging and social media campaigns.
- Staff who have participated in conservation science collaborations report that the work has other benefits:
    - Increases staff connection to the conservation of the species, improving job satisfaction.
    - Provides enrichment and challenges, improving welfare of both staff and animals.
    - Increases quality time spent with the animals and builds stronger relationships.

For additional considerations, see the following publication by Schulz, et al: A Guide for Successful Research Collaborations between Zoos and Universities: https://academic.oup.com/icb/article/62/5/1174/6623667

APPENDIX B

Correspondence between the PBRC and the USFWS re: permitting requirements for sample collection and transport.

In June 2024, members of the Polar Bear Research Council (PBRC) traveled to Anchorage to meet with the U.S. Fish & Wildlife Service (FWS) Alaska Marine Mammal Management team to gain clarification regarding which activities conducted with zoo-housed polar bears would require a research permit. Following the discussion, Table A (below) was generated and submitted to the Office for review, to ensure that our interpretation of the conversation was accurate. Based on the subsequent response from FWS, our understanding is that while many routine health monitoring and husbandry activities technically qualify as "takes" under the Marine Mammal Protection Act (MMPA), these activities are already authorized under the permits or Letters of Authorization associated with the animal's public display status. As long as procedures are conducted for the animal's health, welfare, standard husbandry purposes (including training), or enrichment, and align with Animal Welfare Act (AWA) standards, additional research permits are not required. Furthermore, biological samples collected under these activities do not require additional permits or authorization for transport, as long as sample ownership is not transferred. For a complete copy of the email correspondences, please contact PBRC facilitator Amy Cutting.

United States Department of the Interior

U.S. FISH AND WILDLIFE SERVICE
1011 East Tudor Road
Anchorage, Alaska 99503
November 8, 2024

In Reply Refer to:
FWS/R7/AFES/MMM

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RE: Standard Husbandry Practices for Polar Bears

Dear Ms. Cutting, Dr. Curry, and Dr. Owen:

Thank you for your letter dated July 26, 2024, on behalf of the Polar Bear Research Council (PBRC) to the U.S. Fish & Wildlife Service's (FWS) Marine Mammals Management program (MMM). We understand the PBRC is seeking clarification that activities outlined in Appendix A of your letter do not meet the definition of take pursuant to the Marine Mammal Protection

Act (MMPA), even when they result in biological samples used for research purposes or activities associated with research as enrichment. The samples are obtained as part of standard husbandry practices for preventative health and disease monitoring, are beneficial to the participants' wellbeing, and are in line with Animal Welfare Act (AWA) Standards. For reasons discussed below, many of the activities you have described in your attachment are considered takings under the MMPA, however, an additional permit is generally not required to conduct these types of activities because they are already allowed or authorized under the permit, or Letter of Authorization, under which the animal is being held.

Most polar bears held at public display facilities in the United States (US) were either originally imported into the US under an MMPA public display permit or are the progeny of such an animal. When the FWS issued the permit for the importation of the animal for public display it was conditioned with several requirements. One of those requirements is that the care and maintenance of the polar bear shall be in compliance with the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) Specifications for the Humane Handling, Care, Treatment, and Transportation of Marine Mammals [9 CFR 3 Subpart E].

We consulted with Dr. Carolyn McKinnie, USDA-APHIS Senior Veterinary Medical Officer - Marine Mammals and Exotics who noted under the AWA animals must be handled as expeditiously as possible so as not to cause trauma, for example, behavioral stress, physical harm, or unnecessary discomfort. In addition, she notes the AWA requires adequate veterinary care must be provided, appropriate diagnosis, treatment, analgesics, equipment, instruction etc. given, and that APHIS always refers to current veterinary professional standards.

Therefore, because the activities you describe, while being “takes” under the MMPA, are already authorized when conducted to ensure the health and maintenance of the animal no additional permits are required for the activities. We note that in most circumstances we would defer to the attending veterinarian to ensure procedures were appropriate and necessary for the welfare of the animal. It should also be noted that were the intent to be the collection of samples for a purpose other than the routine care and maintenance of the animal, for example to meet a specific research objective, not associated with the animal’s care and maintenance, a permit may be required for those activities.

If you have additional questions, or would like to discuss this matter further, please feel free to contact me by email at charles_hamilton@fws.gov, or my colleague Sarah Conn via email at sarah_conn@fws.gov. Thank you again for all your efforts to conserve polar bears and help the public understand this important wildlife species.

Sincerely,

Charles Hamilton
Special Assistant
Marine Mammals Management Office

26 July 2024

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PBRC Research Masterplan

To: USFWS-Alaska Marine Mammal Management Team

The Polar Bear Research Council (PBRC) is an ad hoc group of scientists and conservation practitioners supporting polar bear conservation research in zoos and aquariums in North America. Composed of zoological-based professionals, veterinarians, agency and academic scientists, and a facilitator from Polar Bears International, the group formed in 2018 to encourage and contribute to the coordination of research efforts with polar bears in zoological facilities that inform *in situ* conservation and management of the species. (See briefing document).

One of our primary objectives is to increase capacity for, and remove barriers to, polar bear conservation science in zoos and aquariums. In order to enhance meaningful scientific work, we strive to provide optimal care of polar bears in zoos that can simultaneously yield data and samples for research purposes. We would like to share some additional background context illustrating how targeted research in the zoo setting can also serve as important enrichment activities for animal wellbeing.

Optimal and routine care for health and wellbeing of zoo polar bears
Over the last 25 years, modern zoological facilities have increasingly trained the animals in their care to participate in their own health assessments, provided enriched environments and life experiences, built positive relationships with animals and proactively desensitized them to activities that could be stressful or aversive for a naive individual. Animal care teams are composed of veterinarians, behaviorists, nutritionists, caregivers and researchers who create detailed care plans for every life stage, systematically evaluate and balance risks, provide challenging and dynamic experiences, and train animals for indicated as well as possible future veterinary interventions.

Through positive reinforcement training, many zoo polar bears regularly allow unsedated blood draws, vaginal swabs, dental checks, wound treatments, ultrasounds, radiographs, vaccinations, eye drops, and skin and hair sampling. Unlike wild animals, zoo resident polar bears are comfortable around known and unknown individuals, typically unafraid of new objects or novel events and extremely resilient in their responses to potentially disturbing stimuli. A well cared for polar bear is trusting of their care staff, extremely curious, and motivated to investigate new objects, opportunities and tasks.

The list of activities in Appendix A are necessary for the provision of optimal health and wellbeing for polar bears in human care but can also provide samples and data for research. We recognize "take" under the MMPA to be defined as "to harass, hunt, capture, or kill any marine mammal or attempt to do so" and that "harass" is an "act" that has the "potential to injure a marine mammal or disturb a marine mammal by causing disruption to behavioral patterns, including, but not limited to, migration, breathing, nursing, feeding, and sheltering". It is our understanding that per these definitions, the activities outlined in Appendix A do not meet these definitions of take, even when they result in biological samples used for research purposes, because they are part of standard husbandry practices for preventative health and disease monitoring, are beneficial to the participants' wellbeing, and are in line with Animal Welfare Act Standards. While not related to the issue of take, it is also important to note that these activities contribute to the conservation and management of their wild counterparts.

Research as enrichment

Polar bears in human care live in an environment that differs substantially from that of their wild counterparts. A regular and important part of their care is the provision of mental stimulation and enriched environments that help maintain good behavioral health. Research activities, including those that alter a bear's behavior, are important sources of enrichment. With additional time and training, a handful of bears have voluntarily walked on enclosed treadmills (1,2), swam in an enclosed swim flume (3), learned to touch a target in response to measured acoustic cues (4,5), and allowed a research collar to be fitted and removed (6,7). Behavioral changes that may be needed for research often involve food rewards (e.g., providing food to position a bear for a study to validate photogrammetry to estimating body mass) or modifications to their environment (positioning food rewards for a bear to walk to a particular part of the exhibit). While some of these activities require additional time and training to slowly acclimate the animal and build confidence, that experience is stimulating and enriching for the bears involved - a key objective in any health and wellbeing program.

Our team looks forward to hosting Service staff at polar holding facilities in the United States to see firsthand the husbandry activities and care provided to polar bears under various health and wellbeing programs and how research gets integrated into those programs. We look forward to further discussion!

1. Pagano et al. *Science* 359:368-572, 2. Pagano et al. *J. Exp. Bio*. 221, 3. Pagano et al. *Marine Mammal Sci.* 4. Owen & Bowles. *Inter. J. Comp. Psych.* 24:244-254, 5. Owen et al. *J. Wildl. Mgmnt. 85:384-396*, 6. Pagano et al. *Endang. Species Res.* 32:19-33, 7. Ware et al. *Ursus* 26:86-96.

Sincerely,

Erin Curry Megan Owen Amy Cutting

Routine polar bear health and husbandry practices

The following table details the types of samples and data regularly collected from zoo-housed polar bears as part of routine health monitoring and husbandry. All activities are within the confines of animal husbandry practices that meet or exceed the minimum standards for facilities and care under the Animal Welfare Act. We recognize "take" under the Marine Mammal Protection Act as "to harass, hunt, capture, or kill any marine mammal or attempt to do so" and understand "harass" to include any activity with the potential to injure or disturb by causing disruption to behavioral patterns, including, but not limited to, migration, breathing, nursing, feeding, and sheltering. Based on these definitions, it is our understanding that the activities outlined here do not constitute "take," even when they result in biological samples or data used opportunistically for research, if they are performed as part of routine husbandry practices. As such, we acknowledge that any activities conducted outside the scope of routine husbandry practices would necessitate appropriate permitting.

Routine health and husbandry practices for polar bears in U.S. zoological institutions

Sample type/Husbandry practice	Animal care purpose	Category of collection			
		Non-invasive	Voluntarily or via training	Routine examination	Necropsy
Behavioral observations	Health/behavior monitoring, routine husbandry	✔	✔		
Biopsies / tissue samples	Health monitoring, diagnostics			✔	✔
Blood	Health monitoring, diagnostics		✔	✔	✔
Breath	Metabolic check, health monitoring		✔	✔	
Cognitive evaluations	Welfare/enrichment, health monitoring	✔	✔		
Feces	Health monitoring (hormones, parasites, nutritional)	✔		✔	✔
Gametes, gonads	Reproductive evaluation/ gamete preservation			✔	✔
Hair, plucked	Parasite check		✔	✔	✔
Hair, shaved	Prep phlebotomy site, wound cleaning or matting		✔	✔	✔
Imaging (photo or video)	Health/behavior monitoring	✔	✔	✔	✔
Ingesting small, inert items	Track fecal origin or gut passage time		✔		
Modification/manipulation of diet	Welfare/enrichment, husbandry		✔		
Nail/claw	Routine husbandry/care		✔	✔	✔
Radiographs/ultrasonography	Monitoring/diagnostics		✔	✔	
Rectal thermometer	Health monitoring		✔	✔	
Sensory data	Health monitoring/diagnostics (olfaction, vision, etc)		✔	✔	
Skin scrapes	Health monitoring/diagnostics (parasites, dermatitis, etc)		✔	✔	✔
Swabs (epithelial)	Health monitoring/diagnostics (cultures, skin checks)		✔	✔	✔
Training/eliciting specific behaviors	Welfare/enrichment, health monitoring		✔		
Urine (free catch)	Health monitoring (urinalysis, hormone monitoring)	✔	✔	✔	
Urine (catheter or cystocentesis)	Health monitoring (culture, hormone monitoring)			✔	✔
Weight	Health/nutritional monitoring		✔	✔	✔

APPENDIX C

Zoo-housed polar bears have contributed significantly to scientific studies by enabling researchers to conduct controlled investigations that enhance our understanding of polar bear physiology, behavior, and health. Over 100 peer-reviewed scientific papers have informed critical advancements such as non-invasive monitoring techniques, improved dietary recommendations, and enhanced methods for tracking, population assessment, and disease diagnostics.

Aldrich, E. D., Hendrickson, D. A., Schmitt, T. L., Nollens, H. H., Montano, G., Steinman, K. J., O'Brien, J. K., & Robeck, T. R. (2024). Laparoscopic evaluation of the reproductive tract in two female polar bears (three procedures) (Ursus maritimus). Life, 14(1), 105. https://doi.org/10.3390/life14010105

Alroy, J., Baldwin, D., & Maschgan, E. R. (1980). Multiple beta cell neoplasms in a polar bear: An immunohistochemical study. Veterinary Pathology, 17(3), 331–337. https://doi.org/10.1177/030098588001700307

Ames, A. (1994). Object manipulation in captive polar bears. Bears: Their Biology and Management, 9, 443. https://doi.org/10.2307/3872731

Babitz, M., Gibson, A., & Pratte, J. (2023). Improving Animal Wellbeing Using Behavior-Based Methodologies: A Discussion on Enrichment and Bears under Human Care. Journal of Zoological and Botanical Gardens, 4(1), 256–276. https://doi.org/10.3390/jzbg4010022

Best, R. C. (1982). Thermoregulation in resting and active polar bears. Journal of Comparative Physiology ? B, 146(1), 63–73. https://doi.org/10.1007/BF00688718

Bissonnette, P. B., Waterman, J. M., & Petersen, S. D. (2022). The use of infrared thermography to noninvasively measure the surface temperature of polar bears during bouts of social play. Zoo Biology, zoo.21722. https://doi.org/10.1002/zoo.21722

Blix, A. S., & Lentfer, J. W. (1979). Modes of thermal protection in polar bear cubs- at birth and on emergence from the den. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 236(1), R67–R74. https://doi.org/10.1152/ajpregu.1979.236.1.R67

Bourque, J., Desforges, J.-P., Levin, M., Atwood, T. C., Sonne, C., Dietz, R., Jensen, T. H., Curry, E., & McKinney, M. A. (2020). Climate-associated drivers of plasma cytokines and contaminant concentrations in Beaufort Sea polar bears (Ursus maritimus). Science of The Total Environment, 745, 140978. https://doi.org/10.1016/j.scitotenv.2020.140978

Bovee, E., Madry, T., Gartland, K. N., & Fuller, G. (2025). Contextual Factors Associated with Fecal Glucocorticoid Metabolites in Juvenile Polar Bears (Ursus maritimus) and a Cohabitating Juvenile Grizzly Bear (Ursus arctos horribilis) at the Detroit Zoo. Journal of Zoological and Botanical Gardens, 6(1), 1. https://doi.org/10.3390/jzbg6010001

Brandhuber, M., Atkinson, S., Cunningham, C., Roth, T., & Curry, E. (2023). Assessing dehydroepiandrosterone sulfate (DHEAS) as a novel biomarker for monitoring estrus and successful reproduction in polar bears. General and Comparative Endocrinology, 338, 114276. https://doi.org/10.1016/j.ygcen.2023.114276

Brimhall, B., Stenzel, P., Dresler, S. L., Hermodson, M., Stangland, K., Joyce, J., & Jones, R. T. (1977). On the tryptic peptides from hemoglobin chains of six carnivores. Journal of Molecular Evolution, 9(3), 237–260. https://doi.org/10.1007/BF01796113

Bryant, J. L., & Roth, T. L. (2018). Annual faecal glucocorticoid metabolite concentrations in pregnant and pseudopregnant polar bears (Ursus maritimus) in North American zoos. Journal of Zoo and Aquarium Research, 6(1), 6–11.

Cambrelen, D., & Nelson Slater, M. (2023). Case study: Modifying repetitive behavior in a polar bear (Ursus maritimus). Zoo Biology, 42(3), 390–396. https://doi.org/10.1002/zoo.21745

Canino, W., & Powell, D. (2009). Formal behavioral evaluation of enrichment programs on a zookeeper's schedule: A case study

with a polar bear (Ursus Maritimus) at the Bronx Zoo. Zoo Biology, n/a-n/a. https://doi.org/10.1002/zoo.20247

Cavalleri, A., Bell, A., Wilkins, K., Brereton, J., Preziosi, R., & Quintavalle Pastorino, G. (2022). An investigation of the sociality and behaviour of captive polar bears housed in bachelor groups. Acta Scientific Veterinary Sciences, 4(3), 18–25. https://doi.org/10.31080/ASVS.2022.04.0325

Cless, I. T., & Lukas, K. E. (2017). Variables affecting the manifestation of and intensity of pacing behavior: A preliminary case study in zoo-housed polar bears. Zoo Biology, 36(5), 307–315. https://doi.org/10.1002/zoo.21379

Cless, I. T., Voss-Hoynes, H. A., Ritzmann, R. E., & Lukas, K. E. (2015). Defining pacing quantitatively: A comparison of gait characteristics between pacing and non-repetitive locomotion in zoo-housed polar bears. Applied Animal Behaviour Science, 169, 78–85. https://doi.org/10.1016/j.applanim.2015.04.002

Crissey, S., Ange, K., Slifka, K., Bowen, P., Stacewicz-Sapuntzakis, M., Langman, C., Sadler, W., & Ward, A. (2001). Serum concentrations of vitamin D metabolites, vitamins A and E, and carotenoids in six canid and four ursid species at four zoos. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 128(1), 155–165. https://doi.org/10.1016/S1095-6433(00)00289-0

Curry, E., Barnes, J., Donelan, E., Wojtusik, J., Kennedy, V., Virgin, E. E., Philpott, M., & Roth, T. L. (2024). Reproductive health assessments in female polar bears: Anatomy, pathology, and diagnostic techniques. Theriogenology Wild, 5, 100105. https://doi.org/10.1016/j.therwi.2024.100105

Curry, E., Philpott, M. E., Wojtusik, J., Haffey, W. D., Wyder, M. A., Greis, K. D., & Roth, T. L. (2022). Label-free quantification (LFQ) of fecal proteins for potential pregnancy detection in polar bears. Life, 12(6), 796. https://doi.org/10.3390/life12060796

Curry, E., Roth, T., MacKinnon, K., & Stoops, M. (2012). Factors influencing annual fecal testosterone metabolite profiles in captive male polar bears (Ursus maritimus). Reproduction in Domestic Animals, 47, 222–225. https://doi.org/10.1111/rda.12012

Curry, E., Safayi, S., Meyerson, R., & Roth, T. L. (2015). Reproductive trends of captive polar bears in North American zoos: A historical analysis. Journal of Zoo and Aquarium Research, 3, 99–106. https://doi.org/10.19227/jzar.v3i3.133

Curry, E., Skogen, M., & Roth, T. (2021). Evaluation of an odour detection dog for non-invasive pregnancy diagnosis in polar bears (Ursus maritimus): Considerations for training sniffer dogs for biomedical investigations in wildlife species. Journal of Zoo and Aquarium Research, 9(1), 1–7. https://doi.org/10.19227/jzar.v9i1.568

Curry, E., Stoops, M. A., & Roth, T. L. (2012). Non-invasive detection of candidate pregnancy protein biomarkers in the feces of captive polar bears (Ursus maritimus). Theriogenology, 78(2), 308–314. https://doi.org/10.1016/j.theriogenology.2012.02.004

Curry, E., Wyatt, J., Sorel, L. J., MacKinnon, K. M., & Roth, T. L. (2014). Ovulation induction and artificial insemination of a captive polar bear (Ursus maritimus) using fresh semen. Journal of Zoo and Wildlife Medicine, 45(3), 645–649. https://doi.org/10.1638/2013-0055R1.1

Dehnhard, M., & Jewgenow, K. (2013). Measurement of faecal prostaglandins in felids and three ursid species. Wiener Tierärztliche Monatsschrift, 11, 227–237.

Desforges, J.-P., Jasperse, L., Jensen, T. H., Grøndahl, C., Bertelsen, M. F., Guise, S. D., Sonne, C., Dietz, R., & Levin, M. (2018). Immune function in arctic mammals: Natural killer (NK) cell-like activity in polar bear, muskox and reindeer. Veterinary Immunology and Immunopathology, 195, 72–75. https://doi.org/10.1016/j.vetimm.2017.11.010

DiVincenti, L., Garner, M., Thomas, B., & Birkenheuer, A. (2019). Babesia sp. Infection in a zoo-housed polar bear (Ursus maritimus). Veterinary Parasitology: Regional Studies and Reports, 18, 100350. https://doi.org/10.1016/j.vprsr.2019.100350

Dutton, C. J., Quinnell, M., Lindsay, R., DeLay, J., & Barker, I. K. (2009). Paraparesis in a Polar Bear (Ursus maritimus) Associated with West Nile Virus Infection. Journal of Zoo and Wildlife Medicine, 40(3), 568–571. https://doi.org/10.1638/2008-0121.1

Edes, A. N., Liu, N. C., Baskir, E., Bauman, K. L., Kozlowski, C. P., Clawitter, H. L., & Powell, D. M. (2022). Comparing Space Use and Fecal Glucocorticoid Concentrations during and after the COVID-19 Closure to Investigate Visitor Effects in Multiple Species. Journal of Zoological and Botanical Gardens, 3(3), 328–348. https://doi.org/10.3390/jzbg3030026

Eo, K.-Y., & Kwon, O.-D. (2014). Dermatitis Caused by Dermatophilus congolensis in a Zoo Polar Bear (Ursus maritimus). Pak Vet

J.

Fernandez, E. J. (2021). Appetitive search behaviors and stereotypies in polar bears (Ursus maritimus). Behavioural Processes, 182, 104299. https://doi.org/10.1016/j.beproc.2020.104299

Forthman, D. L., Elder, S. D., Bakeman, R., Kurkowski, T. W., Noble, C. C., & Winslow, S. W. (1992). Effects of feeding enrichment on behavior of three species of captive bears. Zoo Biology, 11(3), 187–195. https://doi.org/10.1002/zoo.1430110307

Fortin, J., & Benoit⊠Biancamano, M. (2014). Characterization of a Pancreatic Islet Cell Tumor in a Polar Bear (Ursus maritimus). Zoo Biology, 33, 446–451. https://doi.org/10.1002/zoo.21172

Garner, M. M., Barr, B. C., Packham, A. E., Marsh, A. E., Burek-Huntington, K. A., Wilson, R. K., & Dubey, J. P. (1997). Fatal hepatic sarcocystosis in two polar bears (Ursus maritimus). The Journal of Parasitology, 83(3), 523. https://doi.org/10.2307/3284422

Gartland, K. N., Humbyrd, M., Brightrall, T., Meister, B., & Fuller, G. (2024). Behavior of polar bear (Ursus maritimus) cubs post⊠ den emergence at the Detroit Zoo. Zoo Biology, zoo.21814. https://doi.org/10.1002/zoo.21814

Gartland, K. N., Humbyrd, M. K., Meister, B., & Fuller, G. (2023). Behavioral development of a captive polar bear (Ursus maritimus) cub in the maternal den. Zoo Biology, 42(4), 582–587. https://doi.org/10.1002/zoo.21757

Gatesman, T., & Wiesner, H. (1982). Immobilization of polar (Thalarctos maritimus) and brown (Ursus arctos) bears using etorphine and xylazine. The Journal of Zoo Animal Medicine, 13(1), 11. https://doi.org/10.2307/20094555

Goritz, F., Hildebrandt, T. B., Jewgenow, K., Wagner, N., Hermes, R., Straub, G., & Meyer, H. H. D. (1997). Transrectal ultrasonographic examination of the female urogenital tract in pregnant and nonpregnant captive bears (Ursidae). Journal of Reproduction and Fertility Supplement, 51, 303–312.

Grahl-Nielsen, O., Andersen, M., Derocher, A., Lydersen, C., Wiig, Ø., & Kovacs, K. (2003). Fatty acid composition of the adipose tissue of polar bears and of their prey: Ringed seals, bearded seals and harp seals. Marine Ecology Progress Series, 265, 275–282. https://doi.org/10.3354/meps265275

Greenwald, K. R., & Dabek, L. (2003). Behavioral development of a polar bear cub (Ursus maritimus) in captivity. Zoo Biology, 22(5), 507–514. https://doi.org/10.1002/zoo.10095

Greenwood, A. D., Tsangaras, K., Ho, S. Y. W., Szentiks, C. A., Nikolin, V. M., Ma, G., Damiani, A., East, M. L., Lawrenz, A., Hofer, H., & Osterrieder, N. (2012). A potentially fatal mix of herpes in zoos. Current Biology, 22(18), 1727–1731. https://doi.org/10.1016/j.cub.2012.07.035

Grenfell, J. G. (1883). Intelligence in Animals. Nature, 292.

Hedberg, G. E., Dierenfeld, E. S., Chesney, R. W., & Rogers, Q. R. (2009). Speculations on pathogenesis of metabolic bone disease in captive polar bears (Ursus maritimus) with links to taurine status.pdf. In Zoo Animal Nutrition IV (pp. 87–96). Filander Verlag.

Hedberg, G. E., Dunker, F., Dierenfeld, E. S., & Petty, M. (2006). Polar Bear (Ursus maritimus) Adipose Tissue Fatty Acid Composition Compared to Fatty Acid Constituents of a Common Milk Replacer. Zoo Biology, 25(6), 527–537. https://doi.org/10.1002/zoo.20108

Heier, A., Gröne, A., Völlm, J., Kübber-Heiss, A., & Bacciarini, L. N. (2003). Immunohistochemical Study of Retinol-binding Protein in Livers of Polar Bears (Thalarctos maritimus). Veterinary Pathology, 40(2), 196–202. https://doi.org/10.1354/vp.40-2-196

Hein, A., Baumgartner, K., Von Fersen, L., Bechshoft, T., Woelfing, B., Kirschbaum, C., Mastromonaco, G., Greenwood, A. D., & Siebert, U. (2021). Analysis of hair steroid hormones in polar bears (Ursus maritimus) via liquid chromatography–tandem mass spectrometry: Comparison with two immunoassays and application for longitudinal monitoring in zoos. General and Comparative Endocrinology, 310, 113837. https://doi.org/10.1016/j.ygcen.2021.113837

Hein, A., Palme, R., Baumgartner, K., von Fersen, L., Woelfing, B., Greenwood, A. D., Bechshoft, T., & Siebert, U. (2020). Faecal glucocorticoid metabolites as a measure of adrenocortical activity in polar bears (Ursus maritimus). Conservation Physiology, 8(1), coaa012. https://doi.org/10.1093/conphys/coaa012

Jacobi, E. F. (1968). Breeding Facilities for Polar Bears, Thalarctos Maritimus (Phipps, 1774), in Captivity. Bijdragen Tot de Dierkunde, 38(1), 39–46. https://doi.org/10.1163/26660644-03801007

Jaime-Andrade G., J., Avila-Figueroa, D., J. Lozano-Kasten, F., Hernández-Gutiérrez, R. J., Magallón-Gastélum, E., Kasten-Monges, M. J., & Lopes, E. R. (1997). Acute Chagas' cardiopathy in a polar bear (Ursus maritimus) in Guadalajara, Mexico. Revista Da Sociedade Brasileira de Medicina Tropical, 30(4), 337–340. https://doi.org/10.1590/S0037-86821997000400011

Jenness, R., Erickson, A. W., & Craighead, J. J. (1972). Some comparative aspects of milk from four species of bears. Journal of Mammalogy, 53(1), 34. https://doi.org/10.2307/1378825

Kawata, M., Luziga, C., Miyata, H., Sugiura, T., & Wada, N. (2023). Differential expression of myosin heavy chain isoforms type II in skeletal muscles of polar and black bears. Anatomia, Histologia, Embryologia, 52(3), 363–372. https://doi.org/10.1111/ahe.12893

Kelly, K. R., Harrison, M. L., Size, D. D., & MacDonald, S. E. (2015). Individual Effects of Seasonal Changes, Visitor Density, and Concurrent Bear Behavior on Stereotypical Behaviors in Captive Polar Bears (Ursus maritimus). Journal of Applied Animal Welfare Science, 18(1), 17–31. https://doi.org/10.1080/10888705.2014.924832

Kenny, D. E. (1999). Rickets in Two Hand-Reared Polar Bear (Ursus maritimus) Cubs. Journal of Zoo and Wildlife Medicine, 30(1), 132–140.

Kenny, D. E., & Bickel, C. (2005). Growth and development of Polar bear Ursus maritimus cubs at Denver Zoological Gardens. International Zoo Yearbook, 39(1), 205–214. https://doi.org/10.1111/j.1748-1090.2005.tb00021.x

Kleinlugtenbelt, C., Burkevica, A., & Clauss, M. (2023). Body condition scores of large carnivores in 44 European zoos. Journal of Zoo and Aquarium Research, 11(4), 414–421. https://doi.org/10.19227/jzar.v11i4.741

Knepp, T. H. (1939). A quantitative study of the testes of certain mammals. Zoologica : Scientific Contributions of the New York Zoological Society., 24(18), 329–332. https://doi.org/10.5962/p.203639

Knott, K. K., Mastromonaco, G. F., Owen, M. A., & Kouba, A. J. (2017). Urinary profiles of progestin and androgen metabolites in female polar bears during parturient and non-parturient cycles. Conservation Physiology, 5(1). https://doi.org/10.1093/conphys/cox023

Kroshko, J., Clubb, R., Harper, L., Mellor, E., Moehrenschlager, A., & Mason, G. (2016). Stereotypic route tracing in captive Carnivora is predicted by species-typical home range sizes and hunting styles. Animal Behaviour, 117, 197–209. https://doi.org/10.1016/j.anbehav.2016.05.010

Kutska, D. (2009). Variation in visitor perceptions of a polar bear enclosure based on the presence of natural vs. Un☒natural enrichment items. Zoo Biology, 28(4), 292–306. https://doi.org/10.1002/zoo.20226

LaDouceur, E. E. B., Garner, M. M., Davis, B., & Tseng, F. (2014). A retrospective study of end-stage renal disease in captive polar bears (Ursus maritimus). Journal of Zoo and Wildlife Medicine, 45(1), 69–77. https://doi.org/10.1638/2013-0071R.1

Law, G., & Reid, A. (2010). Enriching the lives of bears in zoos. International Zoo Yearbook, 44(1), 65–74. https://doi.org/10.1111/j.1748-1090.2009.00096.x

Leatherman, J., & Ronald, K. (1981). Plasma concentrations of thyroid hormones in a captive and feral polar bear (Ursus maritimus). Comparative Biochemistry and Physiology, 70A, 575–577.

Leishman, E. M., Franke, M., Marvin, J., McCart, D., Bradford, C., Gyimesi, Z. S., Nichols, A., Lessard, M.-P., Page, D., Breiter, C.-J., & Graham, L. H. (2022). The adrenal cortisol response to increasing ambient temperature in polar bears (Ursus maritimus). Animals, 12(6), 672. https://doi.org/10.3390/ani12060672

Lewin, R. A. (1980). Green polar-bears, and other associations of algae with higher vertebrates. Trends in Biochemical Sciences, 5(4), III–IV. https://doi.org/10.1016/0968-0004(80)90245-5

Li, L., & Chen, H.-X. (2023). Further studies on the morphology of Baylisascaris transfuga (Rudolphi, 1819) (Nematoda: Ascaridomorpha: Ascarididae) from the polar bear Ursus maritimus Phipps (Carnivora: Ursidae). Systematic Parasitology, 100(3), 283–289. https://doi.org/10.1007/s11230-023-10087-3

Lu, J., Petri, R., McCart, D., Baxendell-Young, A., & Collins, S. A. (2024). Distinct fecal microbiome between wild and habitat-housed captive polar bears (Ursus maritimus): Impacts of captivity and dietary shifts. PLOS ONE, 19(11), e0311518. https://doi.org/10.1371/journal.pone.0311518

Marsh, J. P. (1886). A Contribution to the Psychology of the Polar Bear (Ursus maritimus Lin.). Science, ns-8(186), 187–188. https://doi.org/10.1126/science.ns-8.186.187

Maślak, R., Sergiel, A., Bowles, D., & Paśko, Ł. (2016). The Welfare of Bears in Zoos: A Case Study of Poland. Journal of Applied Animal Welfare Science, 19(1), 24–36. https://doi.org/10.1080/10888705.2015.1071671

Miller, L., Luebke, J., Matiasek, J., Granger, D., Razal, C., Brooks, H., & Maas, K. (2020). The impact of in□person and video□recorded animal experiences on zoo visitors' cognition, affect, empathic concern, and conservation intent. Zoo Biology, 39, 367–373. https://doi.org/10.1002/zoo.21565

Nachtigall, P. E., Supin, A. Y., Amundin, M., Röken, B., Møller, T., Mooney, T. A., Taylor, K. A., & Yuen, M. (2007). Polar bear Ursus maritimus hearing measured with auditory evoked potentials. Journal of Experimental Biology, 210(7), 1116–1122. https://doi.org/10.1242/jeb.02734

Owen, M. A., & Bowles, A. E. (2011). In-air auditory psychophysics and the management of a threatened carnivore, the polar bear (Ursus maritimus). International Journal of Comparative Psychology, 24(3). https://doi.org/10.46867/IJCP.2011.24.03.05

Owen, M. A., Pagano, A. M., Wisdom, S. S., Kirschhoffer, B., Bowles, A. E., & O'Neill, C. (2021). Estimating the Audibility of Industrial Noise to Denning Polar Bears. The Journal of Wildlife Management, 85(2), 384–396. https://doi.org/10.1002/jwmg.21977

Owen, M. A., Swaisgood, R. R., Slocomb, C., Amstrup, S. C., Durner, G. M., Simac, K., & Pessier, A. P. (2015). An experimental investigation of chemical communication in the polar bear: Scent communication in polar bears. Journal of Zoology, 295(1), 36–43. https://doi.org/10.1111/jzo.12181

Pagano, A. M., Carnahan, A. M., Robbins, C. T., Owen, M. A., Batson, T., Wagner, N., Cutting, A., Nicassio-Hiskey, N., Hash, A., & Williams, T. M. (2018). Energetic costs of locomotion in bears: Is plantigrade locomotion energetically economical? Journal of Experimental Biology, 221(12), jeb175372. https://doi.org/10.1242/jeb.175372

Pagano, A. M., Cutting, A., Nicassio□Hiskey, N., Hash, A., & Williams, T. M. (2019). Energetic costs of aquatic locomotion in a subadult polar bear. Marine Mammal Science, 35(2), 649–659. https://doi.org/10.1111/mms.12556

Pagano, A. M., Durner, G. M., Rode, K. D., Atwood, T. C., Atkinson, S. N., Peacock, E., Costa, D. P., Owen, M. A., & Williams, T. M. (2018). High-energy, high-fat lifestyle challenges an Arctic apex predator, the polar bear. Science, 359(6375), 568–572. https://doi.org/10.1126/science.aan8677

Pagano, A., Rode, K., Cutting, A., Owen, M., Jensen, S., Ware, J., Robbins, C., Durner, G., Atwood, T., Obbard, M., Middel, K., Thiemann, G., & Williams, T. (2017). Using tri-axial accelerometers to identify wild polar bear behaviors. Endangered Species Research, 32, 19–33. https://doi.org/10.3354/esr00779

Pastorino, G. Q., Cartwright, R., Brereton, J. E., Wilkins, K., & Preziosi, R. (2021). The Challenges of using Camera Traps to Investigate Zoo-Housed Polar Bear (Ursus maritimus) Nocturnal Behaviour. Journal of Veterinary Medicine and Animal Sciences, 4(2), 1080.

Poulsen, E. M. B., Honeyman, V., Valentine, P. A., & Teskey, G. C. (1996). Use of fluoxetine for the treatment of stereotypical pacing behavior in a captive polar bear. Journal of the American Veterinary Medical Association, 209(8), 1470–1474. https://doi.org/10.2460/javma.1996.209.08.1470

Poulsen, M., Madsen, R. V. E., Sørensen, S. B. F., Hansen, T. B., Gottschalk, A., Linder, A. C., Alstrup, A. K. O., Pagh, S., Jensen, T. H., & Pertoldi, C. (2021). Enrichment study in three captive polar bears (Ursus maritimus) at Aalborg Zoo. GABJ, 5(3), 97–106. https://doi.org/10.46325/gabj.v5i3.149

Powell, D. M., & Baskir, E. (2021). Behavior and Habitat Use Remain Diverse and Variable in Modern Zoological Exhibits over the Long-Term: Case Studies in 5 Species of Ursidae. Journal of Zoological and Botanical Gardens, 2(4), 677–703. https://doi.org/10.3390/jzbg2040049

Prop, J., Staverløkk, A., & Moe, B. (2020). Identifying individual polar bears at safe distances: A test with captive animals. PLOS ONE, 15(2), e0228991. https://doi.org/10.1371/journal.pone.0228991

Renner, M. J., & Kelly, A. L. (2006). Behavioral Decisions for Managing Social Distance and Aggression in Captive Polar Bears (Ursus maritimus). Journal of Applied Animal Welfare Science, 9(3), 233–239. https://doi.org/10.1207/s15327604jaws0903_5

Robbins, C. T., Tollefson, T. N., Rode, K. D., Erlenbach, J. A., & Ardente, A. J. (2022). New insights into dietary management of polar bears (Ursus maritimus) and brown bears (U. arctos). Zoo Biology, 41(2), 166–175. https://doi.org/10.1002/zoo.21658

Rode, K. D., Atwood, T. C., Thiemann, G. W., St. Martin, M., Wilson, R. R., Durner, G. M., Regehr, E. V., Talbot, S. L., Sage, G. K., Pagano, A. M., & Simac, K. S. (2020). Identifying reliable indicators of fitness in polar bears. PLOS ONE, 15(8), e0237444. https://doi.org/10.1371/journal.pone.0237444

Rode, K. D., Robbins, C. T., Stricker, C. A., Taras, B. D., & Tollefson, T. N. (2021). Energetic and health effects of protein overconsumption constrain dietary adaptation in an apex predator. Scientific Reports, 11(1), 15309. https://doi.org/10.1038/s41598-021-94917-8

Ross, S. R. (2006). Issues of choice and control in the behaviour of a pair of captive polar bears (Ursus maritimus). Behavioural Processes, 73(1), 117–120. https://doi.org/10.1016/j.beproc.2006.04.003

Ross, T. R., Thiemann, G. W., Kirschhoffer, B. J., Kirschhoffer, J., York, G., Derocher, A. E., Johnson, A. C., Lunn, N. J., McGeachy, D., Trim, V., & Northrup, J. M. (2024). Telemetry without collars: Performance of fur- and ear-mounted satellite tags for evaluating the movement and behaviour of polar bears. Animal Biotelemetry, 12(1), 18. https://doi.org/10.1186/s40317-024-00373-2

Rzucidlo, C. L., Curry, E., & Shero, M. R. (2023). Non-invasive measurements of respiration and heart rate across wildlife species using Eulerian Video Magnification of infrared thermal imagery. BMC Biology, 21(1), 61. https://doi.org/10.1186/s12915-023-01555-9

Scholander, P. F., Hock, R., Walters, V., Johnson, F., & Irving, L. (1950). Heat regulation in some arctic and tropical mammals and birds. The Biological Bulletin, 99(2), 237–258. https://doi.org/10.2307/1538741

Shepherdson, D., Lewis, K. D., Carlstead, K., Bauman, J., & Perrin, N. (2013). Individual and environmental factors associated with stereotypic behavior and fecal glucocorticoid metabolite levels in zoo housed polar bears. Applied Animal Behaviour Science, 147(3–4), 268–277. https://doi.org/10.1016/j.applanim.2013.01.001

Skovlund, C., Kirchner, M., Moos, L., Alsted, N., Manteca, X., Tallo-Parra, O., Stelvig, M., & Forkman, B. (2021). A critical review of animal-based welfare indicators for polar bears (Ursus maritimus) in zoos: Identification and evidence of validity. Animal Welfare, 30(1), 1–18. https://doi.org/10.7120/09627286.30.1.001

Skovlund, C. R., Kirchner, M. K., Contiero, B., Ellegaard, S., Manteca, X., Stelvig, M., Tallo-Parra, O., & Forkman, B. (2023). Qualitative Behaviour Assessment for zoo-housed polar bears (Ursus maritimus): Intra- and inter-day consistency and association to other indicators of welfare. Applied Animal Behaviour Science, 263, 105942. https://doi.org/10.1016/j.applanim.2023.105942

Stamper, M. A. (2024). Hypospadias in a Polar Bear (Ursus maritimus).

Steinman, K. J., O'Brien, J. K., Fetter, G. A., Curry, E., Roth, T. L., Owen, M. A., & Robeck, T. R. (2017). Enzyme immunoassay analysis for androgens in polar bear (Ursus maritimus) urine using enzyme hydrolysis. Aquatic Mammals, 43(3), 245–253. https://doi.org/10.1578/AM.43.3.2017.245

Stirling, I., Laidre, K. L., & Born, E. W. (2021). Do wild polar bears (Ursus maritimus) use tools when hunting walruses (Odobenus rosmarus)? Arctic, 74(2), 175–187. https://doi.org/10.14430/arctic72532

Stoops, M. A., MacKinnon, K. M., & Roth, T. L. (2012). Longitudinal fecal hormone analysis for monitoring reproductive activity in the female polar bear (Ursus maritimus). Theriogenology, 78(9), 1977–1986. https://doi.org/10.1016/j.theriogenology.2012.07.005

Testini, G., Papini, R., Lia, R. P., Parisi, A., Dantas-Torres, F., Traversa, D., & Otranto, D. (2011). New insights into the morphology, molecular characterization and identification of Baylisascaris transfuga (Ascaridida, Ascarididae). Veterinary Parasitology, 175(1–2), 97–102. https://doi.org/10.1016/j.vetpar.2010.09.017

Tidière, M., Colchero, F., Staerk, J., Adkesson, M. J., Andersen, D. H., Bland, L., Böye, M., Brando, S., Clegg, I., Cubaynes, S., Cutting, A., De Man, D., Derocher, A. E., Dorsey, C., Elgar, W., Gaglione, E., Anderson Hansen, K., Jungheim, A., Kok, J., … Conde, D. A. (2023). Survival improvements of marine mammals in zoological institutions mirror historical advances in human longevity. Proceedings of the Royal Society B: Biological Sciences, 290(2009), 20231895. https://doi.org/10.1098/rspb.2023.1895

Travis, A.-M., Luff, J., Womble, M., Garner, M. M., & LaDouceur, E. E. B. (2025). Viral and squamous papillomas in captive polar bears (Ursus maritimus). Veterinary Pathology, 03009858251317478. https://doi.org/10.1177/03009858251317478

van Gessel, C. (2015). Polar Bear Mother-Offspring Interactions in Maternity Dens in Captivity. Zoo Biology, 34, 453–459. https://doi.org/10.1002/zoo.21232

Velguth, K. E., Rochat, M. C., Langan, J. N., & Backues, K. (2009). Acquired Umbilical Hernias in Four Captive Polar Bears (Ursus maritimus). Journal of Zoo and Wildlife Medicine, 40(4), 767–772. https://doi.org/10.1638/2008-0168.1

Ware, J. V., Rode, K. D., Pagano, A. M., Bromaghin, J., Robbins, C. T., Erlenbach, J., Jensen, S., Cutting, A., Nicassio-Hiskey, N., Hash, A., Owen, M., & Jansen, H. T. (2015). Validation of mercury tip-switch and accelerometer activity sensors for identifying resting and active behavior in bears. Ursus, 26(2), 86–96. https://doi.org/10.2192/URSUS-D-14-00031.1

Watts, P. D., Øritsland, N. A., & Hurst, R. J. (1987). Standard metabolic rate of polar bears under simulated denning conditions. Physiological Zoology, 60(6), 687–691. https://doi.org/10.1086/physzool.60.6.30159983

Wechsler, B. (1992). Stereotypies and attentiveness to novel stimuli: A test in polar bears. Applied Animal Behaviour Science, 33(4), 381–388. https://doi.org/10.1016/S0168-1591(05)80074-7

White, B. C., Kozlowski, C., Taylor, S. R., Franklin, J. A., & Burns, R. (2015). Faecal glucocorticoid metabolite concentrations during ACTH challenge tests in captive grizzly bears (Ursus arctos horribilus) and polar bears. Journal of Zoo and Aquarium Research, 3(2), 59–62.

Wojtusik, J., Philpott, M., Donelan, E., Stoops, M. A., Roth, T. L., & Curry, E. (2024). Testosterone concentrations in juvenile male polar bears (Ursus maritimus). Theriogenology Wild, 5, 100104. https://doi.org/10.1016/j.therwi.2024.100104

Wojtusik, J., Roth, T. L., & Curry, E. (2022). Case studies in polar bear (Ursus maritimus) sperm collection and cryopreservation techniques. Animals, 12(4), 430. https://doi.org/10.3390/ani12040430

Wyatt, E. K., Schmidt, V., & Buckley, L. (2024). Diagnosis and treatment of dermatophytic furunculosis in a polar bear (Ursus maritimus). Veterinary Record Case Reports, 12(1), e777. https://doi.org/10.1002/vrc2.777

Zhang, Y. P., & Ryder, O. A. (1993). Mitochondrial DNA sequence evolution in the Arctoidea. Proceedings of the National Academy of Sciences, 90(20), 9557–9561. https://doi.org/10.1073/pnas.90.20.9557

Zuerl, M., Dirauf, R., Koeferl, F., Steinlein, N., Sueskind, J., Zanca, D., Brehm, I., Fersen, L. V., & Eskofier, B. (2023). PolarBearVidID: A video-based re-identification benchmark dataset for polar bears. Animals, 13(5), 801. https://doi.org/10.3390/ani13050801

Zuerl, M., Stoll, P., Brehm, I., Raab, R., Zanca, D., Kabri, S., Happold, J., Nille, H., Prechtel, K., Wuensch, S., Krause, M., Seegerer, S., Von Fersen, L., & Eskofier, B. (2022). Automated Video-Based Analysis Framework for Behavior Monitoring of Individual Animals in Zoos Using Deep Learning—A Study on Polar Bears. Animals, 12(6), 692. https://doi.org/10.3390/ani12060692

Back Cover: A wild bear in Churchill, Manitoba.
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