INTEGRATED APPROACHES TO POLAR BEAR (*URSUS MARITIMUS*) CONSERVATION: EXPLORING THE POTENTIAL OF PHOTOGRAMMETRIC RESEARCH TECHNIQUES AND CITIZEN SCIENCE IN TOURISM SETTINGS

By

Cassandra Daye Debets

A major paper submitted to the Faculty of Environmental Studies
in partial fulfillment of the requirements for degree of

Master in Environmental Studies

Supervised By

Dr. Gregory Thiemann

York University
Toronto, Ontario, Canada
August 30th 2017

Abstract

Rapid environmental change can be seen in many ecosystems today. The Arctic ecosystem is especially being altered by global climate change. It is important to monitor the health of not only the Arctic ecosystem but also the wildlife within it. Wildlife research has been the foundation of many management programs and conservation initiatives. Polar bears (*Ursus maritimus*) are apex predators and have been extensively studied in some regions of the Arctic. However, there are some populations that have not been as well studied, and thus we know little about. The development of new research techniques can contribute to an improved understanding of less-studied populations. Photogrammetric techniques have been used to estimate morphological traits in various species. I investigated the use of digital photogrammetry for polar bears in the western Hudson Bay subpopulation, using a laser rangefinder and camera to obtain photographs with exact distances to measure seven morphological traits. I collected non-invasive morphological measurements from tourist tundra vehicles outside of Churchill, Manitoba during the months of October and November. Non-invasive methods of obtaining measurements and determining relationship to body condition are valuable for monitoring polar bear populations, as many of these populations are being adversely affected by anthropogenic global climate change. The technique I developed shows potential to become a foundation for a non-invasive polar bear body condition-monitoring program for both tourism and community based monitoring practices. In addition to ecological research, environmental education initiatives can also support and enhance conservation outcomes. Providing educational opportunities for citizens to connect to the natural world can deepen their understanding, appreciation and overall desire to protect it. Citizen science is an avenue to achieve both environmental education and research goals, and can also be conducted in tourism settings. Integrating citizen science into mainstream tourism can encourage the creation of educational ecotourism that contributes to wildlife conservation. The educational components in ecotourism may increase the knowledge of tourists and their respect for the environment, hopefully inspiring them to make more sustainable choices.

"We cannot win this battle to save species and environments without forging an emotional bond between ourselves and nature as well- for we will not fight to save what we do not love"

— Stephen. J. Gould

Foreword

This major research was undertaken in partial fulfillment of the requirements for my degree of Master in Environmental Studies and is my final submission for the program. My major paper engages with various elements of my Plan of Study's [POS] area of concentration, *Arctic Wildlife Ecology, Education and Conservation*. I explored the intersection of the three main topics: ecological research; environmental education and ecotourism; and their connections to conservation.

This paper is focused on all of the learning objectives outlined in the first component of my POS, *Biological Conservation*, where I reviewed current issues in Arctic wildlife conservation. I concentrated on the ecology and conservation of polar bears (*Ursus maritimus*), considered an iconic Arctic species, as well as a popular symbol for climate change and Arctic conservation. Specifically I reviewed polar bear research studies that have contributed to the body of knowledge, influencing various policies and status assessments.

My second component, *Environmental Education*, and third component, *Ecotourism*, are both also addressed in this paper. My primary research was focused on the development of a research technique to monitor polar bears that could be utilized in tourism settings. Understanding the theories and principles of both environmental education and ecotourism are necessary to build a citizen science research program aimed at monitoring polar bear body condition successfully, both to acquire data and provide citizens with outreach opportunities to understand the environment better. In order to offer the most value for conservation outcomes, a citizen science program needs to conduct meaningful research in a systematic way, in addition to educating the citizen scientists, so that beyond their tourism experience they can positively contribute to conserving the earth's natural environments.

I had the opportunity to be involved in preliminary research work leading up to my major research, which provided me with a foundation that significantly guided my choice of courses. I had a well-defined concept of the elements to be incorporated into this major paper and I focused on the development of a non-invasive technique to measure polar bear morphological traits. I was able to use many of my courses to do preliminary literature reviews that were incorporated into chapters within this major paper. Courses that were particularly useful were Protected Area Management, Resource Management and Applied Ecology; aspects of my coursework for these courses were incorporated into this major paper.

Acknowledgements

I would like to thank my advisor and supervisor, Dr. Gregory Thiemann, for his expertise, support, kindness and ongoing guidance and patience. I am especially grateful to have been afforded the opportunity to learn a great deal from Greg while working in his lab, where he taught me many skills that extend beyond the boundaries of my MES program and will be valuable in my future career.

This project would not have been possible without the support and cooperation of Polar Bears International [PBI]. I am grateful for being a member of the Citizen Science project team and for being fortunate enough to be able to utilize aspects of the project for my own graduate work. I am especially grateful to Dr. Steven Amstrup, Krista Wright and BJ Kirschhoffer (PBI) for their guidance, advice, and collaboration over the last few years. I thank Dr. Merav Ben-David (University of Wyoming) for her scientific advice over the course of the project as well as scientific collaborations with Dr. Liz Flaherty and Randy Creaser (Purdue University). I also thank Trent McDonald (West Tech Inc.) for his contributions and design in data collection.

I offer my gratitude to JoAnne Simerson, Kt Miller, and Emily Ringer (PBI) for their logistical support, and many laughs in Churchill. Thanks to both Geoff York and Alysa McCall (PBI) for their valuable input and discussions in Churchill regarding the project. I thank the participants of the In-Field Ambassador program for their cooperation, knowledge and friendship. To all the volunteers of PBI who make both the Churchill operations and programs a success, thank you. Also to all the sponsors of PBI for the generous programmatic support and with my gratitude; Canada Goose, Banrock Station, the Body Shop Foundation, the North Carolina Zoo, SeaWorld and the Pittsburg Zoo & PGG Aquarium.

Numerous individuals aided in data collection for this project and I am especially appreciative of Sarah Health, Jadelys Tonos and Jordan Winter for their assistance in the field. I would also like to thank the veterinary and keeper staff of the Assiniboine Park Zoo (APZ) for collecting measurements from their captive polar bears. I am particularly grateful to Dr. Stephen Petersen (APZ) for his coordination efforts and for our many discussions at the zoo and in Churchill.

I gratefully acknowledge Frontiers North Adventures for both their generosity and support of the project. I appreciate the logistical aid from John Gunter, Stephanie Burke, Simon Gee, Tricia Schers, and Su Lowery. Working with a tourism company, I was fortunate to work with many skilled tourism guides who helped make the project possible with their valuable insights, assistance and also made the days I spent out on the tundra so much more enjoyable; thanks to Bob Debets, Kevin Burke, Jim Baldwin, Doug Ross, David Reid, Hayley Shepard, Neil Mumby, JP McCarthy, Alex Mueller, Marc Hebert, Markus Petak, Derek Kyosita, Richard Day, Jessica Finn, and Angele Watrin Prodaehl.

I would also like to thank Dr. Gail Fraser for her advice during my MES II – MES III exam. A special thanks to my lab mates Melissa Galicia, Luana Sciullo and Brandon Laforest for their advice, support and suggestions throughout my research process and comments on early versions of this major paper, but in particular for the fond memories I have working alongside them, even the time I was choking. I am also grateful to the many friends within the FES community, who helped me envision the elements to be incorporated into this major paper. I especially want to thank Brenna Thompson, Maris Grundy, Coral Voss, Aleks Lepiarska, and Edward Marchant for their encouragement, support, and meaningful conversations pertaining to our studies.

I wish to extend heart-felt thanks for the constant support and encouragement from my family and friends, even from far away. I am exceptionally grateful to the support my parents, and especially my dad for sharing his passion for the Arctic and polar bears with me, and encouraging me to pursue my goals. Lastly, my deepest appreciation is extended to Garrett for his continued support and faith in all that I do, thank you.

Table of Contents

Chapter 1: Introduction

"An understanding of the natural world and what's in it is a source of not only a great curiosity but great fulfillment."

— David Attenborough

Background

Anthropogenic climate change is a prominent issue affecting global biodiversity, leading to dire predictions for species persistence (Root et al. 2003; Thomas et al. 2004; Malcolm et al. 2006). Climate change can alter species' life cycles, trophic networks, and distributions, all of which contribute to impairments in overall ecosystem functions (Mawdsley et al. 2009; Bellard et al. 2012). Several studies have predicted species extinction of between 15-57% by 2080 (reviewed by Moritz and Agudo 2013). The viability of species populations depends on the quality, quantity and connectivity of their habitat (Hodgson et al. 2011). It is anticipated that climate change will affect all levels of biodiversity, from the individual to the broader ecosystem levels (Botkin et al. 2007). Thomas et al. (2004), for example, modeled over 1100 species' distributions in six regions and concluded that endemic species with restricted ranges are the most vulnerable. Most anthropogenic activities (e.g. deforestation, urbanization) lead to habitat destruction, which exacerbates species vulnerability to climate change (Schipper et al. 2008). Therefore, understanding how species respond to both climate change and habitat loss is crucial for biological conservation. Furthermore, species inhabiting the Arctic are of particular concern as they face significant climate change-induced habitat modifications (Burek et al. 2008; Laidre et al. 2008; 2015; Moore and Huntington 2008).

Changes in Arctic Sea Ice Habitat

Climate change has decreased the quality and quantity of Arctic sea ice habitat (Stroeve et al. 2007; 2012), negatively affecting Arctic wildlife populations (Laidre et al. 2008; Kovacs et al. 2011; Stirling and Derocher 2012; Post et al. 2013). Since 1979, when Arctic sea ice monitoring via satellites began, declines in both the extent and thickness of sea ice have been observed (Comiso 2006). Forecasts continue to predict further and increasingly rapid declines in sea ice conditions (Stroeve et al. 2007; Overland and Wang 2013). Not only have extent and duration of sea ice changed, but sea ice fragmentation has intensified in three southern regions of the Canadian Arctic (Sahanatien and Derocher 2012). Most notable is the loss of preferred spring sea ice habitat (86-100% sea ice concentration) for polar bears (*Ursus maritimus*) (Sahanatien and Derocher 2012).

Hudson Bay, a large body of water located towards the southern extent of the Arctic ocean, has already experienced warming air temperatures and an increase in the ice-free season (Gagnon and Gough 2005; Comiso 2006; Stirling and Parkinson 2006). Gagnon and Gough (2005) reported a statistically significant trend of ice breakup occurring 1.25 days earlier each year between 1971 and 2003; furthermore, freeze-up was also reported to occur 0.55 days later each year during the same time period. The warmer air temperatures, which have led to longer ice-free seasons, have altered the ecosystem dynamics within the Hudson Bay region (Ferguson et al. 2005; Stirling and Parkinson 2006; Higdon and Ferguson 2009).

Effects of Climate Change on Marine Mammals

Ongoing changes in sea ice phenology are affecting life history traits and behavioral ecology of many marine mammal species. The survival of Arctic marine mammals is contingent on the sea ice and they are sensitive to any alternations to their habitat caused by climate change (Laidre et al. 2008). Numerous Arctic pinnipeds depend on the sea ice for hauling out, whelping, molting, and foraging, and, in addition, some cetaceans use the sea ice as a barrier to predators. The loss of sea ice has resulted in reduced habitat availability, and with continued increases in both air and water temperatures, changes in the primary production, prey availability, and alterations of the Arctic food webs are expected (Bluhm and Gradinger 2008).

Historically, the primary threat to marine mammals was over-hunting by humans, particularly due to the whaling industry. Although harvest management has improved, current threats to marine mammal persistence are still human-caused, including increased boat traffic, industry (oil and gas) exploration, increased pollutants and climate change (Laidre et al. 2008; Huntington 2009). There is still insufficient data regarding life history and ecology of many Arctic species, which are continuing to be affected through habitat disturbance (Laidre et al. 2008). For example, ringed seals (*Pusa hispida*), the most abundant Arctic pinniped, have had lower recruitment rates in the Hudson Bay region due to climatic warming and reduced snowfall (Ferguson et al. 2005; Iacozza and Ferguson 2014). Additionally, there have been increased sightings of a top transient predator, killer whales (*Orcinus Orca*), in southern regions of the Arctic due to longer ice-free periods (Higdon and Ferguson 2009). The change in sea ice phenology has altered, and will continue to alter, the dynamics of the Arctic marine ecosystem, particularly in southern regions, where the effects of climate change will be first seen.

Moore and Huntington (2008) reviewed the impacts of climate change on Arctic marine mammals and their resilience to environmental change, specifically related to sea ice loss. Not all areas of the Arctic have shown the same levels of habitat degradation. For instance, sub-Arctic ecosystems, such as areas in Hudson Bay and Southern Beaufort Sea, have seen especially rapid sea ice decline (Gagnon and Gough 2005; Amstrup et al. 2008; Laidre et al. 2015). It is crucial that frameworks be developed for sampling protocols to enlist and protect Arctic wildlife, particularly sensitive marine mammals. It is vital that efforts be put towards research planning, resource management and proper communication (Folke et al. 2004; Moore and Huntington 2008). Conservation plans must be developed and adjusted rapidly as climate change induced habitat loss continues at accelerated rates (Hannah 2011; Laidre et al. 2015).

Consequences for Polar Bears

Many Arctic marine mammals are sensitive to climate change induced effects on the sea ice habitat (Laidre et al. 2008). The negative consequences for ice-obligate species, such as polar bears, have been documented with associated Arctic sea ice loss (Laidre et al. 2008; Post et al. 2013). Laidre et al. (2008) assessed polar bears as one of the most habitat-sensitive marine mammals because of their dependence on sea ice. Considered an ice-obligate species, polar bears are dependent on sea ice as a platform for travelling, mating, and, in some regions, for denning (Amstrup 2003). Most importantly, polar bears use the sea ice to hunt their primary prey, ringed seals (Thiemann et al. 2008). Studies have demonstrated that without sea ice, access to prey will become increasingly limited, which will lead to declines in body condition, reproduction, and overall survival (Regehr et al. 2007; Rode et al. 2010; Molnár et al. 2010).

The modifications to sea ice conditions are not uniform across the Arctic and there have been disproportionate effects on the sea ice habitat quality and the polar bear populations occupying the various regions (Amstrup et al. 2008). Several polar bear populations have already been negatively affected by climate change and the subsequent habitat degradation, particularly those inhabiting lower latitudes (Stirling and Parkinson 2006). For instance, polar bears in western Hudson Bay have shown signs of reduced body condition, reproduction, and survival, as well as declining population size as a result of sea ice decline (Stirling et al. 1999; Regehr et al. 2007). The Southern Beaufort Sea population, another southern subpopulation, has shown a decline in population of 40% over the last six years in response to sea ice loss (Bromaghin et al. 2015).

Earlier break-up of sea ice is considered to be the cause of the Western Hudson Bay (WH) polar bear population decline (from 1200 to 935 individuals) between 1984 and 2004 (Regehr et al. 2007). It is predicted that if the ice-free period increases, 2-3% of adult male polar bears will die of starvation with a fasting period of 120 days, 9-21% for a fasting period of 180 days, and if 210 days, 29-48% of adult male polar bears are expected to die of starvation in this subpopulation (Molnár et al. 2010; 2014).

Polar bears in southern regions have shown numerous negative ecological responses to the reduced quality of sea ice habitat in the southern extent of the circumpolar range. There is a need for baseline data on polar bears inhabiting higher latitude areas, which have not yet experienced the same consequences of sea ice loss as southern regions. With continued climate warming, there is an increased likelihood that High Arctic areas will become important refugia for Arctic marine species (Derocher et al. 2004). However, recent sea ice modeling suggests future conditions across the Canadian Archipelago may not be able to support polar bear feeding and reproduction with ongoing climate change as previously predicted (Hamilton et al. 2014). Understanding how polar bear populations will respond to climate change-induced habitat modifications is dependent on information gained through ecological research studies aimed at polar bear ecology, prey selection, and habitat preferences, which will also be crucial elements for establishing effective management and conservation strategies.

Lack of data has diminished the number of effective conservation plans for the Arctic and its species (Laidre et al. 2008). With anthropogenic climate change, polar bear conservation and management must quickly adapt to rapid ecosystem change that has affected, and will continue to affect, polar bears (Stirling and Parkinson 2006; Peacock et al. 2011; Derocher et al. 2012). Amstrup et al. (2008) concluded that with current greenhouse gas emissions, polar bears could face extinction by the end of the 21st century, and experience massive population declines by mid-century.

Major Research Objectives

The goal of this major paper was to explore current approaches to Arctic wildlife conservation, specifically polar bears. In particular, I wanted to gain an understanding of the link between ecological research and environmental education outreach opportunities, which may improve future conservation efforts within the Arctic ecosystem. With ongoing climate change, it is essential to understand the ecological consequences for the Arctic and the impacts on wildlife inhabitants. I primarily focused my major research on polar bear ecology. Most importantly, through the application of photogrammetric techniques, I aimed to measure polar bear morphological traits and discuss their application to answering ecological questions related to polar bear body condition. In Chapter 2, *Polar Bear Research and Management*, I summarized polar bear conservation history and current threats. I also discussed how polar bear research has contributed to the current management practices that have been implemented. In Chapter 3, *Estimation of Polar Bear (Ursus maritimus) Morphological Traits Using Photogrammetry,* I primarily investigated how to measure polar bear morphological traits non-invasively using photographs collected from tourism vehicles in Churchill, Manitoba. This chapter is formatted for manuscript preparation. In Chapter 4, *Connecting Citizens to Nature through Environmental Education and Tourism,* I summarized how environmental education affords the public an opportunity to connect with the environment, in the hopes of improving conservation strategies using citizen science as the main example of environmental education. In Chapter 5, *Conclusion,* I discussed the connections between the learning components in my plan of study, summarized implications and conclusions of my research, and identified future research requirements

Chapter 2: Polar Bear Management and Research

"Look deep into nature, and then you will understand everything better."

— Albert Einstein

Polar Bear Conservation History

Polar bears (*Ursus maritimus*) are charismatic megafauna widely distributed throughout the circumpolar Arctic, and are classified into 19 discrete subpopulations (Obbard et al. 2010). Recently, polar bears have become a popular icon to symbolize the need for Arctic Conservation. Beyond captivating the attention of many citizens around the globe, polar bears play an integral cultural role in many northern communities; the Inuit and First Nations in Canada and Eskimos in the United States have historically relied on polar bears as a source of food, dog feed, clothing, and cultural purposes (Jonkel 1970). Additionally, polar bears have been an essential source of income since the fur trade in the early 20th century, and in Inuit guided sport hunting, which also brings tourism to Northern regions (Freeman and Wenzel 2006; Dowsley 2009; Lemelin 2006; Wenzel 2011).

During the late 1960s and early 1970s polar bears were considered to be at risk of extinction due to overharvesting (Freeman and Wenzel 2006), when hunting peaked at 1500 individuals per year throughout their range (Prestrud and Stirling 1994). The decline in polar bear populations raised concerns among the five countries within their range (Canada, Denmark [Greenland], Norway, Russia, and the United States). These concerns lead to the inception and signing of the *International Agreement on the Conservation of Polar Bears* (The Agreement) (Prestrud and Stirling 1994). The Agreement outlined the importance of increased harvest management and scientific research programs, and has guided both of these fields, and thus the conservation of polar bears, since it was signed in 1973 (Prestrud and Stirling 1994; Peacock et al. 2011). Hunting was historically the primary conservation concern for polar bears (Prestrud and Stirling 1994) and Canada has managed a harvest since the Agreement. Aboriginal treaty and land claim rights create a framework under which Canada manages polar bear harvest

(Peacock et al. 2011), and to date harvest in Canada is considered not to be a major threat to polar bear populations. Canada also regulates polar bear sport hunts by non-Inuit people. During a sport hunt, an Inuit person must guide hunters by dog team; consequently, many community members find employment through the polar bear sport hunt (Wenzel 2005; Freeman and Wenzel 2006).

Given the management and compliance by Inuit communities, the sport hunt, which is of great socioeconomic value to many northern indigenous communities (Dowsley 2009), is expected to remain sustainable in forthcoming years (Freeman and Wenzel 2006). A single sport hunting excursion can generate approximately $10,000-30,000 (CDN) in income for a given community (Wenzel 2005; Dowsley 2010). Olar et al. (2011) estimated that the polar bear sport hunt yields $1.3 million (CDN) on an annual basis. The Inuit subsistence hunt reportedly yields an additional $0.6 million (CDN) per year from the Inuit selling meat and hides. Therefore, it is crucial that polar bear management be continued in Canada’s north to ensure economic opportunities for northern communities and sound conservation efforts.
The focus on polar bear conservation has now shifted from depleting populations due to unregulated harvest to habitat loss due to anthropogenic climate change (Stirling and Derocher 1993; Stirling and Parkinson 2006; Peacock et al. 2011). With the growing concern of disappearing sea ice habitat, effective management depends on empirical data from research monitoring of polar bear populations and sea ice dynamics. Several studies have investigated the relationships between polar bear survival and sea ice habitat and have forecasted a continued decline in sea ice (Stirling and Derocher 1993; Derocher et al. 2004; Stirling and Parkinson 2006; Castro de la Guardia et al. 2013).

Polar Bear Management in Canada

Canada plays a prominent role in the conservation of polar bears, as 13 out of the 19 subpopulations are within the nation's boundaries (Figure 2-1), representing approximately two thirds of the global population (Obbard et al. 2010). Canada manages polar bears in compliance with the Agreement, the *Convention on International Trade in Endangered Species* (CITES), and the federal *Species at Risk Act* (SARA), along with provincial and territorial statutes. The Canadian federal government lists polar bears as a species of special concern under SARA, resulting in no legal federal policy requiring explicit protection of polar bears or their habitat. A review of species' listings in Canada found that many species were outright denied listing (Mooers et al. 2010). Notable for polar bears, the review concluded that many species listed as special concern did not have the necessary action plans with any conservation goals (Mooers et al. 2010), which is a common issue within mammalian conservation (Redford et al. 2011). Research efforts are not distributed equally across polar bear subpopulations, thus there are some subpopulations where population trends are poorly understood. For example, many High Arctic subpopulations have not been assessed since the mid-1990s (Table 2-1), leaving their current status unknown. As a result, determining sustainable harvest levels is difficult and requires managers to make assumptions about general population dynamics and recruitment (Vongraven et al. 2011). Managing and researching each subpopulation can be difficult – if not impossible – and changes in sea ice is not occurring equally across the circumpolar basin (Amstrup et al. 2008). To simplify these complex ecological processes for management purposes, the 19 subpopulations have been grouped into four broad ecoregions (Table 2-1; Figure 2-1) based on sea ice dynamics. For this management strategy to function, it must be assumed that polar bears in subpopulations in the same ecoregion will respond similarly to habitat changes, and data collected from one subpopulation could be extrapolated to predict trends that are happening in other subpopulations that are less researched.

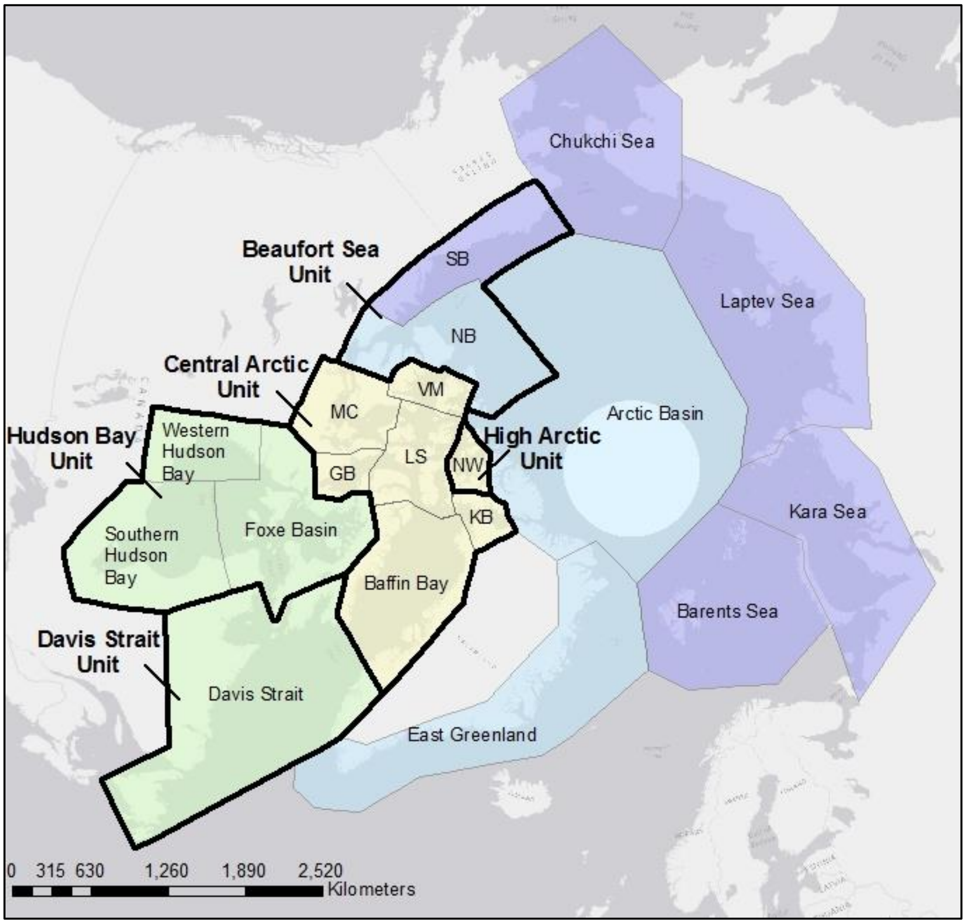


Figure 2-1: The 19 discrete subpopulations of polar bears distributed throughout the circumpolar Arctic as recognized by the IUCN/Polar Bear Specialist Group categorized according to sea ice ecoregions identified by Amstrup et al. (2008). Bolded Lines depict proposed designatable units for Canadian management proposed by Thiemann et al. (2008). Abbreviations refer to the following subpopulations: Gulf of Boothia (GB), Kane Basin (KB), Lancaster Sound (LS), M'Clintock Channel (MC), Northern Beaufort Sea (NB), Norwegian Bay (NW), Southern Beaufort Sea (SB), and Viscount Melville Sound (VM). Green is Seasonal Ice, Yellow is Archipelago, Blue is Convergent Ice and Purple is Divergent Ice.

Within Canada, Thiemann et al. (2008b) proposed five biologically distinct designatable units (DU) to improve conservation efforts. DUs are used by COSEWIC to recognize genetically/biogeographically-distinct intraspecific groups when assessment of the species as a single unit is insufficient (Green 2005). This approach has been adopted by COSEWIC in

Table 2-1: Attributes of the 19 polar bear subpopulations grouped by sea-ice ecoregions and further by purposed designatable units for Canadian management.

Sea Ice Region[1]	Designatable Unit[2]	Subpopulation[3]	Jurisdiction	Population Estimate (95% CI)[4]	Year Assessed[4]	Trend[4]	Methods[a]	Quality of Baseline Data[5]
Archipelago	High Arctic Unit	Norwegian Bay	Canada	203(115-291)	2006	Unknown	CMR	Medium
Archipelago	Central Arctic Unit	Kane Basin	Canada	164 (94-234)	1997	Declining	CMR	Medium
Archipelago	Central Arctic Unit	Gulf of Boothia	Canada	1592 (870-2314)	2000	Stable	CMR	Medium
Archipelago	Central Arctic Unit	M'Clintock Channel	Canada	284 (166-402)	2000	Increasing	CMR	Medium
Archipelago	Central Arctic Unit	Lancaster Sound	Canada	2541 (1759-3323)	1997	Unknown	CMR	Medium
Seasonal Ice	Central Arctic Unit	Viscount Melville	Canada	161 (121-201)	1992	Unknown	CMR	Medium
Seasonal Ice	Central Arctic Unit	Baffin Bay	Canada	1546 (690-2402)	2004	Declining	PVA	Medium
Seasonal Ice	Hudson Bay Unit	Southern Hudson Bay	Canada	951 (662-1366)	2012	Stable	DS	Medium
Seasonal Ice	Hudson Bay Unit	Western Hudson Bay	Canada	1030 (754-1406)	2011	Stable	DS/CMR	High
Seasonal Ice	Hudson Bay Unit	Foxe Basin	Canada	2580 (2093-3180)	2010	Stable	DS	Medium
Seasonal Ice	Davis Straight Unit	Davis Straight	Canada/Denmark	2158 (1833 – 2542)	2007	Stable	CMR	Medium
Convergent Ice	No Unit Assessed	East Greenland*	Denmark	Unknown	-	Unknown	-	Medium
Convergent Ice	No Unit Assessed	Arctic Basin*	International	Unknown	-	Unknown	-	Low
Convergent Ice	Beaufort Sea Unit	Northern Beaufort Sea	Canada	980 (825-1135)	2006	Stable	CMR	Medium
Divergent Ice	Beaufort Sea Unit	Southern Beaufort Sea	United States/Canada	907 (548-1270)	2010	Declining	CMR	High
Divergent Ice	No Unit Assessed	Chukchi Sea*	Russia/United States	Unknown	-	Unknown	-	Medium
Divergent Ice	No Unit Assessed	Laptev Sea*	Russia	Unknown	1993[5]	Unknown	-	Low
Divergent Ice	No Unit Assessed	Kara Sea*	Russia	Unknown	-	Unknown	-	Low
Divergent Ice	No Unit Assessed	Barents Sea*	Norway	2644 (1899-3592)	2004	Unknown	DS	High

Note: DS – Distance Sampling via Aerial Survey; CMR – Physical Mark-Recapture; PVA – Population Viability Analysis
[1] From Amstrup et al. (2008)
[2] From Thiemann et al. (2008) * Indicates subpopulation not assessed by Thiemann et al. (2008), therefore no Designatable Unit assigned
[3] From Obbard et al. (2010)
[4] From IUCN/SSC Polar Bear Specialist Group (2014)
[5] Vongraven et al. (2011)

assessing other Arctic wildlife such as caribou (*Rangifer tarandus*), with strong data supporting genetic subspecies (COSEWIC 2011), and beluga whale (*Delphinapterus leucas*), based on biogeographical data (COSEWIC 2004).

Polar bears have a wide biogeographical range; only small genetic differences have been observed among subpopulations (Paetkau et al. 1999). Using genetic and dietary differences among Canadian subpopulation of polar bears, Thiemann et al. (2008a) grouped the 13 subpopulations based on shared characteristics. For example, Southern populations share a higher risk of decline because of sea-ice loss and likely will be extirpated before subpopulations in the High Arctic (Stirling and Parkinson 2006; Stirling and Derocher 2012). Using designatable units would likely increase geographically specific and important areas for future protected areas, and could possibly be concentrated in regions within the Canadian Archipelago suggested by Stirling and Derocher (2012) as likely polar bear refugia areas. How we manage polar bear subpopulations determines harvest limits; predicting future abundance and distribution depends on empirical data collected in various regions throughout the north. To improve current conservation efforts, ongoing research aimed at understanding the relationships between polar bears and their sea ice habitat is required. As Vongraven et al. (2011) point out in their circumpolar polar bear monitoring framework, there is a need for high quality baseline data in a minimum of one subpopulation within each of the sea ice ecoregions.

Moreover, to improve Canadian management and conservation efforts for polar bears, DUs should be used when assessing the status and trends of polar bears across the Canadian Arctic. Therefore, there should also be a priority to monitor at minimum one subpopulation within each proposed DU to understand how less researched subpopulations within the same

DU are responding to environmental change. To achieve effective management, research is required to establish baseline data and to monitor subpopulations, and there are a variety of research techniques that could be used to best achieve management and conservation goals.

Researching Polar Bears

Ecological research studies have been useful in assessing the health and status of wildlife populations, in particular when research is aimed at monitoring population size and range. Gathering population and demographic information is essential to improve management plans (Redford et al. 2011). Polar bear research has primarily focused on gathering abundance and distribution data to provide estimates of sustainable harvest limits to management boards (Prestrud and Stirling 1994; Taylor et al. 2005; 2006). In addition to population estimates, current research aims to understand the individual and population responses (behavioral and physiological) to environmental change (Stirling and Parkinson 2006; Peacock et al. 2011). It is essential to understand how polar bears respond to sea ice changes, increased Arctic contaminants, and industrial development; this will aid in ascertaining the most effective management plans and ultimately ensure the conservation of the species.

Field Studies

Polar bears are usually distributed in low densities over large and remote areas, which present a challenge to the way monitoring and research can be conducted (Stirling et al. 1989). Polar bears are often only accessible by helicopter, increasing the financial cost of field studies. Polar bear population monitoring frequently involves the capture and handling of free-ranging polar bears with use of chemical immobilization (Stirling et al. 1989; 1999).

The drawbacks of physical handling of polar bears include risk of injury to the animal and researchers, the use of large and cumbersome equipment, and the expense of these studies. The benefit of physical capture studies of polar bears is that they allow researchers to collect necessary demographic and morphometric data. Additionally, physical capture studies allow telemetry collars to be fitted on individual bears to gain further knowledge of movement and habitat selection (Ferguson et al. 2001; Parks et al. 2006; Cherry et al. 2013; McCall et al. 2015). The handling of chemically immobilized polar bears remains the only reliable way to determine age (Calvert and Ramsey 1998) and estimate population vital rates (survival and reproduction). Moreover, these studies collect important biological samples (e.g. blood and fat), allowing for body condition estimates (McKinney et al. 2014), diet assessments (Thiemann et al. 2008b; 2009), and establishing contaminant concentrations (McKinney et al. 2009; Dietz et al. 2013).

Mark-recapture

Physical handling of any free-ranging wildlife has been essential in addressing questions of population ecology (Redford et al 2011). Mark-recapture methods are commonly used in ecological field studies to census populations and assess population dynamics. These studies involve capturing and marking an initial sample of individuals and then subsequently recapturing to observe the proportion of marked individuals. Equations are then used to estimate the size of the population (McDonald and Amstrup 2001). Methods such as mark-recapture to assess population size are not without bias (Derocher and Stirling 1995; McDonald and Amstrup 2001; Evans et al. 2003; Stapleton et al. 2014a). In some cases, only a portion of the total area occupied by a population can be sampled, and therefore to estimate total population size data must be extrapolated to un-sampled areas which results in a risk of misrepresentation of true population size (either overestimating in areas with low density or underestimating in areas of higher density).

Polar bear research has guided harvest management for decades by using information gathered from physical mark-recapture studies. A research priority is to gain an understanding of populations that are either hunted, or where little is known about the life history patterns of that particular subpopulation (Vongraven et al. 2012). To better inform policy decisions for polar bear populations, research should contribute to the understanding of population viability, as it could also better inform harvest quotas. For instance, Taylor et al. (2006) used mark-recapture data to assess the population viability of the M'Clintock Channel subpopulation, which is depleted from historic levels. The conclusion of the assessment was that only small harvest quotas were acceptable to allow the population to recover and it was found that overharvesting was due to lack of accurate population information (Taylor et al. 2006). The data collected through the physical handling of chemically immobilized bears is thus crucial for management decisions and the conservation of the species. Nonetheless, many Inuit have expressed concern over the potential negative effects of scientific research (Dowsley 2005). Specifically, the use of helicopters, snowmobiles and immobilizing drugs caused the greatest concern (Dowsley 2005). Studies suggest that mortalities on average occur in 1 out of 1000 bears handled (Messier 2000). However, these mortalities were significantly reduced when using standardized protocols and different drug combinations (Stirling et al. 1989; Rode et al. 2014). From 1986 to 2013, only three mortalities occurred out of 2517 captures in the Southern Beaufort Sea subpopulation (Rode et al. 2014). While mortalities have certainly been managed, there are still effects of the chemical immobilization on bear physiological responses (Stirling et al. 1997), recovery rates, and movement patterns

(Thiemann et al. 2013: Rode et al. 2014). Thiemann et al. (2013) investigated the effects of chemical immobilization on female polar bear movement patters in relation to their recovery rates. Using satellite GPS collars, the authors concluded that polar bears were able to recover predictably and in a relatively short period of time (generally 2-3 days). There was no evidence to support that telemetry collars impede movement or recovery rates post capture (Rode et al. 2014). These studies examining the effects of chemical immobilization all provide evidence that chemical immobilization does not contribute to long term individual effects, and the technique is manageable and necessary in order to gain essential data.

Vongraven et al. (2012) state that it is essential to monitor the reductions in polar bear body size as it will provide an indication of nutritional stress, and could have fitness consequences that may also influence reproductive success and overall population size. Several studies have aimed at monitoring body condition through various techniques in the field and the laboratory (Farley and Robbins 1994; Cattet et al. 2002; Stirling et al. 2008; Rode et al. 2012; McKinney et al. 2014). Body condition has been assessed in the field via estimates of overall fatness, whether measured by overall appearance (i.e. fatness index; Stirling et al. 2008) or more quantitatively (e.g., Cattet et al 2002).

Accurately assessing the body condition of polar bears often requires the mass of the individual. Many field studies have shown a relationship between morphometric measurements (e.g., straight line body length and axillary girth) and the mass of the immobilized polar bear, which gives insight to the overall body size and relative condition of the individual (Durner and Amstrup 1996; Cattet et al. 2002;Obbard et al. 2006; Thiemann et al. 2011). Body condition can also be assessed in the laboratory by the lipid content of polar bear adipose tissue (subcutaneous fat), which requires taking a biopsy on the rump of the bear (Thiemann et al. 2006; Stirling et al. 2008; McKinney et al. 2014).

Remote Sampling

A less intrusive technique than typical chemical immobilization, remote biopsy darting, has been used to study marine mammals with low behavioral and physiological impacts (Noren and Mocklin 2012). Using remote biopsy darting, the collection of a single sample can provide insights into genetics, foraging ecology, and other physiological processes (Noren and Mocklin 2012; Pagano et al. 2014). Remote biopsy darting is an alternative methodology to chemical immobilization for polar bear field studies, and could be used in areas where it is difficult or dangerous to chemically immobilize free-ranging polar bears (e.g. on steep terrain or near open water) (Pagano et al. 2014). A remote biopsy dart is injected into a polar bear the way immobilizing drugs are administered in other field studies, however the dart is designed to collect a biopsy which includes fur, skin and fat and will fall out after injection (Pagano et al. 2014). The samples that are collected through the remote biopsy dart can reliably gather genetic identification, sex, and diet information, and can also mark individuals to avoid sampling the individual repeatedly (Pagano et al. 2014). The genetic identification of individuals can then be used to estimate population size via mark-recapture models. Newly modified biopsy darts have been successfully used to obtain a biopsy of polar bears subcutaneous fat and skin. This research method does not provide reliable health (body condition) information, but can be used to gather demographic and genetic data.

Some field studies make use of less invasive methods to gather abundance and distribution data of polar bears remotely (e.g. aerial surveys, satellite imagery), which can provide population size information (Evan et al. 2003; Stapleton et al. 2014a; Stapleton et al. 2014b). Aerial surveys cannot provide in-depth information about population demographics or body condition the way mark-recapture studies and remote biopsy darting can. However, a major advantage to aerial surveys is that larger areas of habitat can be covered to provide a more spatially complete estimation of population size (Stapleton et al. 2014a). Conversely, using satellite imagery to monitor abundance and distribution of polar bears is restricted to onshore habitats (Stapleton et al.2014a).

Non-Invasive Research

Non-invasive research cannot provide the level of specific individual information available from mark-recapture methods, but can supplement long term monitoring. In some instances, non-invasive techniques could be used for preliminary assessment of areas where polar bears are not studied extensively due to logistical reasons (Vongraven et al. 2012). Non-invasive studies on polar bears have used techniques such as hair snags (Van Coeverden De Groot et al. 2012; Herreman and Peacock 2013), photo identification (Anderson et al. 2007; 2010), opportunistic scat sampling (Gormezano and Rockwell 2012), harvest-based sampling (Thiemann et al. 2008), and Inuit interpretation (Wong et al. 2011) to aid in answering questions about genetic, age, demographic, and diet structures in a given population.

Non-invasive methods can be taught with little difficulty to individuals who often come into contact with polar bears, while offering ways to increase scientific knowledge and providing northern communities an opportunity to become familiar with the scientific process. For example, photographic research methods can be easily used by researchers, as well as those with little scientific background and could increase our knowledge of subpopulations that have been previously harder to study. Anderson et al. (2007) used photographs of polar bears collected by tourists in Churchill, Manitoba to create an identification system based on polar bears' individual whisker spot pattern. Applying the identification system to polar bears within the western Hudson Bay subpopulation, 57 individuals were identified (Anderson et al. 2010). In addition to photographs, non-invasive research has also involved other techniques to identify individuals by collecting hair-snags as a form of genetic mark-recapture (Van Coeverden De Groot et al. 2012). The hair-snags were able to estimate a minimum count of individuals in the M'Clintock Channel by coordinating several trapping stations (De Groot et al. 2012).

Other non-invasive research makes use of reference tools, such as standardized index cards to provide a way to systematically collect data in communities or tourism settings. Stirling et al. (2008) quantified the use of the standardized fatness index card (Figure 2-2) to assess polar bear body condition. The scale is from 1-5 where a bear scored 1 is emaciated in appearance, and when scored 5 appears obese. When a polar bear is in good body condition, their overall appearance is high (i.e. 4 or 5 on scale; Stirling et al. 2008). Studies have indicated the given rating of a bear determined by the fatness index is consistent with the percent lipid content in the adipose tissue (Stirling et al. 2008; McKinney et al. 2014), indicating that it is a useful alternative tool to assess body condition when direct handling of the animal is not feasible.

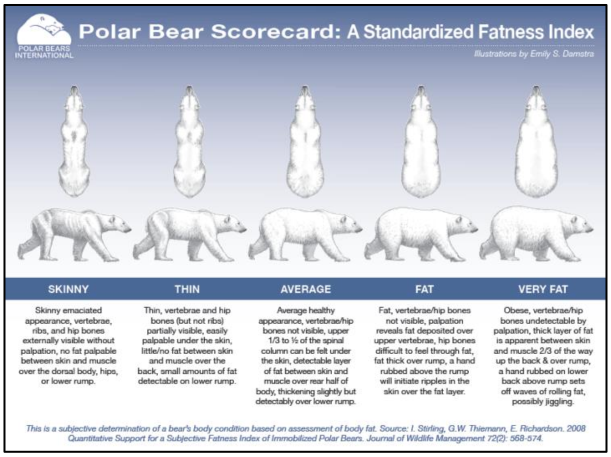


Figure 2-2: Polar Bear Fatness Index (1-5) Score Card used to assess physically and/or visually the amount of fat on a bear, where fat and very fat are considered good body condition, and skinny and thin are poor body condition.

Incorporating Traditional Ecological Knowledge

Community based monitoring (CBM) can be an effective management tool as local communities are often privileged to vast information on the surrounding ecosystem. Vongraven et al. (2012) indicate that traditional ecological knowledge (TEK) and CBM are essential for polar bear monitoring, and suggest that short, in-person community questionnaires be used to gather information about sea ice conditions and the number of bears in the area to supplement other mark-recapture or aerial survey estimates. Incorporating communities in research can aid in development of new study techniques and expand existing research datasets (Huntington 2000). Additionally, the involvement of Inuit communities in research could strengthen the relationships between researchers, managers, and resource users (Huntington 2000).

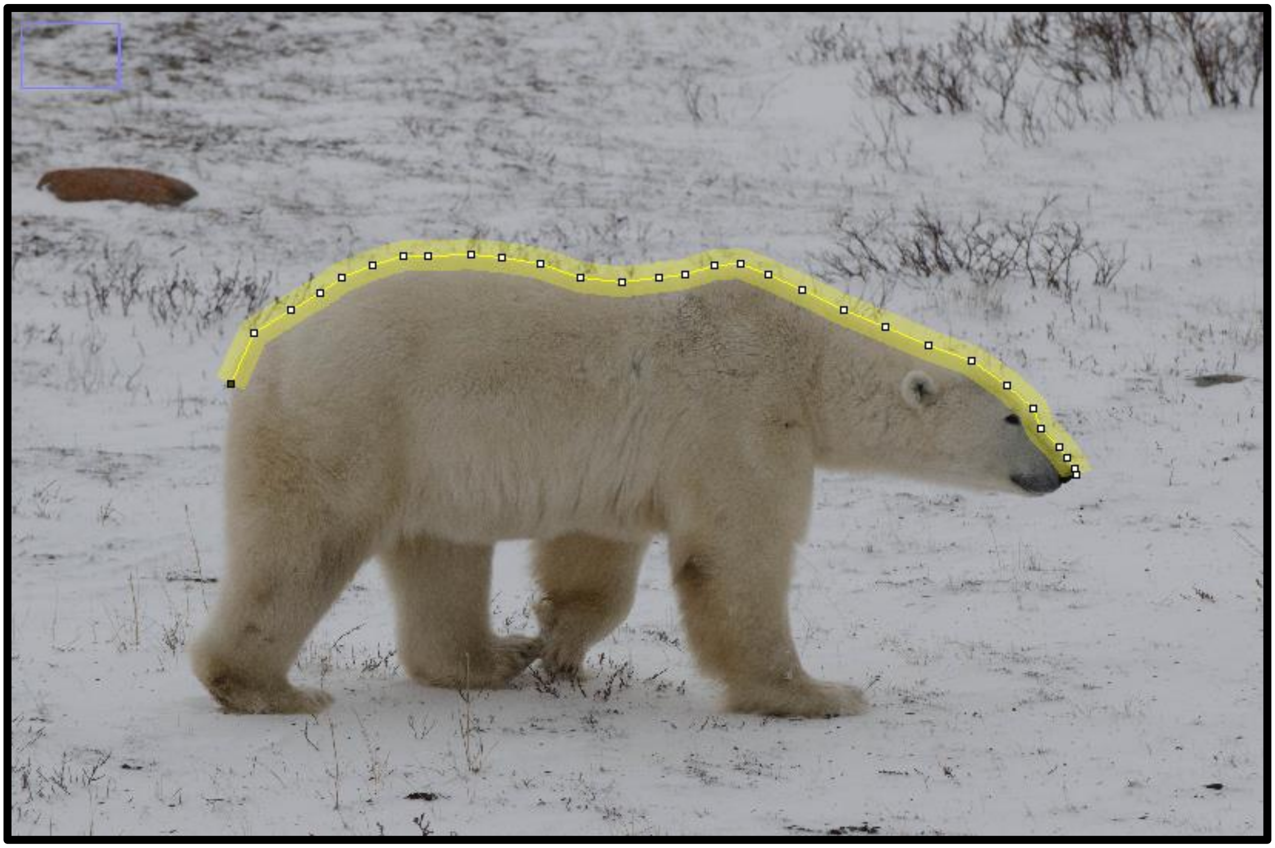
CBM and the incorporation of TEK will enhance polar bear conservation when defined and conducted appropriately (Peacock et al. 2011). Studies with CBM and TEK will be great supplements to existing research databases and could also provide initial information for areas where little research has been conducted (Huntington 2000). When incorporating Inuit hunter documentation and knowledge of their observations and interpretations, it is important to understand the limitation to testing these observations using traditional scientific methods. However, it remains important to combine the inclusion of Inuit knowledge and interpretation of results to better understand polar bear populations and encourage more involvement of the Inuit and northern communities in western science for improved co-management strategies (Peacock et al. 2011).

Future Polar Bear Conservation

For effective polar bear conservation in the future, it will be essential to invest in further consultations with Inuit communities and fund polar bear research studies. Creating a way to integrate both western science and traditional ecological knowledge will be essential for co-management boards to make effective decisions regarding polar bears (Peacock et al. 2011). It will be important to educate the public on the issues and threats facing polar bears, as it could help alleviate some of the controversy that surrounds the effects of climate change on Arctic ecology. In particular, it will be important to work more closely with northern communities. Clark et al. (2010) organized a workshop with 24 attendees made up of government wildlife officers, aboriginal community members, and academics. The objective was to discuss the issues surrounding polar bear conservation and management; the main conclusion included consensus of a need for increased polar bear research and the development of co-management boards (Clark et al. 2010).

Ongoing anthropogenic climate change has been shown to drive polar bear population decline through the loss of primary sea ice habitat (Stirling and Parkinson 2006; Regeher et al. 2007; Stirling and Derocher 2012; Sahantian and Derocher 2012). However, evidence to date indicates that reductions in greenhouse gas emissions would stimulate increases in sea ice habitat and thereby benefit polar bears (Amstrup et al. 2010). Therefore, the continuation of research and public education will be essential to effectively conserve polar bear populations throughout their circumpolar range. The circumpolar monitoring framework for polar bears outlined by Vongraven et al. (2012) identified areas that require higher research intensities (i.e. where data is deficient). Attention should be focused on areas where more research is required to better understand the dynamics of interactions of polar bears and their sea-ice habitat within the Arctic ecosystem.

Chapter 3: Estimation of Polar Bear (*Ursus maritimus*) Morphological Traits Using Photogrammetry



"Science is based on experiment,
on a willingness to challenge old dogma,
on an openness to see the universe as it really is.
Accordingly, science sometimes requires courage
- at the very least the courage to
question the conventional wisdom."

— Carl Sagan

Abstract

Current anthropogenic induced environmental change is associated with declines in wildlife populations. Non-invasive methods of obtaining measurements, and determining relationships to body condition are valuable for monitoring wildlife populations. Here a digital photogrammetry technique was used for estimating seven morphological traits and their possible relationship to polar bear (*Ursus maritimus)* body condition in the Western Hudson Bay subpopulation. Measurements from four captive polar bears revealed that this photogrammetric technique underestimates morphological traits compared to manual measurements. The mean error of photogrammetric measurements was 22.9 $\pm$ 12.6 %, the two measures with the lowest mean error rates were Side Girth and Rump (10.7 and 11.4% respectively). Average photogrammetric measurements from free-ranging polar bears yielded realistic values similar to other reported values from field studies. There are errors that can lead to biases using this non-invasive technique; however with proper data collection and analysis protocols and increased validation of the method, these error rates can be minimized. The photogrammetric method described here is easy to use and can be rapidly applied to a large number of polar bears by researchers and untrained citizens.

Introduction

Current climate change is altering ecosystems across the globe and is undoubtedly affecting wildlife species (Moritz and Agudo 2013). The Arctic region has experienced greater climatic warming compared to other ecosystems (Post et al. 2013), particularly the changes in both the spatial and temporal extent of sea ice (Comiso 2006; Stroeve et al. 2014). Climatic warming in the Arctic is negatively affecting the demography of Arctic wildlife populations (Stirling et al. 1999; Ferguson et al. 2005; Stirling and Parkinson 2006;Laidre et al. 2008). Particularly, decline in sea ice has been linked to declines in polar bear (*Ursus maritimus*) body size and condition (Rode et al. 2010; Sciullo et al. 2016), survival rates and population size (Stirling et al. 1999;Regehr et al. 2007 and Molnàr et al. 2010) and overall polar bear health (Patyk et al. 2015).

Assessing the health of an individual or population requires a quantitative assessment of body condition (Stevenson and Woods 2006; Patyk et al. 2015). A condition index can quantify the health of individuals, particularly through estimating the size of energy (fat) reserves (Cattet et al. 2002; Stevenson and Woods 2006; and Peig and Green 2009). Methods involving: physiological, biochemical and morphometric parameters, such as, relationships between morphological traits (i.e. body length) and body mass have been used (Wirsing et al. 2002;Stevenson and Woods 2006). There are also morphometric relationships that can provide an index for body condition (Peig and Green 2010). Body condition allows for estimation of population reproduction rates and also overall growth or decline (Stirling et al. 1999; Regeher et al. 2007;Rode et al. 2010). For instance, polar bear body condition declines have been empirically linked with sea ice changes (Regeher et al. 2007) in Western Hudson Bay.

Polar bear body condition has been assessed in the field through techniques that measure the individual’s water, lipid and protein contents, referred to as bioelectrical impedance analysis (BIA) and isotopic water dilution (Farley and Robbins 1994; Sciullo et al. 2016) and also lipid content extracted from adipose tissue (Thiemann et al. 2006;Stirling et al. 2008;McKinney et al. 2014). Stirling et al. (2008) validated the use a qualitative method measuring a polar bears fatness index (FI), through lipid content of adipose tissue samples, and concluded that FI accurately reflected body condition.

Assessing body condition of polar bears often requires the mass of the individual, and many field studies have shown a relationship between straight-line body length and the mass of immobilized polar bears (Durner and Amstrup 1996; Derocher and Wiig 2002; Cattet and Obbard 2005; Thiemann et al. 2011). Specifically within the western Hudson Bay subpopulation, Thiemann et al. (2011) showed a strong relationship between the two morphological body measurements (SLEN and AXG) and the mass of polar bears and these variables have been linked to body condition and the reproduction potential of individuals (Atkinson and Ramsay 1995). Polar bears are currently monitored by invasive field studies, and relatively little attention has been paid to the development of non-invasive techniques to non-invasively gathering measurements to study polar bear body condition.

Non-invasively obtaining morphological measurements from wildlife populations has increased our efficiently to monitor populations. Previous studies have been able to measure morphological traits from seals (Bell et al. 1997), elephants (Shrader et al. 2006), primates (Rothman et al. 2008), ungulates (Berger 2006 and Bergeron 2007; Willisch et al. 2013), and other marine species (Durban and Parsons 2006; Webster et al. 2010; Rohner et al. 2011); these studies were able to reliably estimate morphological traits and use the measurements to gain insights into growth, body mass, age structure in wildlife populations. Parallel laser techniques have been used to obtain measurements of morphological traits at short distances away from the observer (Berger 2006; Durban and Parsons 2006). Parallel lasers are not effective over long distances as visibility of the laser dots can be reduced (Shrader et al. 2006; Willisch et al. 2013). Digital stereoscopy has been used to photograph and measure individual animals over 400 m away with relatively little bias, relying on an object (animal of known size) to be adjacent to the individual being photographed (Willisch et al. 2013). The approach of using objects or another animals of known size to provide scale for photographs is beneficial for animals that poses a low risk to humans and can often be observed in groups (Berger 2006; Bergeron 2008 and Willisch et al. 2013). Polar bears are generally solitary animals, with the largest congregation occurring in Churchill, Manitoba when they are forced onshore (Derocher and Stirling 1990; Parks et al. 2006; McCall et al. 2015). Thus, using methods described by Willisch et al. (2013) are not suitable for polar bear research. However, laser range finders have been used to accurately estimate the shoulder height of African elephants (*Loxodonta africana)* of distances up to 115 m (Shrader et al. 2006); about 50 m more than traditional parallel laser techniques (Berger 2006; Durban and Parsons 2006 and Webster et al. 2010).

The primary research objective is to determine how polar bear morphological traits can be monitored non-invasively. I will determine whether using parallel lasers or a laser rangefinder is the best method for obtaining photogrammetric measurements of polar bears. Furthermore, I seek to discover what biological data can be collected non-invasively from polar bear ecotourism vehicles in Churchill, Manitoba. In particular, I aim to determine how morphological features can be measured through photogrammetric techniques, and if they provide reliable information and indicators of polar bear health (body condition).

Methods

Study Area

I collected data within the Churchill Wildlife Management Area (CWMA), approximately 30-35 km east of Churchill, Manitoba (58.3 °N, 93.8 °W). The CWMA is 850,000 ha in size and is dominated by peatland areas (Brook 2001). Polar bears of the Western Hudson Bay subpopulation frequent the area during the fall as they congregate along the shorelines awaiting Hudson Bay to freeze (Derocher and Stirling 1990; Towns et al. 2010; Cherry et al. 2013). In this study, most polar bear encounters occurred between Polar Bear and Gordon Point along pre existing gravel trails that lie on the southwestern coast of Hudson Bay, and all encounters recorded were between the Buggy Dock and Tundra Buggy Lodge (Figure 3-1). See Clark et al. (1997) for a more detailed description of Churchill's coastal region.

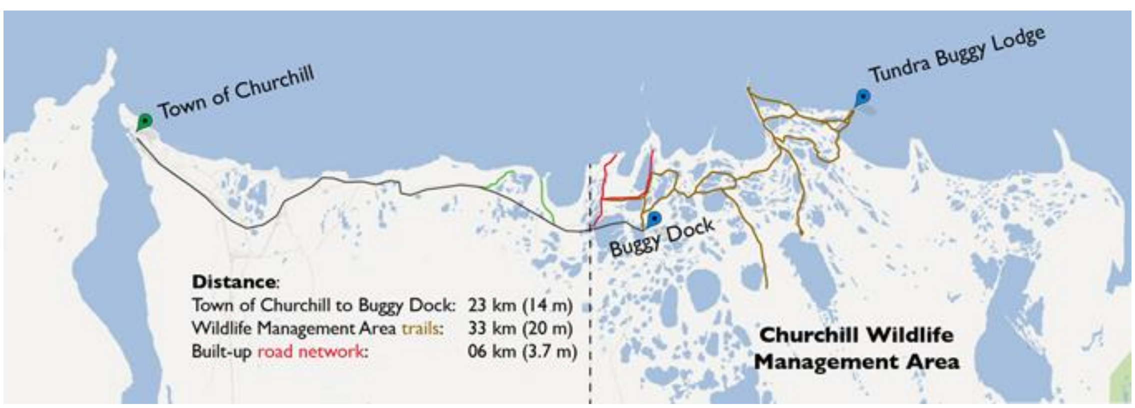


Figure 3-1: Visual representation of tundra vehicle trails system within the Churchill Wildlife Management Area. Photo Courtesy of Frontiers North Adventures.

Field Data Collection

I opportunistically photographed free-ranging polar bears during the fall (October 14 – November 19) of 2012, 2013 and 2014 while on tundra buggy tours operated by Frontiers North Adventures between the hours of 09:00 and 17:00. Each polar bear encountered was given a unique encounter ID, photographed, and also assessed for sex and age class. I assigned a body condition score by using a standardized index for polar bear fatness (Stirling et al. 2008) with a range of scores from 1 (skinny) to 5 (very fat). A bear was only scored if their torso was viewed laterally. To determine the sex of the bears, I relied on visual criteria such as dependent young with adult females, visible long penile hair (males) or hind leg urine stains (females), and/or facial scarring (males). If a bear was not easily identified as male or female it was marked as an unknown. I recorded age among four different classes: adult, subadult, yearling or cub-of-year (COY) based on overall size of the bear and general agreement with experienced guides while on tundra vehicles. If I was unable to confidently assess the age class of an individual bear it was recorded as an unknown. There was no reliable way of identifying individual bears due to a lack of unique visual markers. It is likely that several of the encounters were of the same few bears in the tourist area over a span of a few days or even weeks during the field season. To reduce the risk of pseudoreplication, I recorded useful information to aid in identifying individuals (e.g. scars and wounds). However each time a bear was encountered, regardless if it had been previously identified it was given an unique encounter ID and notes were taken regarding if the bear had been previously encountered. GPS locations were logged electronically to reduce sampling the same individual repeatedly throughout a tour day.

Captive Bear Data Collection

Measurements of four captive polar bears immobilized for transfer by Assiniboine Park Zoo veterinarians were obtained. The four bears in captivity were all immature (<5 years old), two were female (Aurora and Kaska) and two were male (Hudson and Storm). All four bears were assigned the same fatness index (FI) rating of 4 or fat. Using a measuring tape, zoo veterinarians measured six morphological traits: shoulder height (SH) measured from the bottom of the anterior paw to the top of scapula; straight line body length (SLEN) from the tip of the nose to the sacrum, where the measuring tape was held just above the body; traced body length (TBL) measured from the tip of the nose to the sacrum where the measuring tape followed the contours of the body; head length (HL) tip of the nose to the base of the ear; rump (RUMP) from the pelvic region to sacrum; and side girth (SAXG) from the axilla to the top of the thoracic vertebrate behind the scapula.

Photograph Collection

I used Nikon D90, D100 and D7000 digital SLR cameras equipped with either a 70-200 mm or 18-105 mm zoom lens, to obtain photographs during the three field seasons (2012,2013 and 2014) and of captive bears. In 2012, I initially used a custom parallel laser frame was secured to the digital camera equipped with green-light lasers (Durban and Parsons 2006;Bergeron 2007; Rothman et al. 2008). The distance between the lasers was 35.4 cm and was calibrated before each use. The Lasers would be turned on immediately before a photograph was taken of a bear. I also used a 360R TruPulse laser range finder (Laser Technology Inc., Centennial, CO, USA) to simultaneously obtain distance data (i.e., exact meters between camera and the bear). The distance data provides the scale in the photograph as I was measuring objects (polar bears) of unknown size (Shrader et al. 2006). The laser range finder was aimed at the middle of the bear's torso to determine the distance (m). Distance data and photograph IDs were hand recorded along with polar bear encounter information. Photographing captive polar bears followed the same procedure where photographs and distance measurements were captured simultaneously.

Photograph Processing

Photographs were imported into Adobe Photoshop Lightroom 4 (Adobe Systems Incorporate, San Jose, CA, USA) and were rated from poor to excellent based on bear position and pose in the photograph (Table 3-1). There were no photographs where the bear was completely obscured or the image quality itself was low (i.e., out of focus). Photographs that were paired with distance data were then rated based on the bears' body position and then converted into .JPEG files for analysis.

Rating Photographs

All photographs were rated based on the position of the polar bear, excellent photographs contained the bear standing in lateral view occupying most of the frame, and poor photographs contained the bear either sitting or laying down in such a position that no meaningful body condition measurements could be made (Table 3-1). Only photographs rated good or excellent were included in the analyses. Some bear encounters had numerous photographs collected, therefore only the single best photograph (excellent rated) was used. No photographs scored lower than good were included in analysis.

Measuring Photographs

To estimate the length of the seven morphological traits of both free-ranging and captive polar bears I used the measurement tool in ImageJ to obtain the number of pixels of the given trait (Schneider et al. 2012). Photographs in ImageJ were zoomed between 16.7% and 75%, the zoom aided in determining the definition of body outline and distinguishing between long fur and the body. The zooming process does not alter the pixel measurements, and thus depending on the distance and focal length of the image some were magnified more than others.

Table 3-1: Rating criteria and representative photographs of polar bears encountered in the Churchill Wildlife Management Area for scoring photographs collected.

Excellent	• Standing in natural pose • Direct broad side view • Consume ¼ of frame or more • Head straight forward • Paws visible on the ground	
Good	• Standing in a natural pose • Broad size view • Head up/down • Slight angle of body	
Fair	• Standing • Obvious angle of body • Part of body obstructed	
Poor	• Sitting or laying down • Body cut off by frame	

Using the straight measuring tool, I measured shoulder height (SH) from the bottom of the anterior paw to the top of the scapula. I measured hind leg length (HLL) from the bottom of the posterior paw to the top of the spine. I measured rump (RUMP) from the hind leg pelvic area to the top of sacrum. Head length (HL) was measured from the tip of the nose to the base of the same side ear. Body length was measured in two different ways; straight line body length (SLEN) from the tip of the nose to the sacrum and traced body length (TBL) from the tip of the nose to the sacrum following the outline of the bears' body using several landmarks along the spine. I measured the girth from the lateral side (SAXG) from the axilla to the top of the thoracic vertebrae behind the scapula (Figure 3-2). Not all traits were measured in each photograph due to an obstruction (e.g. hidden paw) or lack of definition of the body's outline.

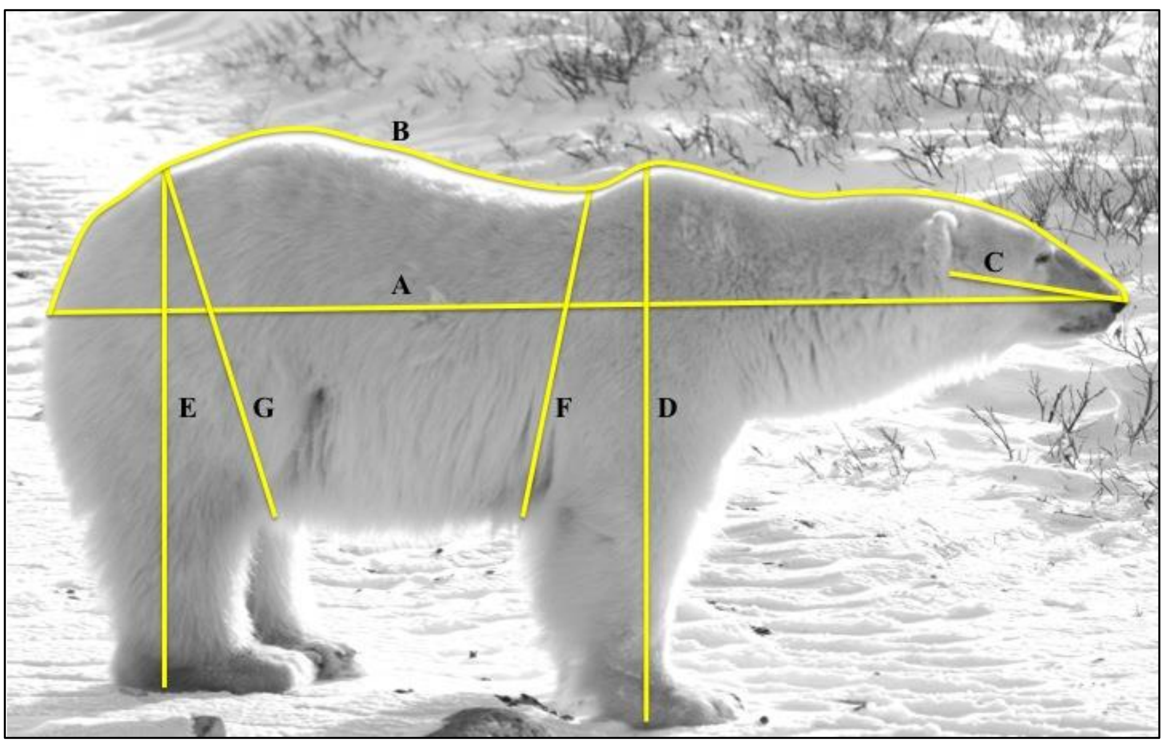


Figure 3-2: Representative photograph of the seven morphological traits measured on free-ranging and captive polar bears. A) Straight line body length B) Traced body length C) head length D) Shoulder height E) Hind leg Height F) Side Girth and G) Rump.

To ensure I was measuring the morphological traits consistently, I randomly selected 10 excellent photographs and measured each trait three times to ensure my measurements were within <3% of each other as outlined by Bell et al. (1997). My precision of measuring the same trait multiple times provided the confidence to take one measurement of each trait per photograph to avoid measuring photographs multiple times and taking an average (Jaquet 2006; Rothman et al. 2008). Thus, only one measurement was taken for each morphological trait per photograph.

Camera Calibration

Digital images are comprised of pixels of known size; these pixels can be counted and used to make an inference to true size of an object (cm) when the distance between the camera and an object is known. The size of an object can be calculated from the number of pixels it comprised, the focal length of the lens (mm) and the distance (m) from object to the camera Equation (1) (Remondino and Fraser 2006).

Equation 1:

Estimated Size (cm) = (((Distance to subject (m)) * (10/Focal Length (mm))*100)*Image Size (pixels))

The camera's sensor size (s) was incorporated into the equation, as it will calibrate for the number of megapixels used in a standard image taken by that camera and will standardize the image size generated when counting the number of pixels in a photograph Equation (2).

Equation 2:

Image Size (pixels) = (Measured Size (pixels)*Horizontal Sensor (mm))/Horizontal Pixel (pixels)

Alternatively, as per a method described by Jaquet (2006) and Shrader et al. (2006), I related the distance between the bear and the camera to bear morphological traits that were measured through calibration of the cameras. This was achieved by photographing an objective of known length (wooden meter stick) at ranges from 3 m to 50 m, and measuring the photographed meter stick in ImageJ to count the number of pixels from end to end of the object (Figure 3-2). At each range multiple photographs were taken using varying focal lengths. The D90 camera was calibrated with focal lengths of 18 mm, 50 mm, 75 mm and 105 mm, as it was paired with an 18-105 mm lens. Whereas both the D100 and D7000 were calibrated with focal lengths of 70 mm, 105 mm, and 200 mm, as they were paired with a 70-200 mm lens. I then calculated the number of pixels per centimeter of the meter stick and used linear regression to describe the relationship between cm/pixel (y in Table 3-3) and distance (x in Table 3-3) between the camera and the object. The focal lengths were chosen because they would be the most commonly used. The focal length influences the size and density of pixels measurements represented by the pixel (Focal length is effectively zooming in on an object). The sensor of the camera determines the pixel density (i.e. how many pixels/cm), which is predetermined by manufacturer information. As the number of pixels increase, their size decreases (Remondino and Fraser 2006). Therefore, when pixel density increased the number of pixels per unit also increases (Figure 3-2; Table 3-3).

Table 3-2: Linear equations between the cm/pixel and the distance to the subject for three different pixel density cameras at varying focal lengths used to photograph polar bears.

Pixel Density	Focal Length (mm)	Linear Equation	r^2
D100	70	y = 0.0108x + 0.00007	0.9999
6.31 Megapixels	105	y = 0.0074x - 0.0013	0.9999
	200	y = 0.0039x - 0.0007	0.9999
D90	18	y = 0.0314x + 0.0008	0.9998
12.3 Megapixels	50	y = 0.0115x - 0.0003	0.9991
	75	y = 0.0080x + 0.0012	0.9994
	105	y = 0.0058x - 0.00001	0.9999
D7000	70	y = 0.0067x - 0.0006	0.9999
16.2 Megapixels	105	y = 0.0045x + 0.00002	0.9999
	200	y = 0.0024x - 0.0004	0.9999

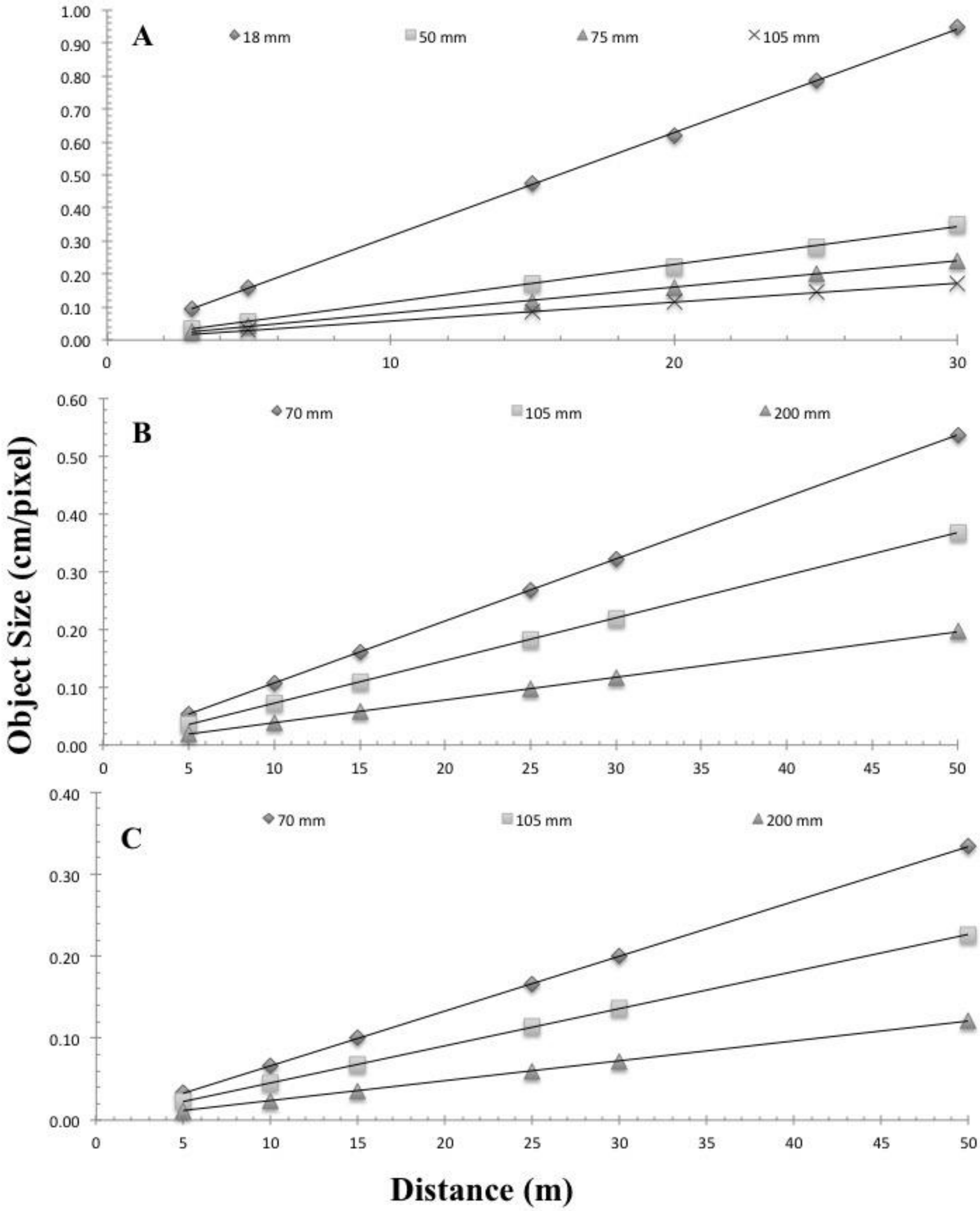


Figure 3-2: Changes in object size (cm/pixel) with distance for the three cameras with varying pixel densities used (A) D90 [12.3 megapixels], (B) D100 [6.31 megapixels], (C) D7000 [16.2 megapixels) and the associated focal lengths, determined from photographing an object of known size. Camera C was most commonly used in the study (2013 and 2014), where Cameras A and B were used in 2012.

Statistical Analysis

Captive polar bear measurement data were normally distributed, but homoscedasticity was not achieved through standard data transformations, thus to test if there were significant differences between measurements (manual and photogrammetric) I performed independent Wilcoxon signed rank test for the different morphological traits. I calculated the mean error (%) for each morphological trait and used spearman correlations to compare both distance (m) and focal length (mm) with mean error. I used a simple linear regression model to compare hand measurements to those estimated using photogrammetry.

Free-ranging polar bear data were nonparametric (Shapiro-Wilk test, $p<0.05$). Therefore Spearman's rank correlations were used to compare morphological trait measurements (SLEN, TBL, SH, HLL, SAXG, RUMP, and HL) on all the 113 bear photographs included in analyses. Kruskal-Wallis ANOVA tests were used to compare fatness index scores across sex and age classes. I also used Kruskal-Wallis ANOVA to test if fatness index scores varied among years (2012-2014).

A classification tree determined RUMP and SAXG were the two morphological traits that explained the most of the variability in fatness index scores. I used linear regression analysis to compare both RUMP and SAXG measurements to fatness index scores in adult bears (n = 71). I assessed trends in both RUMP and SAXG measurements as a function of body length (SLEN and TBL). All data were statistically analyzed using the statistical software program R (http://cran.r-project.org/). For all statistical analyses, α was set to 0.05.

Results

Validation Using Captive Polar Bears

I was able to photograph the four captive polar bears from distances of between 4 m and 50 m. I collected 107 photographs that were used to generate 404 measurements of the six traits combined. Not all photographs were of high quality for all six traits and therefore for each photograph only traits that were not obviously biased by an obstruction were measured.

There were no statistically significant differences between photogrammetric and hand measurements for RUMP ($Z=3107$, $p= 0.605$) and SAXG ($Z = 3121$, $p= 0.569$), and SH ($Z = 3472$, $p= 0.217$). There was a statistically significant difference between the two measurement techniques for HL ($Z= 2632$, $p=<0.05$), SLEN ($Z = 3169$, $p = <0.05$), and TBL ($Z = 1903$, $p = <0.05$). The average manual measurements were underestimated by photogrammetric measurements (Table 3-3). The photogrammetric estimates were higher for shoulder height for two of the captive bears and for Hudson in both RUMP and SAXG (Figure 3-3).

I detected a significant difference among error rates for the different morphological traits (Kruskal-Wallis $\chi^2 = 77.175$, df= 5, $p <0.001$), Side Girth (SAXG) had the lowest mean error (10.7 %), while HL had the largest mean error (22.9%) (Table 3-3). Both SLEN and TBL had the largest variability in measurements (manual and photogrammetric). Traced body length had lower mean error than straight line body length (11.8% and 16.2 % respectively). Mean error in photogrammetric measurement was negatively correlated with distance ($r_s = -0.21$, $p < 0.05$), and focal length ($r_s = -0.18$, $p < 0.05$). Longer focal lengths (more internal zoom) produced less error than shorter focal lengths, and short distances produced more error compared to long distances.

Boxplots show the variability of the measured morphological traits for the four captive bears, the bars represent the full range of measurements, grey boxes represents the inter-quartile range of the central 75% of the measured values, and the mean is shown in black, hand measurements are indicated by a blue marker (Figure 3-3). SLEN had the least variability within individuals; conversely RUMP had the most variability.

Table 3-3: Comparison of manual and photogrammetric measurements (mean ± SD) of six morphological traits derived from four captive polar bears

Morphological Trait	Photo Sample (n)	Mean Manual Measurement ± SD (cm)	Mean Photo Measurement ± SD (cm)	Mean Error ± SD (%)
Head Length (cm)	53	37.5±4.3	28.7±3.8	22.9±8.7
Shoulder Height (cm)	79	88.4±16.2	85.1±8.3	13.1±6.9
Side Girth (cm)	77	55.4±5.4	55.2±4.9	10.7±5.5
Rump (cm)	77	61.1±3.9	60.9±6.7	11.4±9.2
Straight Body Length (cm)	63	186.51±24.0	155.9±21.7	16.2±8.1
Traced Body Length (cm)	52	205.3±25.4	183.0±23.7	11.8±7.9

RUMP and SAXG were more accurately predicted using a linear regression model (Figure 3-4). All other morphological traits were underestimated using the photogrammetry technique (Figure 3-4, Table 3-3). The two measures of length (SLEN and TBL) deviated from the 1:1 regression line more than other morphological traits (Figure 3-4).

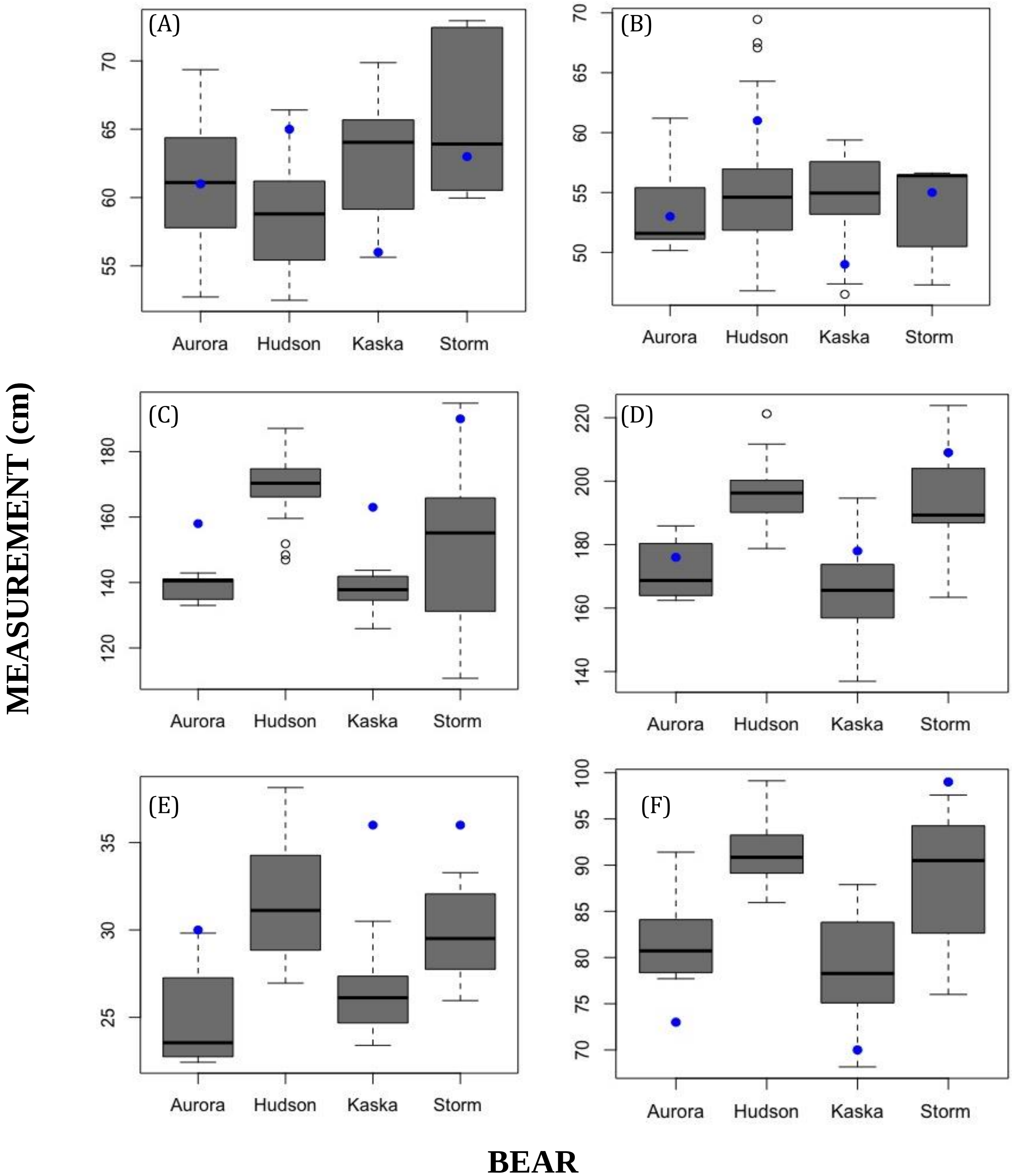


Figure 3-3: Distributions of photogrammetric measurements of the six morphological traits obtained from captive polar bears. (A) Rump (B) Side Girth (C) Straight Line Body Length (D) Traced Body Length (E) Head length (F) Shoulder Height. Blue marks represent the hand measurements (cm), in cases where they are not seen they are above the upper quartile of the boxplot.

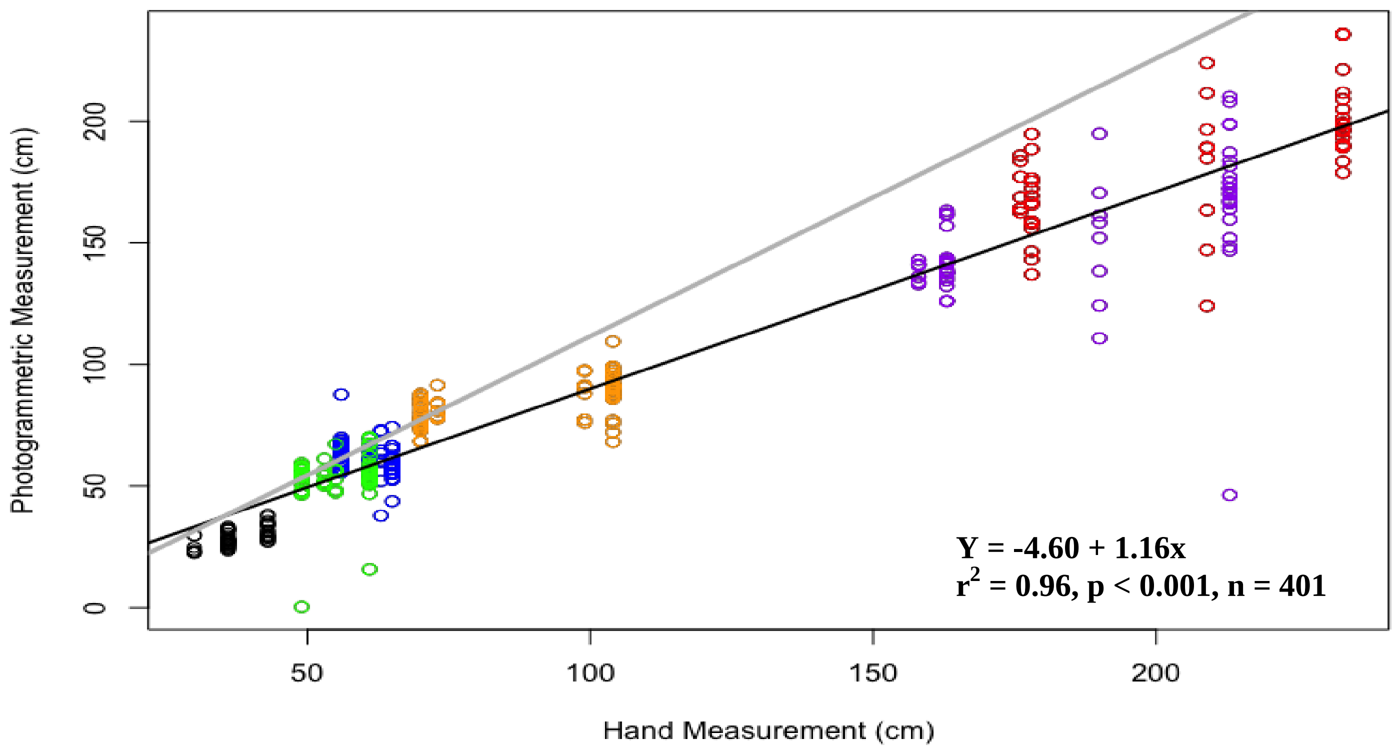


Figure 3-4: Relationship between hand measurement and photogrammetric measurements of six morphological traits measured on captive polar bears. Gray line represents 1:1 line and black line represents trend line for data.

Free-Ranging Polar Bears

I acquired digital photographs from 720 polar bear encounters during 92 tourist buggy daytrips (Table 3-4). All photographs collected for the photogrammetric estimations were from varying distances between 3.7 m and 389 m using the laser rangefinder. The parallel lasers did not operate effectively to scale photographs. Most photographs using the parallel lasers have only one laser point showing and would only work in close distances (>20m) likely due to cold temperature exposure. All photogrammetric measurements were obtained using a laser rangefinder to scale the photograph.

I was able to assign age, sex and FI scores to bears from approximately half (369) of all encounters. Most polar bear encounters were of bears that were assigned an unknown label to either age or sex (43.5%). Of the remaining encounters adult males were most commonly viewed (22.9%), followed by adult females (11.3%), both male and female sub adults (11%) and cub-of-year (9.8%) (Table 3-4). The number of unknown bears increased throughout the study period.

I detected no difference in the frequency with which I assigned different FI scores to bears of different sexes (Kruskal-Wallis $\chi^2 = 1.261$, df= 1, p = 0.262), age classes ($\chi^2 = 6.483$, df = 3, p = 0.09). There was a significant difference in the frequency of FI scores assigned among years (Kruskal-Wallis $\chi^2 = 14.024$, df = 2, p<0.005). More bears were assigned a fatness index score of 2 in 2014 compared to 2012 (Table 3-4). Bears were most often assigned a FI score of 3 (54%, 388 individuals); of the 720 encounters, 6% (42) were in condition of 2 and 3% (21) were in condition of 4. Only one bear was in condition of 1, and none were assign a FI score of 5 (Table 3-4).

All photogrammetric measurements were positively correlated with one another based on Spearman's rank order correlation test. The two highest correlated measurements were shoulder height (SH) and side girth (SAXG) ($r_s = 0.81$,P<0.0001). The two lowest correlated measurements were hind leg length (HLL) and head length (HL) ($r_s = 0.37$, P<0.001); side girth was correlated with both measures of length, straight line length (SLEN) ($r_s = 0.72$, P<0.0001) and with traced body length (TBL) ($r_s = 0.71$, P<0.0001) (Figure 3-5). Rump was also correlated with SLEN ($r_s = 0.64$, P<0.0001) and TBL ($r_s = 0.71$, P<0.0001) (Figure 3-5). The two different measurements of length (SLEN and TBL) were also correlated ($r_s = 0.65$, P<0.0001).

Table 3-4: Distribution of polar bears encountered in the Churchill Wildlife Management Area during the fall season (2012-2014)

Year	Total	Body Condition Score					
		1	**2**	**3**	**4**	**5**	**Unknown**
				Adult Female			
2012	18			15	3		
2013	16			15	1		
2014	47		9	25	2		11
				Adult Male			
2012	74	1	2	66	5		
2013	51		8	43			
2014	40		6	31	1		2
				Subadullt Female			
2012	17			16	1		
2013	15			14	1		
2014	14		2	9	2		1
				Subadult Male			
2012	17			16	1		
2013	12			12			
2014	5			5			
				Yearling			
2012	5			3			
2013	7			2			
2014	5			2	1		2
				COY			
2012	6			6			
2013	25			12	1		12
2014	40		4	23			13
				Unknown			
2012	67		0	24	1		42
2013	108		2	24	1		81
2014	138		9	25	0		104
TOTAL	**720**	**1**	**42**	**388**	**21**		**268**

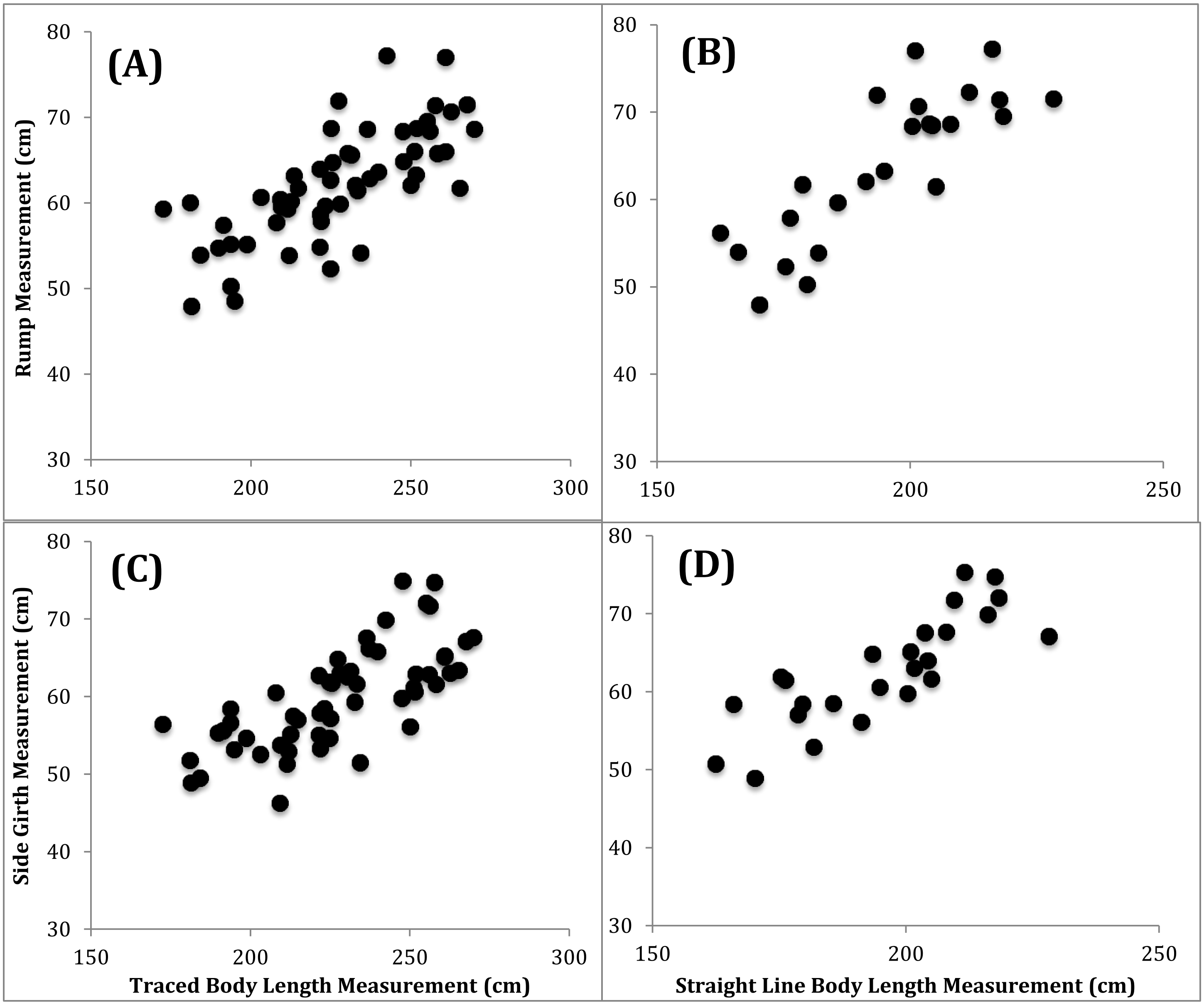


Figure 3-5: Scatterplots of morphological traits that indicate fatness (Rump [A and B] and Side Girth [C and D]) and the relationship with body length (Traced Body Length [A and C] and Straight Line Body Length [B and D] of 63 Adult male and female polar bears encountered in the Churchill Wildlife Management Area.

The seven morphological traits measured from free-ranging polar bears demonstrate differences between assigned sex and age classes (Table 3-5). TBL had the great variation among adult males and SLEN had the greatest variation among sub adults (both sexes were pooled) (Table 3-5). HL, RUMP and SAXG had the lowest variation among individuals in each of the assigned groups. Both RUMP and SAXG measurements varied between fatness scores assigned to adult polar bears. There was no significant relationship detected, slight positive relationships were found for both (Figure 3-6).

Table 3-5: Estimated mean (± SD) of seven measured morphological traits of 113 polar bears in the Churchill Wildlife Management Area in October and November 2012-2014.

Morphological Trait	COY	Subadult	Adult Female	Adult Male
Head Length (cm)	26.2 ± 2.4	32.2 ± 8.1	32.3 ± 6.6	36.4 ± 5.8
Shoulder Height (cm)	63.0 ± 5.8	95.2 ± 18.0	92.5 ± 16.0	110.0 ± 13.9
Hind Leg Height (cm)	68.5 ± 3.7	93.2 ± 8.1	96.5 ± 8.1	115.9 ± 13.8
Side Girth (cm)	39.0 ± 2.5	53.0 ± 13.3	53.5 ± 7.9	64.9 ± 9.4
Rump (cm)	45.5 ± 6.0	59.6 ± 10.4	56.4 ± 9.4	67.0 ± 9.3
Straight Body Length (cm)	109.9 ± 6.0	160.7 ± 29.7	180.9 ± 9.6	200.1 ± 15.8
Traced Body Length (cm)	141.6 ± 14.2	207.0 ± 34.3	212.5 ± 18.6	239.6 ± 43.3

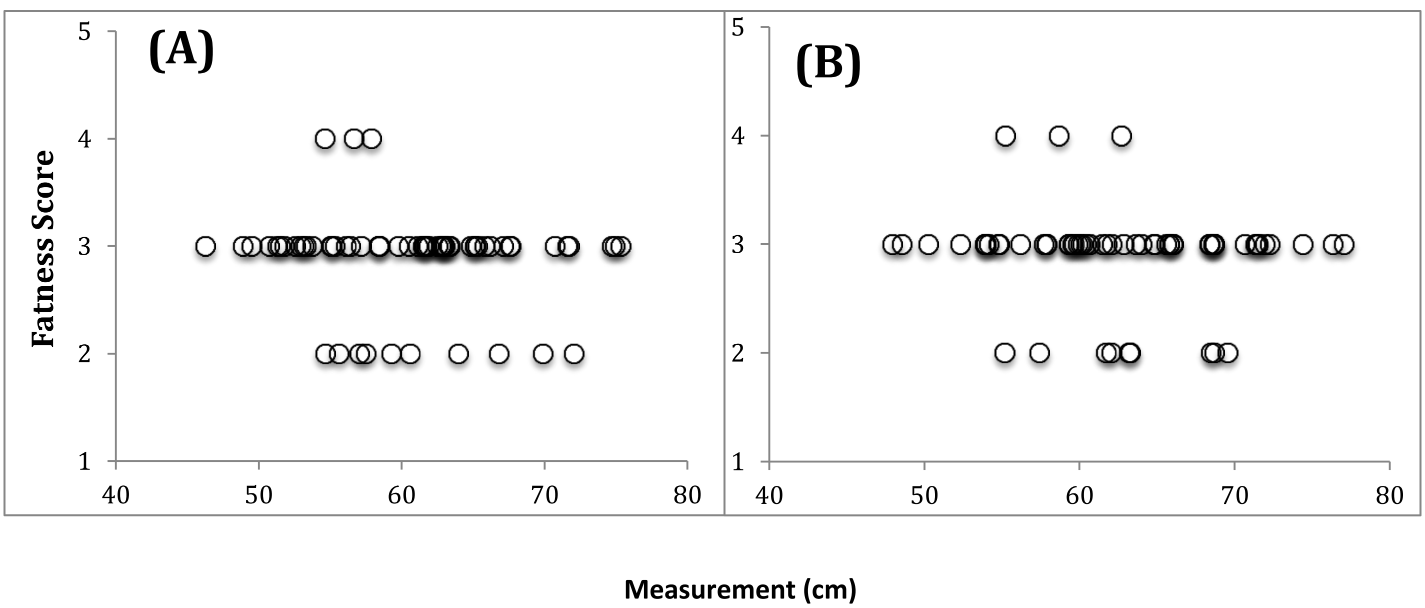


Figure 3-6: Scatterplots of polar bear body condition as a function of Side Girth (A) and Rump (B) of 63 Adult male and female polar bears encountered in the Churchill Wildlife Management Area in October and November 2012-2014.

Discussion

Overall, photogrammetric techniques of measuring polar bear body size produced comparable results to manual measurements. Mean error rates indicated the photogrammetric technique underestimated actual measurements of the morphological traits investigated. Measures of Rump and Side Girth had the lowest error rate, and were the best measures of fatness. The rapid collection of morphological measurements using photogrammetry allows for comparative assessment of body size and fatness index. Applying this technique to more individuals of varying known body sizes could allow for calibration of correction factors for the photogrammetric technique. Though, the findings of photogrammetric estimated measurements are encouraging, there are several limitations of this technique that warrant further research.

Measurement Comparisons

Variability of Photogrammetric Measurements

Variability of photogrammetric measurements generally increased proportionately with estimated morphological trait size (Figure 3-4). This pattern in measurement variability is consistent with other studies utilizing photogrammetric techniques, for instance Durban and Parsons (2006) found that variability of killer whale (*Orcinus orca*) fin measurements increased for larger sized whales. For the morphological measurements in this study, both traced and straight line body lengths were consistently the largest estimated measurements, had the most variability and straight line body length had the highest error (Table 3-3;Table 3-5). The mean error rates in this study were higher than other photogrammetric studies (Durban and Parsons 2006; Shrader et al. 2006; Webster et al. 2010). In other studies using this technique the animals have not had a large presence of fur on their bodies, which make it easier to visualize their skeletal features.

Bell et al. (2005) were able to collect measurements of elephant seals (*Mirounga leonina*) onshore, which made photographing them at desirable distances and angles possible.

Photogrammetric Errors

To obtain sufficiently precise and accurate estimations of polar bear morphological traits several considerations must be taken. Many photogrammetric approaches have dealt with limitations by using additional transformations or calculations to account for errors (Bergeron 2007; Breuer et al. 2007; Rothman et al. 2008). In some circumstances correction equations may not be feasible and therefore using a rating system to deal with deviations of the animals body from the ideal situation have been reliable (Webster et al. 2010; Willisch et al. 2013).

Horizontal axis error occurs when the bears' body position is not aligned with the camera and may interfere with height measurements (Durban and Parsons 2006) and increase mean error rates (Webster et al. 2010). Reducing an angle of the bears' body to the camera is essential to avoid exaggerated estimates of the morphological traits. This error was at times unavoidable during captive trails as there were only two observation points for both Hudson and Storm. Their position in the enclosure and body orientation limited the ability to collect a large sample size of excellent rated photographs; a majority of photographs of these two bears were rated good and could have lead to biased estimations at varying distances and focal lengths. Having a limited number of high quality photographs of two captive bears (Hudson and Storm) explains the wide variations in morphological trait size estimations (Figure 3-3). Specifically straight line length and shoulder height produce measurements not as precise as other morphological traits. This is also a limitation in the field because tundra vehicles are often parked or limited to where they can drive and the bears' position around the vehicle were not angled toward the camera.

Parallax error occurs when there is a vertical angle between the camera and subject (e.g. looking down to the subject) (Durban and Parsons 2006; Rothman et al. 2008) and results in a negative bias where the measured trait will be smaller than the actual (Durban and Parsons 2006). The result of parallax error is photogrammetric measurements underestimating the actual, which was limited as much as possible in the validation trails of captive bears (Table 3-3). However, the accuracy of photogrammetric measurements is less desirable (Figure 3-3;Figure 3-4). These measurements may have large error rates because of manual measurement errors; specifically measuring the shoulder height of a bear while in recumbent position may have produced an inaccurate manual measurement. While photographing captive polar bears there may have been vertical angles between the camera and the bears' body depending where in the enclosure the bear was. I was standing on the ground while taking photographs, and if the bear was near the front of the enclose would be on the same vertical plane; however, in Hudson and Storm's enclosure at distances >20m they were generally standing on an elevated hill, which could create biases in the photogrammetric measurements. Conversely, photographing polar bears within the CWMA at close distances (<10 m) the camera would be angled down and thus biasing the measurements collected. To avoid this, high quality photographs collected at distances less than <10 m were avoided and I recommend to decrease this bias to only take photographs between >15 m following criteria outlined by Durban and Parsons (2006).

Lastly, Definition error occurs when measuring photographs in imaging software. The polar bears' body (target surface) is not flat or free of measurement obstacles (e.g. hair), which can be challenging to distinguish the location of morphological trait landmarks. While this is an important error to consider, in this study measurement from the same photograph produced results that was within <3% of each other as outlined and considered acceptable as outlined by Bell et al. (1997). Definition error will always be an important consideration when measuring any morphological trait in imaging software and can be reduce by ensuring measurements of the same photograph are similar (Bell et al. 1997; Durban and Parsons 2006; Rothman et al. 2008). For example, both Rump and Side Girth measure from the underside of the belly where long guard hairs hide the pelvic girdle or axilla of the bear. However, zooming the photographs in ImageJ proved to alleviate this bias as both Rump and Side Girth yielded similar results to the paired manual measurements (Figure 3-3). Head Length was also measured using the bottom of the ear opposed to the middle of the ear to avoid definition ear of determining the middle of the ear consistently, however the wide variety of measurements seen in the four captive bears (Figure 3-3;Figure 3-4) and the significant underestimation (Table 3-3) suggest that this may not be a good measurement to include in analyses as definition error may be unavoidable and gives inaccurate results.

Polar Bear Size Estimates

The free-ranging polar bears encountered in the CWMA photogrammetric study were realistic compared to other polar bear body size studies (Derocher et al. 2004). Adult males were consistently larger in all morphological traits compared to other groups and COYs were consistently the smallest (Table 3-5). The subadult measurements closely resembled the adult females likely because both sexes were pooled in the subadult group due to difficulty in confidently assigning sex in this age class, so it is likely that some males are increasing the means and the ranges of the seven morphological traits (Table 3-5). A similar non-invasive study done in the Churchill Wildlife Management Area estimated shoulder height using a laser range finder and reported an average height of all bears being 0.98 ± 0.02m with a range of 0.55-1.21m (Eckhardt 2005), similar to the results found in this study (Table 3-5). The average shoulder height of sub adults and adults in this study was 0.95 m and ranged from 0.77-123.9 m.

Cattet and Obbard (2005) reported an average straight-line body length of 1.91m, measured from field studies in the southern Hudson Bay subpopulation during 1984-1986. In this study, traced body length and straight-line body length were used to compare to SLEN of other studies. However, the straight-line body length likely had several biases due to slight variations in the bear's head and neck position. The mean error of traced body length was 5% lower compared to straight-line body length (Table 3-3). Thus comparing traced body length, the average straight line body length declined to 1.83 m in the same subpopulation during 2000-2003 field-sampling years (Cattet and Obbard 2005). The average straight body length calculated in this study is similar in adult males (2.4 m) and females (2.1 m), the average straight body length calculated in this study in adult males (2.0 m) and females (1.8 m) (Table 3-3) were more similar to field studies (Cattet and Obbard 2005;).

Monitoring Polar Bear Body Condition and Demography

The measurements collected from free ranging polar bears in the CWMA during 2012-2014 yields realistic results that can be used to investigate trends in body condition. The main variable defining body condition was the fatness index. However, the lack of data contrast in fatness index scores of polar bears encountered limited the ability to determine relationships of morphological measurements (Rump and Side Girth) and fatness index scores (Figure 3-5). There was a weak tendency for Rump and Side Girth measurements to increase with a higher fatness index score. These measurements will vary depending on the total fat deposited to the subcutaneous layer of adipose tissue (Pond et al. 1992). Rump measurements will be more sensitive to changes in fat deposits as these subcutaneous depots enlarge twice as quickly as depots anteriorly (Side Girth) (Pond et al. 1992). Since most fast is deposited in the subcutaneous layer the appearance of the bear is greatly affected (fatness index). Body mass also increases with increasing fatness index rating score (Stirling et al. 2008)

Photogrammetric studies could be improved for monitoring body condition by obtaining morphological measurements that are known to be predictive of body mass could help establish a method to non-invasively monitor body condition. Known relationships between straight-line body length and axillary girth to body mass have enabled researchers to predicts weights of polar bears where in cases it wouldn’t be feasible (Durner and Amstrup 1996; Thiemann et al. 2011). Using three-dimensional (3D) photogrammetric techniques could obtain measurements of axillary girth, given that in this study 2D photogrammetric methods can only measure a straight line at the site of axillary girth (Figure 3-2). Waite et al. (2007) used 3D photogrammetry to estimate the body mass of stellar sea lion (*Eumetopias jubatus*), which was more accurate than comparable 2D techniques. Obtaining measures of Axillary Girth (AXG) using photogrammetric techniques may be applied to pre-existing equations (e.g. Thiemann et al. 2011) to determine body mass which will increase our understanding of polar bear body condition monitored non-invasively.

Polar bear body condition is known to decline throughout the on-shore period (Derocher et al. 1993; Atkinson and Ramsay 1995; Laforge et al. 2017). Polar bears may consume terrestrial foods while onshore but do not receive energetic benefit (Ramsay and Hobson 1991; Derocher et al. 1993;Rode et al. 2015). Furthermore, there is no relationship between terrestrial foraging and body condition of WHB polar bears (Sciullo et al. 2016). Thus the polar bears studied here were all likely fasting and approaching their lowest body condition.

Laforge et al. (2017) used remote cameras at field camps within Wapusk National Park, east of the CWMA detected the decline in polar bear body condition throughout the year. The timing of this study occurs in October and November, if this technique where to be applied elsewhere for comparative purposes it would be essential to understand the ecology and condition patterns of polar bears occupying that area.

Towns et al. (2010) found an overall northeastern shift in polar bears; meaning polar bears are not in the CWMA as much as they once were. The changes in land distribution of polar bears in this area will affect the likelihood of detecting changes in body condition. The majority of bears encountered were assigned a fatness score of 3, and it is possible that bears in poor body condition do not migrate towards the CWMA due to energetic limitations (Derocher and Stirling 1990). The distribution of polar bears of different age and sex classes' encountered throughout the study period is consistent with previous descriptions of polar bear locations during October and November; where lone adult females and adult females with dependent young do not occupy the same areas as adult males and sub adults (Derocher and Stirling 1990a). Adult males have been observed injuring sometimes fatally females and cubs (Derocher and Wiig 1999; Dyck and Daley 2002). Thus, Females and family groups could be avoiding areas where most polar bear encounters occur because of the presence of adult males.

Improving Photogrammetric Estimates

To improve our understanding of the differences between manual and photogrammetric measurements increased validation efforts are required. Many studies used animals of known size to obtain measurements of known size and to compare error rates (Sharder et al. 2006 and Webster et al. 2010). Using captive polar bears helped determine which photogrammetric measurements had more variability and were more accurate. While the technique can measure flat objects with little error (Figure 3-2) Improving the validation of this technique using a museum specimen will help gain insight to definition, and horizontal axis errors as a specimen will more accurately represents contours more similar to free-ranging polar bears opposed to a flat object (Bell et al. 1997). Additionally, understanding the relationship of the morphological traits collected and their relationship and predictive power of condition requires more bears of known size and of varying fatness index ratings. The four captive bears were all in good condition and there may be undetected biases of this technique when applied to bears of smaller body sizes and condition.

An alternative approach to using captive animals would be to collect measurements and paired photographs on individual polar bears handled and detained by

Manitoba Conservation and Water Stewardship during the open-water period near Churchill. The number of polar bears caught in Churchill has steadily increased since the 1970's, and represents all sex and age classes (Towns et al. 2009) and could be used to further understand the measurement errors presented in this study. The number of detained bears varies each year (10-90) and during 2009-2014, 142 different polar bears were handled and weighed in the holding facility (Pilfold et al. 2016). The bears that are held in this facility could be photographed pre/post capture, depending on safety then and measured and weighed while in the holding facility. This would increase sample size of known size bears in multiple fatness index categories.

There is potential that bears were repeatedly measured through each season and between seasons. Incorporation of a photographic identification system would be required to monitor individual body condition non-invasively; identifying the individuals would also decrease any pseudoreplication of measuring the same bear throughout the season. A technique has been developed using polar bears from the CWMA (Anderson et al. 2007; 2010). Photographs can be a reliable way of identifying individuals when pictures are taken in close proximity (<50m) and are of good quality (i.e. in focus). For identification purposes a good quality photographs requires the bear be in lateral position and the head occupy most of the frame, similar to the requirement needed to measure head length in this study. Thus, it can be achievable to simultaneously gather photographs that can measure body size and condition and also be used to identifying the individuals.

Conclusion

Photogrammetric studies have been widely applied in wildlife research and have shown promise for studying aspects of wildlife ecology in a relatively inexpensive and rapid way (Bell et al. 2005;Durban and Parsons 2006;Willisch et al. 2013). Photogrammetric techniques can be used to measure polar bear body traits reliably and with limitation. Increasing sampling effort to bears of known size of all fatness index scores will improve our understanding of the photogrammetric error rates in relation to body condition. Reducing the mean error is already minimized by photo rating process and taking photos at reasonable distances (<15 m).

Ongoing climate change is going to have considerable effects on the Arctic ecosystem and consequently polar bears. Over the last three decades sea ice now breaks up approximately three weeks earlier (Gagnon and Gough 2005), consequently polar bear body condition has declined (Stirling et al. 1999; Sciullo et al. 2016) which will have detrimental effects on population health (Patyk et al. 2015). Creating rapid non-invasive techniques to monitor subpopulations will allow for increased monitoring in subpopulations not as well studied as Western Hudson Bay. Improving these photogrammetric techniques can provide insight into changes of polar bear body condition and could benefit future management and conservation efforts.

Chapter 4: Connecting to Nature using Environmental Education and Tourism

“When you look into a polar bear's eyes from two feet away,
your life will change forever. During this connection
a polar bear can pierce through your heart straight
into your soul so that you instantly understand how privileged
you are to live on this planet at this time"

— Robert Buchanan

Background

Social support is a vital aspect of any successful conservation strategy and can only be achieved through an informed public (McKinney 2002). Unfortunately, nature is often viewed as something separate and disconnected from our everyday lives (Miller 2004). However, environmental education and outreach can bridge the perceived and/or realized gap between nature and today's society. Indeed, the best way to build a connection to our environment is through experiential and place-based learning (Gruenewald 2003a; Ardoin 2006). Citizen science projects are an excellent platform for individuals to immerse themselves in, and contribute to, biological surveys in their local environment or by vising exotic regions as a tourist (Brightsmith et al. 2008; Jones et al. 2012; Ries and Oberhauser 2015). Affording the public the opportunity to experience, understand, and appreciate the environment, both locally and in remote regions, will enhance conservation efforts by increasing public interest through experience-based engagement and learning (Brightsmith et al. 2008; McKinney 2002; Miller 2004).

Environmental Education

In order to effectively conserve the environment, it is imperative for our society to understand the natural world and the connection between all inhabitants, including human societies and wildlife (Berkowitz et al. 2005; Jordan et al. 2009). Environmental issues today are weaved into our personal relationships with nature, and these issues can be addressed with increased education (Liefländer et al. 2013). The decisions we make daily are reflections of our lifestyles and contribute to the overall health of our environment, and, unfortunately, a large portion of the public is unaware of this connection (Kollmuss and Agyeman 2002; Spence and Pidegon 2009). Such environmental ignorance stems from lack of awareness, lack of information, or, potentially more damaging, misinformation, which in turn can cause feelings of disconnect from the environment. Kollmuss and Agyeman (2002) suggest that many people do not live sustainable or pro-environmental lifestyles as a result of this lack of understanding. A factor contributing to the knowledge gap between science and the general public is poor communication between the two groups; simply put, communication and interpretation of scientific knowledge is failing. Therefore, environmental education and outreach can serve as an important tool in the current environmental crisis and can promote pro-environmental behaviour in our society.

Environmental education works towards improving environmental issues by increasing citizens' awareness, understanding, and connections with nature (Schultz et al. 2004; Liefländer et al. 2013). In order for participants to understand and relate to nature, they need to create positive relationships between themselves and the environment (Schultz et al. 2004; Liefländer et al. 2013). Furthermore, environmental education works towards developing the skills required to solve environmental issues, thus inspiring citizens to take action. Education alone cannot increase human pro-environmental behaviour; there also needs to be a positive relationship with nature (Schultz 2011; Liefländer et al. 2013). Participation in scientific data collection can help foster positive attitudes towards conservation and instill pro-environmental behaviour in individuals (Schultz 2011; Dickinson et al. 2012). For environmental education to be successful, it is vital that citizens develop a connection with nature and their surroundings to become inspired as environmentally active citizens in their communities (Gruenewald 2003b;

Ardoin 2006; Liefländer et al. 2013). Much of our environmental knowledge is lacking when it comes to distant regions; citizens generally know more about their local surroundings and less about places that they may not ever experience, or experience only during brief periods of time during tourism opportunities. Citizen science is an excellent form of environmental education that can create a connection between participants and nature during volunteer tourism opportunities (Dickinson et al. 2012).

Citizen Science

While most environmental education programs target youth in schools, citizens of all ages should be exposed to environmental education and outreach opportunities (Bass 2012; Puk 2012). An easy way to continue environmental education is to implement citizen science projects aimed at monitoring biodiversity, changes in the environment, or other natural sciences research (Booney et al. 2009; Dickinson et al. 2010; Jones et al. 2012). Citizen science effectively engages people of all ages in investigating scientific questions about their natural communities (Cooper et al. 2007; Jones et al. 2012) and is a way to unite science and society.

The process of conducting citizen science requires collaboration between scientific researchers (i.e. trained professionals) and volunteer citizens who will have limited formal training (Dickinson et al. 2010). The contributions of citizen scientists can involve participation in research design, data collection and analysis, and project conclusions (Bhattacharjee 2005; Booney et al. 2009; and Dickinson et al. 2010), and in some case, have even aided in the publication of scientific reports, which influence environmental policies (Conrad and Hilchey 2011).

Challenges of Citizen Science

Obtaining accurate and high quality data can be a barrier when using citizen science; errors in data collection in citizen science projects are usually a consequence of complex sampling protocols, ineffective training exercise, and lack of experience (Gardiner et al. 2012). However, citizen-collected data can be reliable if proper training and protocols are implemented (Cooper et al. 2007; Cohn 2008), and when volunteer citizens are accompanied by trained professionals (Dickinson et al. 2010). Implementing quizzes and games to test participants' ability to effectively collect data can help increase the reliability of citizen-collected data (Cohn 2008; Dickinson et al. 2010).

Benefits of Citizen Science

Citizen science can be beneficial not only for the researchers but also for the participants (Bhattacharjee 2005; Booney et al. 2009; and Dickinson et al. 2010; 2012). The reduction of research-associated costs in conjunction with increased manpower results in more cost- and time-effective studies. Citizen scientists can collect three to four times the number of samples and observations than those provided by researchers alone for the same cost (Gardiner et al. 2012). For the citizen scientists, the benefits include the opportunity to explore their natural surrounding more and understand the process of collecting data.

Understanding of the scientific method will provide citizens with the underlying knowledge and understanding of the process of how scientific conclusions are made which can increase the willingness to accept scientific results (Booney et al. 2009; Jones et al. 2012). Citizens will also become more inquisitive about scientific research (Mueller et al. 2012). The acquisition of scientific evidence that is more closely related to personal experience rather than typical scientific studies has become increasingly appreciated by the public and policy makers (Mueller et al. 2012). The citizen science approach, based upon easily interpretable observations can be an important part of providing that personal experience and, thus, can improve scientific outcomes for conservation. For instance, a non-invasive study in Churchill, Manitoba used citizen science by training volunteers to collect photographs that would later be analyzed for polar bear identification purposes (Anderson et al. 2007). The trained volunteers not only participated in data collection, but also were able to aid in the analysis of the photographs by selecting which possessed the necessary data for identification (Anderson et al. 2007), furthering their knowledge of the scientific method.

Increasing the Effectiveness of Citizen Science Projects

In order for participants to achieve optimal outcomes from their involvement in citizen science projects it will be crucial to understand how and if citizens do increase their scientific literacy as a result of participation in citizen science (Brossard et al. 2005; Cronje et al. 2011). Brossard et al. (2005) concluded that scientific literacy did not increase but participants' knowledge of bird biology did increase after being involved in a citizen science project aimed at monitoring songbirds. Understanding the motivations of participants' in citizen science projects is critical, and most participants are more interested in the subject area of the study, as was concluded by Brossard et al. (2005). It is important to link an increase in scientific literacy and understanding of the scientific method to participation in citizen science projects. To investigate if participation in a citizen science project would increase scientific literacy Cronje et al. (2011) surveyed 57 citizen scientists participating in a project monitoring invasive plant species in Wisconsin and Colorado. Participants completed pre and post surveys to determine their scientific literacy. Both Brossard et al. (2005) and Cronje et al. (2011) emphasized more surveys are required to assess the effect of citizen science programs on participant scientific literacy and acceptance, which will allow for a better understanding of participant motivations.

A citizen science project in Michigan determined that most participants indicated that they were strongly motivated to volunteer to gain an understanding of natural ecosystems and conservation, where up to 96% agreed they were motivated by wanting to be involved in a conservation cause (Van Den Berg et al. 2009). If motivations are driven by the willingness to learn about the environment, it is essential that projects focus on engaging the participants so they can gain an understanding of the complex functions of the ecosystem in which they were working (Van Dan Berg et al. 2009).

Citizen science provides an opportunity to not only advance scientific knowledge (Cohn 2008), but also enhance ecotourism endeavors by providing the tourists with environmental education opportunities that increase their scientific literacy (Cronje et al. 2011). As citizens experience and understand the environment, they will become more scientifically literate. Thus, it is crucial that environmental education be available to not only school aged children, but also adults. By giving all citizens opportunities to connect to the environment, they will become active citizens with the desire to create change in current environmental conservation (Ballantyne et al. 2009; Cooper et al. 2015).

Incorporating Citizen Science in Tourism

Integrating citizen science projects into tourism would create education outreach opportunities for tourists, while also providing tourists the chance to contribute to wildlife conservation efforts. With an increase in demand for ecotourism opportunities (Meletis and Campbell 2007; Weaver and Lawton 2007), and the lack of conservation funding, volunteer ecotourism is a relatively new concept that has become increasingly popular (Caissie and Halpenny 2003; Brightsmith et al. 2008). People seek educational and cultural experiences in their travels and this contributes to the growing popularity of ecotourism (Lemelin et al. 2010). Last chance tourism has become increasingly popular, as people want to have the chance to experience nature and explore some of the planet's vanishing ecosystems before they are gone (Caissie and Halpenny 2003; Scott et al. 2007; Dawson et al. 2010; Lemelin et al. 2010).

Ecotourism strongly encourages a connection to nature or a foreign community. The environmental benefits for increased sustainable behaviors or pro-environmental thoughts could increase through tourism experiences (Lemelin 2006; Cooper et al. 2015). The increasing demand for ecotourism opportunities (Meletis and Campbell 2007; Weaver and Lawton 2007) and the lack of conservation funding, have made volunteer ecotourism programs valuable and increasingly popular (Campbell and Smith 2006; Brightsmith et al. 2008). Volunteer tourism utilizes volunteer citizens for funding and labor for community and/or wildlife projects (Caissie and Halpenny; McIntosh and Sahra 2007; Brightsmith et al. 2008).

There are many organizations that offer volunteer tourism opportunities to collect scientific data, for example an organization known as Earthwatch has run multiple expeditions to a variety of ecosystems, where many scientific field studies were conducted using volunteers (McGehee 2002; Brightsmith et al. 2008). Since the inception of Earthwatch in 1972, more than 50,000 participants have been involved (McGehee 2002). Tourist satisfaction with the experience and contributing to the research project averages 97.4% (Brightsmith et al. 2008). Often people who participate in volunteer tourism experience lesser costs than the average tourist to mainstream Eco-lodges and will learn more than normal tourists. Participants in volunteer ecotourism have multiple motivations for becoming involved; for example, “to be more than just a tourist” and “to work and give” were responses by volunteer tourists in New Zealand (McIntosh and Sahra 2007). Another study on participant motivation determined that participants predominantly wanted to learn and experience new places, cultures, and ecosystems, a common answer given by interviewees indicating they wanted to travel (Sin 2009). Volunteer ecotourism gives people the chance to learn about the ecosystem they are immersed in and hopefully when they go home, as Jones et al. (2012) suggests of citizen scientists, they will devote time from their lives to further conservation efforts or other pro-environmental behaviors (Jensen 2002).

Involving Citizen Science in Polar Bear Tourism

Most wildlife tourism is photography-based, particularly for polar bear viewing in Churchill (Lemelin 2006). Non-invasive photographic studies can also be useful in monitoring populations by identifying individuals in a population. For polar bears, a technique has been developed to identify individual bears from the Western Hudson Bay subpopulation in the Churchill Wildlife Management Area in Manitoba (Anderson et al. 2007; 2010). The findings of this preliminary polar bear identification study show that photographs can be a reliable way of identifying individuals when pictures are taken in close proximity (<50m) and are of good quality.

Citizen science contributes greatly to the field of ecology when projects involve monitoring biodiversity at broad geographic scales (Dickenson et al. 2010). By spatially increasing study sites of species ranges or entire ecosystems, ecologists are able to better understand or address fundamental ecosystem questions. Polar bears have a wide circumpolar range and, as discussed in *Chapter 2 – Polar Bear Research and Management*, some subpopulations are logistically challenging to research in traditional ways. Thus, citizen science offers opportunities to collect baseline data in areas that have been understudied, and where ecological processes are poorly understood.

Polar Bear Tourism in Canada

In Canada, there are many areas that attract tourists to view polar bears. The most popular polar bear tourism destination is Churchill, Manitoba. Each fall polar bears belonging to the Western Hudson Bay (WHB) subpopulation congregate along the shorelines waiting for the ice to freeze (Derocher and Stirling 1990; Cherry et al. 2013), making the area one of the most accessible for tourism and research. The polar bear tourist season is approximately six weeks long (October and November). Annually, an estimated 10,000 tourists from around the world travel to view polar bears (Dawson et al. 2010) in their natural habitat from specially designed tundra vehicles (Dyck and Baydack 2004; Lemelin 2006, 2008). These vehicles are able to maneuver on the sub-Arctic tundra and safely bring tourists close to free-ranging polar bears (Figure 4-1).

Figure 4-1: Polar bear encounters with Tundra Buggy® vehicles in the Churchill Wildlife Management Area, Manitoba, Canada.

Churchill also experiences a smaller influx of visitors during the spring, when tourists travel through Churchill to go to Wat'Chee Lodge, located within Wapusk National Park, which provides visitors with the opportunity to watch family groups (adult females and newborn cubs) emerge from their dens before they migrate out onto the sea ice. The Wat'Chee Lodge is an on-foot operation, and only allows 20 guests per group. To minimize disturbance, visitors remain 100 feet away from the dens, but are guarded by an armed Parks Canada employee.

Recently, Torngat Mountain National Park (TMNP) has become another popular area for polar bear encounters and viewings. The park was established in 2005 and is located on the northeastern tip of Labrador, Canada. Between 2005 and 2011 there were 171 polar bear observations recorded in TMNP mainly by local residents and cruise ship visitors (Parks Canada 2011). The polar bears viewed within this region belong to the Davis Straight population (Lemelin and Maher 2009). The non-resident visitation of the area of Newfoundland and Labrador increased from 2003-2007 by 15% and generated approximately $357 million in provincial revenue (Maher and Lemelin 2011). An estimated 21,000 cruise adventure tourists visited the region, even though not all visited TMNP, and this number is expected to increase in the future (Maher and Lemelin 2011). Using local Inuit guides as polar bear monitors within the park is a main component of the management plan of the park (Lemelin and Maher 2009). This will allow for more contact between Inuit and tourists and forge effective relationships with park managers.

Cruise opportunities are the most popular platforms for polar bear viewing outside of the Churchill tourism operations. Most likely, smaller boat operations that also guide tours exist, such as yachts or small boat vessels. Cruise ships access many of the northern National Parks (Lemelin and Maher 2009) and with the increased duration in the ice-free season, due to climate change, many inaccessible areas of the past are now passable. This will likely result in increased tourism and opportunity for citizen science to be conducted.

Effects of Polar Bear Tourism

There are many impacts to an ecosystem with increased ecotourism including: environmental damage (loss of ecological integrity), urbanization, human waste (including garbage, noise, and light pollution), and wildlife disturbances (Stem et al. 2003; Almeyda et al. 2010a; Almeyda et al. 2010b; Broadbent et al. 2012). Successful ecotourism operations will draw a higher amount of tourists, which will ultimately stimulate the economy, an added benefit of ecotourism. However, this will lead to an increase in the negative impacts, such as waste generation, habitat disturbance and forest degradation resulting from an increasing human demand (Almeyda et al. 2010a and Almeyda et al. 2010b). Many studies have been devoted to the investigating the impacts on wildlife from ecotourism (Lemelin et al. 2006; Lemelin et al. 2010; McKinney 2014).

Higham and Hendry (2008) highlight an excess of human-made sound during tourism excursions, which can have negative consequences animal behaviour. When investigating the impact of sound on polar bear behaviour, it was found that 6.1% of 49 individual bears in human sound playback experiments showed a response to noise that was 106.1 $\pm$ 0.6 decibels (dB) (Eckhardt, 2005). The average noise level on a touring tundra vehicle was 105.6dB. Thus, there does not seem to be a significant effect of noise on polar bears in the CWMA (Eckhardt, 2005). During the same study, polar bear behavior in response to tundra vehicles was examined, and it was found that, of 186 tundra vehicle approaches, 25% resulted in a behavioral response, defined as either a bear lifting its head up or movement away from tundra vehicle (Eckhardt 2005). Of the responses, 57% resulted in the polar bear walking away (Eckhardt 2005), which creates bad photograph opportunities for tourists and could result in their dissatisfaction (Lemelin 2006). Polar bear behaviour, specifically vigilance, was influenced by the presence, distance, and number of tundra vehicles (Dyck and Baydack 2004). Ensuring that the tundra vehicles do not affect polar bear behavior is important to their life history and also to visitor experience. Dyck and Baydack (2004) and Eckhardt (2005) both suggest that more research is required for continued monitoring of tourism effects on polar bears. However, the conclusions of both Dyck and Baydack (2004) and Eckhardt (2005) do state that the tourism is generally safe for both tourists and polar bears, and that the largest concern is the increased number of polar bears becoming habituated to humans, which could cause increased human-polar bear conflict.

The environmental impact of polar bear tourism should also be considered when evaluating the effectiveness of such tourism opportunities. The average polar bear viewing tourist season is estimated to emit 20,892 tonnes of CO_2 (Dawson et al. 2010). The authors also calculated the estimated emissions for travel to Churchill, as it will be different depending where the tourist trip originated. Thus, it is important to create opportunities that will work to offset the cost of carbon emissions to travel to tourism locations. Education outreach and citizen science programs provide a platform to combine both research and tourism activities, and work towards offsetting the negative impacts of the tourism experience.

Tourism and Conservation Benefit

Ecotourism or wildlife tourism facilitates a connection to nature by participants, and hopefully inspires them to want to help in conservation efforts (Hvenegaard 1994). Lemelin (2006) reported that participants in polar bear tourism expressed their desire to understand and form bonds with people and animals and were concerned for their future welfare. Therefore, ecotourism does strongly encourage that connection to nature or to a different community. Thus, beyond economic benefits, the environmental benefits for increased sustainable behaviors or pro-environmental thought could increase through experiences such as wildlife tourism (Lemelin 2006). Wildlife tourism can involve viewing and photographing wildlife in captive, semi-captive, and free-ranging natural environments (Roe et al 1997). Wildlife tourism involves a wide range of activities, such as photography tours, or bird or whale watching. Demand to view wildlife in their natural habitat is increasing, especially for charismatic megafauna, or species facing the threat of extinction (Lemelin et al. 2010).

The greatest benefit of wildlife tourism is to provide opportunities for tourists to engage with an ecosystem, community, or species they would otherwise not ever see for themselves.

> *'What do you want to provide the wildlife tourists with? The opportunity to photograph a big cuddly animal? Or the opportunity to see and understand an extraordinary rare and complex creature, living its life in its natural environment?'*
>
> Lemelin 2009, p. 531

Tourism can be useful for conservation because of the potential to generate funds and increase public support in protection of a particular species and their habitat (Wadpole and Leader-Williams 2001). Thus, polar bear tourism can be used to raise public awareness and draw attention to specific needs of polar bear conservation. Involving tourism in any form of data collection has a two-fold impact: first, data can be collected in large quantities compared to the capabilities of wildlife managers or researchers, and second, the tourists have the opportunity to learn more about the species and the scientific method.

Tourism combined with citizen science has the capacity to allow for strong connections to nature to be built or strengthened. Thus, beyond economic benefits, the environmental benefits of increased sustainable behaviour or pro-environmental thought could be increased through wildlife or ecotourism experiences (Lemelin 2006). Citizen science provides an opportunity to enhance the conservation value of ecotourism endeavors by providing the tourists with environmental education and increasing their scientific literacy and pro-environmental behaviors that will extend beyond their tourism experience.

Chapter 5: Conclusion

"It's not enough to understand the natural world.
The point is to defend and preserve it."

— Edward Abbey

The goal of my major paper was to investigate ways of improving Arctic wildlife conservation, specifically focusing on polar bears (*Ursus maritimus*). I was particularly interested in understanding the ways in which ecological research studies influence polar bear management and conservation strategies, as well as how the integration of environmental education into tourism endeavors could improve conservation goals. I primarily focused on investigating the use of photogrammetric techniques to determine polar bear body size. Photogrammetric techniques have been successfully used to monitor other wildlife species (Shrader et al. 2006;Bergen 2006; Willisch et al. 2013) and report low error rates. The findings in this project indicate that more research of subjects (bears) of known size will be required increase the accuracy of this technique, and account for photogrammetric measurement errors. Using four captive polar bears I found no statistically significant difference between hand and photogrammetric measurement of two morphological traits (rump and side girth). The results of my study present realistic estimations of polar bear morphological traits, that is consistent with findings from other field studies (Derocher et al. 2004; Cattet and Obbard 2005; Eckhardt 2005).

Continued monitoring of polar bears and other Arctic species upon which polar bears rely for food (e.g. ringed seals [*Pusa hispida*]) is required to ensure we have the necessary knowledge to inform management decisions and to effectively conserve Arctic wildlife in the future. Future research into the dynamics within the Hudson Bay ecosystem are required to better determine how polar bears in this area will respond to rapid environmental change. Given that the Western Hudson Bay subpopulation is one of the most southerly subpopulations, it can demonstrate how other subpopulations will respond to climate change in the future. For these reasons it is important that continued research and monitoring programs focus on this subpopulation; however, attention should also be paid to this accessible subpopulation to test new technologies and other techniques that could be applied to other subpopulations.

Further research investigating tourists' responses and perceptions regarding polar bears and climate change after tourism experiences and exposure to citizen science projects would be beneficial to validate the ideas expressed here: that tourism opportunity and citizen science platforms further connect individuals to an ecosystem, species, and the scientific process. Understanding factors that effectively make tourists more informed citizens and will positively influence conservation initiatives either through donations to non-profit organizations dedicated to Arctic conservation (e.g. Polar Bears International and World Wildlife Fund) or lifestyle choices, is crucial for citizen science projects and tourism planning.

With a risk of further habitat loss due to climate warming, ecological assessments will be essential to understand and monitor the possible changes in body condition of polar bears throughout their range. For now, due to financial and time constraints, only a few subpopulations can be sufficiently studied to further our understanding of their ecology in relation to climate change. Creating new research techniques and forging new collaborations between the scientific community, the Inuit, and the public will be essential for polar bear management and conservation plans. Non-invasive research and citizen science projects will likely contribute to the understanding of polar bears in certain areas. In regards to the Western Hudson Bay subpopulation, citizen science research can be most effective by primarily serving as a platform for education, and secondarily for research. Amstrup et al. (2010) concluded that a reduction of greenhouse gas emission would allow polar bears to persist. If emissions are not reduced, polar bears in the Western Hudson Bay subpopulation could be extirpated by mid century (Castro de la Guardia et al. 2013).

It is vital to build public support in pushing for better climate policies within Canada and across the globe. Polar bears are considered an Arctic icon, and are familiar as a poster species for climate change (Slocum 2004), capturing the attention of many people who may never see polar bears in their natural habitat. Most people will never visit the Arctic or sub-Arctic region and will not be able to connect with the wildlife that lives there. Therefore, Environmental education can serve to connect nature and our society. The best way to make this connection is through experiential and place based learning. In order to develop citizens who are prepared to deal with ongoing global environmental issues it is first and foremost important that citizens be able to develop a sense of place in their environment (Ardoin 2006). Affording the public an opportunity to familiarize, understand and appreciate the environment in their own backyard, or in distant areas, such as tropical rainforests, Arctic tundra, or the deep ocean, will enhance global conservation efforts. Environmental education should not be confined to educational institution curricula; there are multiple ways for the public to become involved in their communities. Such involvement will further strengthen their sense of place or connection to their natural community and environment. By giving all individuals opportunities to connect to the environment, they will, hopefully, become active citizens with the desire to protect it, and will create positive change in our current conservation and environmental crises.

Literature Cited

Almeyda, A.M., Broadbent, E.N., Wyman, M.S. and Durham, W.H. 2010. Ecotourism impacts in the Nicoya Peninsula, Costa Rica. International Journal of Tourism research, 12(6): 803-819.

Almeyda, A.M., Broadbent, E.N. and Durham, W.H. 2010. Social and environmental effects of ecotourism in the Osa Peninsula of Costa Rica: the Lapa Rios case. Journal of Ecotourism, 9(1): 62-83.

Amstrup, S. C. 2003. Polar Bear, *Ursus maritimus*. Pages 587–610 *in* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, editors. Wild Mammals of North America Biology. Management, and Conservation. 2nd Edition. Johns Hopkins Unversity Press, Baltimore, Maryland, USA.

Amstrup, S.C., Marcot, B.G. and Douglas, D.C. 2008. A Bayesian network modeling approach to forecasting the 21st century worldwide status of polar bears. Arctic sea ice decline: observations, projections, mechanisms, and implications: 213-268.

Amstrup, S.C., DeWeaver, E.T., Douglas, D.C., Marcot, B.G., Durner, G.M., Bitz, C.M. and Bailey, D.A. 2010. Greenhouse gas mitigation can reduce sea-ice loss and increase polar bear persistence. Nature, 468(7326): 955.

Anderson, C.J.R., Roth, J.D. and Waterman, J.M. 2007. Can whisker spot patterns be used to identify individual polar bears?. Journal of Zoology, 273(4): 333-339.

Anderson, C.J., Da Vitoria Lobo, N., 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.

Ardoin, N.M. 2006. Toward an interdisciplinary understanding of place: Lessons for environmental education. Canadian Journal of Environmental Education, 11(1): 112-126.

Atkinson, S.N. and Ramsay, M.A. 1995. The effects of prolonged fasting of the body composition and reproductive success of female polar bears (Ursus maritimus). Functional Ecology: 559-567.

Ballantyne, R., Packer, J. and Hughes, K. 2009. Tourists' support for conservation messages and sustainable management practices in wildlife tourism experiences. Tourism Management, 30(5): 658-664.

Bass, C. 2012. Learning Theories & Their Application to Science Instruction for Adults. The American Biology Teacher, 74(6): 387-390.

Bell, C.M., Hindell, M.A. and Burton, H.R. 1997. Estimation of body mass in the southern elephant seal, Mirounga leonina, by photogrammetry and morphometrics. Marine Mammal Science, 13(4): 669-682.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. and Courchamp, F. 2012. Impacts of climate change on the future of biodiversity. Ecology letters, 15(4): 365-377.

Berger, J. 2012. Estimation of body-size traits by photogrammetry in large mammals to inform conservation. Conservation Biology, 26(5): 769-777.

Bergeron, P. 2007. Parallel lasers for remote measurements of morphological traits. Journal of Wildlife Management, 71(1): 289-292.

Berkowitz, A.R., Ford, M.E. and Brewer, C.A. 2005. A framework for integrating ecological literacy, civics literacy, and environmental citizenship in environmental education. Environmental education and advocacy: Changing perspectives of ecology and education, 227: 66.

Bhattacharjee, Y. 2005. Citizen scientists supplement work of Cornell researchers. Science, 308: 1402-1403.

Bluhm, B.A. and Gradinger, R. 2008. Regional variability in food availability for Arctic marine mammals. Ecological Applications, 18(sp2).

Booney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., and Shirk, J. 2009. Citizen Science: A developing tool for expanding science knowledge and scientific literacy. BioScience, 59(11): 977-984.

Botkin, D.B., Saxe, H., Araujo, M.B., Betts, R., Bradshaw, R.H., Cedhagen, T., Chesson, P., Dawson, T.P., Etterson, J.R., Faith, D.P. and Ferrier, S. 2007. Forecasting the effects of global warming on biodiversity. AIBS Bulletin, 57(3): 227-236.

Brightsmith, D.J., Stronza, A. and Holle, K. 2008. Ecotourism, conservation biology, and volunteer tourism: A mutually beneficial triumvirate. Biological Conservation, 141(11): 2832-2842.

Broadbent, E.N., Zambrano, A.M.A., Dirzo, R., Durham, W.H., Driscoll, L., Gallagher, P., Salters, R., Schultz, J., Colmenares, A. and Randolph, S.G. 2012. The effect of land use change and ecotourism on biodiversity: a case study of Manuel Antonio, Costa Rica, from 1985 to 2008. Landscape ecology, 27(5): 731-744.

Bromaghin, J.F., McDonald, T.L., Stirling, I., Derocher, A.E., Richardson, E.S., Regehr, E.V., Douglas, D.C., Durner, G.M., Atwood, T. and Amstrup, S.C. 2015. Polar bear population dynamics in the southern Beaufort Sea during a period of sea ice decline. Ecological Applications, 25(3): 634-651.

Brook, R.K. 2001. Structure and dynamics of the vegetation in Wapusk National Park and the Cape Churchill Wildlife Management Area of Manitoba: community and landscape scales. M.N.R.M thesis, Natural Resource Institute, The University of Manitoba, Winnipeg, Manitoba.

Brossard, D., Lewenstein, B. and Bonney, R. 2005. Scientific knowledge and attitude change: The impact of a citizen science project. International Journal of Science Education, 27(9): 1099-1121.

Burek, K.A., Gulland, F. and O'Hara, T.M. 2008. Effects of climate change on Arctic marine mammal health. Ecological Applications, 18(sp2).

Calvert, W. and Ramsay, M.A. 1998. Evaluation of age determination of polar bears by counts of cementum growth layer groups. Ursus: 449-453.

Campbell, L.M. and Smith, C. 2006. What makes them pay? Values of volunteer tourists working for sea turtle conservation. Environmental Management, 38(1): 84–98.

Castro de la Guardia, L., Derocher, A.E., Myers, P.G., Terwisscha van Scheltinga, A.D. and Lunn, N.J. 2013. Future sea ice conditions in Western Hudson Bay and consequences for polar bears in the 21st century. Global Change Biology, 19(9):2675-2687.

Cattet, M.R., Caulkett, N.A., Obbard, M.E. and Stenhouse, G.B. 2002. A body-condition index for ursids. Canadian Journal of Zoology, 80(7): 1156-1161.

Cattet, M.R. and Obbard, M.E. 2005. To weigh or not to weigh: conditions for the estimation of body mass by morphometry. Ursus, 16(1): 102-107.

Cherry, S.G., Derocher, A.E., Thiemann, G.W. and Lunn, N.J. 2013. Migration phenology and seasonal fidelity of an Arctic marine predator in relation to sea ice dynamics. Journal of Animal Ecology, 82(4): 912-921.

Clark, D.A., Clark, S.G., Dowsley, M., Foote, L., Jung, T.S. and Lemelin, R.H. 2010. It's not just about bears: a problem-solving workshop on aboriginal peoples, polar bears, and human dignity. Arctic, 63(1): 124-127.

Clark, D.A., Stirling, I. and Calvert, W. 1997. Distribution, characteristics, and use of earth dens and related excavations by polar bears on the western Hudson Bay lowlands. Arctic: 158-166.

Cohn, J.P. 2008. Citizen science: Can volunteers do real research?. AIBS Bulletin, 58(3): 192-197.

Comiso, J.C. 2006. Abrupt decline in the Arctic winter sea ice cover. Geophysical Research Letters, 33(18).

Conrad, C.C. and Hilchey, K.G. 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental monitoring and assessment, 176(1): 273-291.

Cooper, C., Dickinson, J., Phillips, T. and Bonney, R. 2007. Citizen science as a tool for conservation in residential ecosystems. Ecology and Society, 12(2).

Cooper, C., Larson, L., Dayer, A., Stedman, R. and Decker, D. 2015. Are wildlife recreationists conservationists? Linking hunting, birdwatching, and pro-environmental behavior. The Journal of Wildlife Management, 79(3): 446-457.

COSEWIC. 2004. COSEWIC assessment and update status report on the beluga whale *Delphinapterus leucas* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. Vii + 70 pp.

COSEWIC. 2011. COSEWIC assessment and update status report on the caribou *Rangifer tarandus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. Vii + 88 pp.

Cronje, R., Rohlinger, S., Crall, A. and Newman, G. 2011. Does participation in citizen science improve scientific literacy? A study to compare assessment methods. Applied Environmental Education & Communication, 10(3): 135-145.

Dawson, J., Stewart, E.J., Lemelin, H. and Scott, D. 2010. The carbon cost of polar bear viewing tourism in Churchill, Canada. Journal of Sustainable Tourism, 18(3): 319-336.

Derocher, A.E., Andriashek, D. and Stirling, I. 1993. Terrestrial foraging by polar bears during the ice-free period in western Hudson Bay. Arctic: 251-254.

Derocher, A.E., Lunn, N.J. and Stirling, I. 2004. Polar Bears in a Warming Climate. Integrative and Comparative Biology, 44(2): 163-176.

Derocher, A.E. and Stirling, I. 1990. Distribution of polar bears (Ursus maritimus) during the ice-free period in western Hudson Bay. Canadian Journal of Zoology, 68(7): 1395-1403.

Derocher, A.E. and Stirling, I. 1995. Temporal variation in reproduction and body mass of polar bears in western Hudson Bay. Canadian Journal of Zoology, 73(9): 1657-1665.

Derocher, A.E. and Wiig, Ø. 1999. Infanticide and cannibalism of juvenile polar bears (Ursus maritimus) in Svalbard. Arctic: 307-310.

Derocher, A.E. and Wiig, Ø. 2002. Postnatal growth in body length and mass of polar bears (Ursus maritimus) at Svalbard. Journal of Zoology, 256(3): 343-349.

Dickinson, J.L., Zuckerberg, B., and Bonter, D.N. 2010. Citizen Science as an Ecological Research Tool: Challenges and Benefits. Annual Review of Ecology, Evolution and Systematics, 41: 149-172.

Dickinson, J.L., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., Phillips, T. and Purcell, K. 2012. The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment, 10(6): 291-297.

Dietz, R., Rigét, F.F., Sonne, C., Born, E.W., Bechshøft, T., McKinney, M.A. and Letcher, R.J. 2013. Three decades (1983–2010) of contaminant trends in East Greenland polar bears (Ursus maritimus). Part 1: legacy organochlorine contaminants. Environment international, 59: 485-493.

Dowsley, M. 2009. Community clusters in wildlife and environmental management: using TEK and community involvement to improve co-management in an era of rapid environmental change. Polar Research, 28(1): 43-59.

Durban, J.W. and Parsons, K.M. 2006. Laser-metrics of free ranging killer whales. Marine Mammal Science, 22(3): 735-743.

Durner, G.M. and Amstrup, S.C. 1996. Mass and body-dimension relationships of polar bears in northern Alaska. Wildlife Society Bulletin: 480-484.

Dyck, M.G. and Baydack, R.K. 2004. Vigilance behaviour of polar bears (Ursus maritimus) in the context of wildlife-viewing activities at Churchill, Manitoba, Canada. Biological Conservation, 116(3): 343-350.

Dyck, M.G. and Daley, K.J. 2002. Cannibalism of a yearling polar bear (Ursus maritimus) at Churchill, Canada. Arctic: 190-192.

Eckhardt, G., 2005. The effects of ecotourism on polar bear behavior. M.S. Thesis. Brock University, Orlando, FL, USA.

Evans, T.J., Fischbach, A., Schliebe, S., Manly, B., Kalxdorff, S. and York, G. 2003. Polar bear aerial survey in the eastern Chukchi Sea: a pilot study. Arctic: 359-366.

Farley, S.D. and Robbins, C.T. 1994. Development of two methods to estimate body composition of bears. Canadian Journal of Zoology, 72(2): 220-226.

Ferguson, S.H., Stirling, I. and McLoughlin, P. 2005. Climate change and ringed seal (Phoca hispida) recruitment in western Hudson Bay. Marine Mammal Science, 21(1): 121-135.

Ferguson, S.H. Taylor, M.K., Born, E.W., Rosing-Asvid, A., and Messier, F. 2001. Activity and movement patterns of polar bears inhabiting consolidated versus active pack ice. Arctic, 54(1): 49-54.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. and Holling, C.S. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics, 35.

Freeman, M.M. and Wenzel, G.W. 2006. The nature and significance of polar bear conservation hunting in the Canadian Arctic. Arctic: 21-30.

Gagnon, A.S. and Gough, W.A. 2005. Trends in the dates of ice freeze-up and breakup over Hudson Bay, Canada. Arctic: 370-382.

Gardiner, M.M., Allee, L.L., Brown, P.M., Losey, J.E., Roy, H.E. and Smyth, R.R. 2012. Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. Frontiers in Ecology and the Environment, 10(9): 471-476.

Gormezano, L.J. and Rockwell, R.F. 2013. What to eat now? Shifts in polar bear diet during the ice-free season in western Hudson Bay. Ecology and evolution, 3(10): 3509-3523.

Green, D.M. 2005. Designatable units for status assessment of endangered species. Conservation Biology, 19(6): 1813-1820.

Gruenewald, D.A. 2003a. The best of both worlds: A critical Pedagogy of Place. Educational Researcher, 32(4): 3-12.

Gruenewald, D.A. 2003b. Foundations of place: A multidisciplinary framework for place-conscious education. American educational research journal, 40(3): 619-654.

Halpenny, E.A. and Caissie, L.T. 2003. Volunteering on nature conservation projects: volunteer experience, attitudes and values. Tourism Recreation Research, 28(3): 25-33.

Hamilton, S.G., de la Guardia, L.C., Derocher, A.E., Sahanatien, V., Tremblay, B. and Huard, D. 2014. Projected polar bear sea ice habitat in the Canadian Arctic Archipelago. *PLoS One*, *9*(11): e113746.

Hannah, L.E.E. 2011. Climate change, connectivity, and conservation success. Conservation Biology, 25(6): 1139-1142.

Higdon, J.W. and Ferguson, S.H. 2009. Loss of Arctic sea ice causing punctuated change in sightings of killer whales (*Orcinus orca*) over the past century. Ecological Applications, 19(5): 1365-1375.

Higham, J.E.S. and Hendry, W.F. 2008. Marine wildlife viewing: Insights into the significance of the viewing platform. Marine wildlife and tourism management: Insights from the natural and social sciences: 347-360.

Hodgson, J.A., Moilanen, A., Wintle, B.A. and Thomas, C.D. 2011. Habitat area, quality and connectivity: striking the balance for efficient conservation. Journal of Applied Ecology, 48(1): 148-152.

Huntington, H.P. 2000. Using traditional ecological knowledge in science: methods and applications. Ecological applications, 10(5): 1270-1274.

Huntington, H.P. 2009. A preliminary assessment of threats to arctic marine mammals and their conservation in the coming decades. Marine Policy, 33(1): 77-82.

Hvenegaard, G.T. 1994. Ecotourism: A status report and conceptual framework. Journal of Tourism Studies, 5(2): 24.

Iacozza, J. and Ferguson, S.H. 2014. Spatio-temporal variability of snow over sea ice in western Hudson Bay, with reference to ringed seal pup survival. Polar biology, 37(6): 817-832.

Jaquet, N. 2006. A simple photogrammetric technique to measure sperm whales at sea. Marine Mammal Science, 22(4): 862-879.

Jensen, B.B. 2002. Knowledge, action and pro-environmental behaviour. Environmental education research, 8(3): 325-334.

Jones, G., Childers G., Stevens, V., and Whitley, B. 2012. Citizen Scientists: investigating science in the community. The Science Teacher, 12: 36-39.

Jonkel, C.J. 1970. Some comments on polar bear management. Biological Conservation, 2(2): 115-119.

Jordan, R., Singer, F., Vaughan, J. and Berkowitz, A. 2009. What should every citizen know about ecology?. Frontiers in Ecology and the Environment, 7(9): 495-500.

Kollmuss, A., and Agyeman, J. 2002. Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research, 8(3): 239-260.

Kovacs, K.M., Lydersen, C., Overland, J.E. and Moore, S.E. 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Marine Biodiversity, 41(1): 181-194.

Laforge, M.P., Clark, D.A., Schmidt, A.L., Lankshear, J.L., Kowalchuk, S. and Brook, R.K. 2017. Temporal aspects of polar bear (Ursus maritimus) occurrences at field camps in Wapusk National Park, Canada. Polar Biology: 1-10.

Laidre, K.L., Stern, H., Kovacs, K.M., Lowry, L., Moore, S.E., Regehr, E.V., Ferguson, S.H., Wiig, Ø., Boveng, P., Angliss, R.P. and Born, E.W. 2015. Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conservation Biology, 29(3): 724-737.

Laidre, K.L., Stirling, I., Lowry, L.F., Wiig, Ø., Heide-Jørgensen, M.P. and Ferguson, S.H. 2008. Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. Ecological Applications, 18(sp2).

Lemelin, R.H. 2006. The gawk, the glance, and the gaze: Ocular consumption and polar bear tourism in Churchill, Manitoba, Canada. Current Issues in Tourism, 9(6): 516-534.

Lemelin, H., Dawson, J., Stewart, E.J., Maher, P. and Lueck, M. 2010. Last-chance tourism: The boom, doom, and gloom of visiting vanishing destinations. Current Issues in Tourism, 13(5): 477-493.

Lemelin, R.H., Fennell, D. and Smale, B. 2008. Polar bear viewers as deep ecotourists: How specialised are they?. Journal of Sustainable Tourism, 16(1): 42-62.

Lemelin, H. and Maher, P. 2009. Nanuk of the Torngats: human–polar bear interactions in the Torngat mountains National Park, Newfoundland and Labrador, Canada. Human Dimensions of Wildlife, 14(2): 152-155.

Liefländer, A.K., Fröhlich, G., Bogner, F.X., and Schultz, P.W. 2013. Promoting connectedness with nature through environmental education. Environmental Education Research, 19(3): 370-384.

Maher, P.T. and Lemelin, R.H. 2011. Northern exposure: opportunities and challenges for tourism development in Torngat Mountains National Park, Labrador, Canada. Polar Record, 47(1): 40-45.

Malcolm, J.R., Liu, C., Neilson, R.P., Hansen, L. and Hannah, L.E.E. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conservation biology, 20(2): 538-548.

Mawdsley, J.R., O'malley, R. and Ojima, D.S. 2009. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology, 23(5): 1080-1089.

McCall, A.G., Derocher, A.E. and Lunn, N.J. 2015. Home range distribution of polar bears in western Hudson Bay. Polar Biology, 38(3) :343-355.

McDonald, T.L. and Amstrup, S.C. 2001. Estimation of population size using open capture-recapture models. Journal of Agricultural, Biological, and Environmental Statistics, 6(2): 206-220.

McGehee, N.G. 2002. Alternative tourism and social movements. Annals of tourism research, 29(1): 124-143.

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 & Technology, 43(12): 4334-4339.

McKinney, M.A., Atwood, T., Dietz, R., Sonne, C., Iverson, S.J. and Peacock, E. 2014. Validation of adipose lipid content as a body condition index for polar bears. Ecology and evolution, 4(4): 516-527.

McKinney, M.L. 2002. Urbanization, biodiversity, and conservation. BioScience, 52(10): 883–890.

McKinney, T. 2011. The effects of provisioning and crop-raiding on the diet and foraging activities of human-commensal white-faced capuchins (Cebus capucinus). American Journal of Primatology, 73(5): 439-448.

Meletis, Z.A. and Campbell, L.M. 2007. Call it consumption! Re-conceptualizing ecotourism as consumption and consumptive. Geography Compass, 1(4): 850-870.

Messier, F. 2000. Effects of capturing, tagging and radio-collaring polar bears for research and management purposes in Nunavut and Northwest Territories. University of Saskatchewan, Saskatoon, Saskatchewan.

Miller, J. D. 2004. Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. Public Understanding of Science, 13(3): 273-294.

Molnár, P.K., Derocher, A.E., Thiemann, G.W. and Lewis, M.A. 2010. Predicting survival, reproduction and abundance of polar bears under climate change. Biological Conservation, 143(7): 1612-1622.

Molnár, P.K., Derocher, A.E., Thiemann, G.W. and Lewis, M.A. 2014. Corrigendum to "Predicting survival, reproduction and abundance of polar bears under climate change"[Biol. Conserv. 143 (2010) 1612–1622]. Biological Conservation, (177): 230-231.

Mooers, A.O., Doak, D.F., Scott Findlay, C., Green, D.M., Grouios, C., Manne, L.L., Rashvand, A., Rudd, M.A. and Whitton, J. 2010. Science, policy, and species at risk in Canada. BioScience, 60(10): 843-849.

Moore, S.E. and Huntington, H.P. 2008. Arctic marine mammals and climate change: impacts and resilience. Ecological Applications, 18(sp2).

Moritz, C. and Agudo, R. 2013. The future of species under climate change: resilience or decline?. Science, 341(6145): 504-508.

Mueller, M.P. and Tippins, D. 2012. The future of citizen science. Democracy and Education, 20(1): 2.

Obbard, M.E., Cattet, M.R., Moody, T., Walton, L.R., Potter, D., Inglis, J. and Chenier, C. 2006. Temporal trends in the body condition of Southern Hudson Bay polar bears. Climate change research, 3: 1-8.

Obbard, M.E., Thiemann, G.W., Peacock, E. and DeBruyn, T.D. 2010. Polar bears: Proceedings of the 15th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 29 June-3 July 2009, Copenhagen, Denmark. IUCN.

Olar, M., Louvel, J., Hernandez, M., Sauve, C., Zussy, S., and Messier, J. 2011. Evidence of the Socio-Economic Importance of Polar Bears for Canada. EcoResources Consultants for Environment Canada. Ottawa. 88pp.

Overland, J.E. and Wang, M. 2013. When will the summer Arctic be nearly sea ice free?. Geophysical Research Letters, 40(10): 2097-2101.

Paetkau, D., Amstrup, S.C., Born, E.W., Calvert, W., Derocher, A.E., Garner, G.W., Messier, F., Stirling, I., Taylor, M.K., Wiig, Ø. and Strobeck, C. 1999. Genetic structure of the world's polar bear populations. Molecular Ecology, 8(10): 1571-1584.

Pagano, A.M., Peacock, E. and McKinney, M.A.2014. Remote biopsy darting and marking of polar bears. Marine Mammal Science, 30(1): 169-183.

Parks Canada. 2011. Annual Report of Research and Monitoring in Torngat Mountains National Park. Parks Canada, Ottawa. 55pp.

Parks, E.K., Derocher, A.E. and Lunn, N.J. 2006. Seasonal and annual movement patterns of polar bears on the sea ice of Hudson Bay. Canadian Journal of Zoology, 84(9): 1281-1294.

Patyk, K.A., Duncan, C., Nol, P., Sonne, C., Laidre, K., Obbard, M., Wiig, Ø., Aars, J., Regehr, E., Gustafson, L.L. and Atwood, T. 2015. Establishing a definition of polar bear (*Ursus maritimus*) health: a guide to research and management activities. Science of the Total Environment, 514: 371-378.

Peacock, E., Derocher A.E., Thiemann, G.W., and Stirling, I. 2011. Conservation and management of Canada's polar bears (*Ursus maritimus*) in a changing Arctic. Canadian Journal of Zoology, 89: 371 -385.

Peig, J. and Green, A.J. 2009. New perspectives for estimating body condition from mass/length data: the scaled mass index as an alternative method. Oikos, 118(12): 1883-1891.

Peig, J. and Green, A.J. 2010. The paradigm of body condition: a critical reappraisal of current methods based on mass and length. Functional Ecology, 24(6): 1323-1332.

Pilfold, N.W., Hedman, D., Stirling, I., Derocher, A.E., Lunn, N.J. and Richardson, E. 2016. Mass loss rates of fasting polar bears. Physiological and Biochemical Zoology, 89(5): 377-388.

Pond, C.M. 1992. An evolutionary and functional view of mammalian adipose tissue. Proceedings of the Nutrition Society, 51(3): 367-377.

Post, E., Bhatt, U.S., Bitz, C.M., Brodie, J.F., Fulton, T.L., Hebblewhite, M., Keryby, J., Kutz, S.J., Stirling, I. and Walker, D.A. 2013. Ecological consequences of sea-ice decline. Science, 341: 519-524.

Prestrud, P., and Stirling, I. 1994. The International Polar Bear Agreement and the current status of polar bear conservation. Aquatic Mammals, 20: 113.

Puk,T. 2012. The influence of neurobiology on lifelong ecological literacy and ecological consciousness. International Journal of Environmental and Science Education, 7(1): 3-18.

R Core Team. 2017. R: A Language and Environment for Statistical Com- puting. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org

Ramsay, M.A. and Hobson, K.A. 1991. Polar bears make little use of terrestrial food webs: evidence from stable-carbon isotope analysis. Oecologia, 86(4):598-600.

Redford, K.H., Ray, J.C., and Boitani, L. 2011. Mapping and navigating mammalian conservation: from analysis to action. Philosophical Transactions of the Royal Society B, 366: 2712-2721.

Regehr, E. V., Lunn, N. J., Amstrup, S. C., and Stirling, I. 2007. Effects of earlier sea ice breakup on survival and population size of polar bears in western Hudson Bay. The journal of wildlife management, 71(8): 2673-2683.

Remondino, F. and Fraser, C. 2006. Digital camera calibration methods: considerations and comparisons. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 36(5): 266-272.

Ries, L. and Oberhauser, K. 2015. A citizen army for science: quantifying the contributions of citizen scientists to our understanding of monarch butterfly biology. BioScience, 65(4): 419-430.

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(3): 768-782.

Rode, K. D., Peacock, E., Taylor, M., Stirling, I., Born, E. W., Laidre, K. L., and Wiig, Ø. 2012. A tale of two polar bear populations: ice habitat, harvest, and body condition. Population Ecology, 54(1): 3-18.

Rode, K.D., Regehr, E.V., Douglas, D.C., Durner, G., Derocher, A.E., Thiemann, G.W. and Budge, S.M. 2014. Variation in the response of an Arctic top predator experiencing habitat loss: feeding and reproductive ecology of two polar bear populations. Global Change Biology, 20(1): 76-88.

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

Roe, D., Leader-Williams, N. and Dalal-Clayton, D.B. 1997. Take only photographs, leave only footprints: the environmental impacts of wildlife tourism, 10.

Root, T.L., Price, J.T., Hall, K.R. and Schneider, S.H. 2003. Fingerprints of global warming on wild animals and plants. Nature, 421(6918): 57.

Rohner, C.A., Richardson, A.J., Marshall, A.D., Weeks, S.J. and Pierce, S.J. 2011. How large is the world's largest fish? Measuring whale sharks Rhincodon typus with laser photogrammetry. Journal of Fish Biology, 78(1): 378-385.

Rothman, J.M., Chapman, C.A., Twinomugisha, D., Wasserman, M.D., Lambert, J.E. and Goldberg, T.L. 2008. Measuring physical traits of primates remotely: the use of parallel lasers. American Journal of Primatology, 70(12): 1191-1195.

Sahanatien, V., and Derocher, A. E. 2012. Monitoring sea ice habitat fragmentation for polar bear conservation. Animal Conservation, 15(4): 397-406.

Schipper, J., Chanson, J.S., Chiozza, F., Cox, N.A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A.S., Stuart, S.N., Temple, H.J. and Baillie, J. 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. Science, 322(5899): 225-230.

Schneider, C. A., Rasband, W. S., and Eliceiri, K.W. 2012. NIH Image to ImageJ: 25 years of image analysis, Nature methods, 9(7): 671-675.

Schultz, P. 2011. Conservation means behavior. Conservation Biology, 25(6): 1080-1083.

Schultz, P.W.,Shriver, C., Tabanico, J.T., and Khazian, A.M. 2004. Implicit connections with nature. Journal of Environmental Psychology, 24: 31-42.

Sciullo, L., Thiemann, G.W., and Lunn, N.J. 2016. Comparative assessment of metrics for monitoring the body condition of polar bears in western Hudson Bay. Journal of Zoology, 300(1): 45-58.

Scott, D., Jones, B. and Konopek, J. 2007. Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. Tourism management, 28(2): 570-579.

Shrader, A.M., Ferreira, S.M. and Van Aarde, R.J. 2006. Digital photogrammetry and laser rangefinder techniques to measure African elephants. South African Journal of Wildlife Research, 36(1): 1-7.

Sin, H.L., 2009. Volunteer tourism—“involve me and I will learn”?. Annals of Tourism Research, 36(3): 480-501.

Slocum, R. 2004. Polar bears and energy-efficient lightbulbs: strategies to bring climate change home. Environment and Planning D: Society and Space, 22(3): 413-438.

Spence, A. and Pidgeon, N., 2009. Psychology, climate change & sustainable bahaviour. Environment: Science and Policy for Sustainable Development, 51(6): 8-18.

Stapleton, S., Atkinson, S., Hedman, D., and Garshelis, D. 2014a. Revisiting Western Hudson Bay: Using aerial surveys to update polar bear abundance in a sentinel population. Biological Conservation, 170: 38-47.

Stapleton, S., LaRue, M., Lecomte, N., Atkinson, S., Garshelis, D., Porter, C. and Atwood, T. 2014b. Polar bears from space: assessing satellite imagery as a tool to track Arctic wildlife. PloS one, 9(7): e101513.

Stem, C.J., Lassoie, J.P., Lee, D.R., Deshler, D.D. and Schelhas, J.W. 2003. Community participation in ecotourism benefits: The link to conservation practices and perspectives. Society and Natural Resources, 16(5): 387-413.

Stevenson, R.D. and Woods, W.A. 2006. Condition indices for conservation: new uses for evolving tools. Integrative and comparative biology, 46(6): 1169-1190.

Stirling, I., and Derocher, A.E. 1993. Possible impacts of climatic warming on polar bears. Arctic, 46: 240-245.

Stirling, I., and Derocher, A. E. 2012. Effects of climate warming on polar bears: a review of the evidence. Global Change Biology, 18(9): 2694-2706.

Stirling, I., Lunn, N.J., and Iacozza, J. 1999. Long-term trends in the population ecology of polars in western Hudson Bay in relation to climatic change. Arctic: 294-306.

Stirling, I. and Parkinson, C.L. 2006. Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. Arctic: 261-275.

Stirling, I., Spencer, C., and Andriashek, D. 1989. Immobilization of Polar Bears (*Ursus maritimus*) with Telazol in the Canadian Arctic. Journal of Wildlife Diseases, 25(2): 59-168.

Stirling, I., Thiemann, G.W., and Richardson, E. 2008. Quantitative support for a subjective fatness index for immobilized polar bears. Journal of Wildlife Management, 72(2): 568-574.

Stroeve, J., Holland, M.M., Meier, W., Scambos, T. and Serreze, M. 2007. Arctic sea ice decline: Faster than forecast. Geophysical research letters, 34(9).

Stroeve, J.C., Markus, T., Boisvert, L., Miller, J. and Barrett, A. 2014. Changes in Arctic melt season and implications for sea ice loss. Geophysical Research Letters, 41(4): 1216-1225.

Taylor, M. K., Laake, J., McLoughlin, P. D., Born, E. W., Cluff, H. D., Ferguson, S. H., and Messier, F. 2005. Demography and viability of a hunted population of polar bears. Arctic: 203-214.

Taylor, M.K., Laake, J., McLoughlin, P.D., Cluff, H.D., and Messier, F. 2006. Demographic parameters and harvest-explicit population viability analysis for polar bears in M'Clintock Channel, Nunavut, Canada. Journal of Wildlife Management, 70 (6): 1667-1673.

Thiemann, G.W., Iverson, S.J. and Stirling, I. 2006. Seasonal, sexual and anatomical variability in the adipose tissue of polar bears (*Ursus maritimus*). Journal of Zoology, 269(1): 65-76.

Thiemann, G. W., Iverson, S. J., and Stirling, I. 2008a. Polar bear diets and arctic marine food webs: insights from fatty acid analysis. Ecological Monographs, 78(4): 591-613.

Thiemann, G.W., Derocher, A.E., and Stirling, I. 2008b. Polar bear Ursus maritimus conservation in Canada: an ecological basis for identifying designatable units. Oryx, 42(4): 504-515.

Thiemann, G.W., Iverson, S.J., and Stirling, I. 2009. Using fatty acids to study marine mammal foraging: The evidence from an extensive and growing literature. Marine Mammal Science, 25:243-249.

Thiemann, G.W., Lunn, N.J., Richardson, E.S., and Andriashek, D.S. 2011. Temporal change in the morphometry-body mass relationship of polar bears. Journal of Wildlife Management,75:580-587.

Thiemann, G.W., Derocher, A.E., Cherry, S.G., Lunn, N.J., Peacock, E., and Sahanatien, V. 2013. Effects of chemical immobilization on the movement rate of free-ranging polar bears. Journal of Mammology, 94(2): 386-397.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F., De Siqueira, M.F., Grainger, A., Hannah, L. and Hughes, L. 2004. Extinction risk from climate change. Nature, 427(6970): 145-148.

Towns, L., Derocher, A. E., Stirling, I., Lunn, N. J., and Hedman, D. 2009. Spatial and temporal patterns of problem polar bears in Churchill, Manitoba. Polar Biology, 32(10), 1529-1537.

Towns, L., Derocher, A.E., Stirling, I. and Lunn, N.J., 2010. Changes in land distribution of polar bears in western Hudson Bay. Arctic: 206-212.

Van Coeverden De Groot, P., Wong, P.B.Y., Harris, C., Dyck, M.G., Kamookak, L., Pagés, M., Michaux, J., and Boag, P.T. 2012. Toward a non-invasive Inuit polar bear survey: genetic data from polar bear hair snags. Wildlife Society Bulletin, 37(2): 394-401.

Van Den Berg, H., Dann, S.L., and Dirkx, J.M. 2009. Motivations of adults for non-formal conservation education and volunterrism: implications for programming, Applied Environmental Education and Communication, 8: 6-17.

Vongraven, D. and Richardson, E., 2011. Biodiversity–Status and trends of polar bears. Arctic Report Card, NOAA Report : 75-78.

Vongraven, D., Aars, J., Amstrup, S.C., Atkinson, S.N., Belikov, S., Born, E.W., DeBruyn, T.D., Derocher, A.E., Durner, G., Gill, M., Lunn, N.J., Obbard, M.E., Omelak, J., Ovsyanikov, N., Peacock, E., Richardson, E., Sahanatien, V., Stirling, I., and Wiig, Ø. 2012. A circumpolar monitoring framework for polar bears. Ursus Monograph Series, 5: 1-66.

Waite, J.N., Schrader, W.J., Mellish, J.A.E. and Horning, M. 2007. Three-dimensional photogrammetry as a tool for estimating morphometrics and body mass of Steller sea lions (*Eumetopias jubatus*). Canadian Journal of Fisheries and Aquatic Sciences, 64(2): 296-303.

Walpole, M.J. and Leader-Williams, N., 2001. Masai Mara tourism reveals partnership benefits. Nature, 413(6858): 771.

Weaver, D.B. and Lawton, L.J. 2007. Twenty years on: The state of contemporary ecotourism research. Tourism management, 28(5): 1168-1179.

Webster, T., Dawson, S. and Slooten, E. 2010. A simple laser photogrammetry technique for measuring Hector's dolphins (*Cephalorhynchus hectori*) in the field. Marine Mammal Science, 26(2): 296-308.

Wenzel, G.W. 2005. Nunavut Inuit and polar bear: the cultural politics of the sport hunt. Senri Ethnological Studies, 67: 363-388.

Wenzel, G.W. 2011. Polar bear management, sport hunting and Inuit subsistence at Clyde River, Nunavut. Marine Policy, 35(4): 457-465.

Willisch, C.S., Marreros, N. and Neuhaus, P. 2013. Long-distance photogrammetric trait estimation in free-ranging animals: a new approach. Mammalian Biology, 78(5) : 351-355.

Wirsing, A.J., Steury, T.D. and Murray, D.L. 2002. Relationship between body condition and vulnerability to predation in red squirrels and snowshoe hares. Journal of Mammalogy, 83(3): 707-715.

Wong, P.B.Y., Van Coeverden De Groot, P., Fekken, C., Smith, H., Pagés, M., and Boag, P.T. 2011. Interpretations of polar bear (*Ursus maritimus)* tracks by Inuit hunters: inter-rater reliability and inferences concerning accuracy. Canadian Field-Naturalist, 125(2): 140-153.