Eastern Beaufort Sea Beluga (*Delphinapterus leucas*) Body Condition Indicators for Monitoring the Tarium Niryutait Marine Protected Area

by

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Abstract

Two body condition indicators, blubber thickness and maximal half-girth measurements, were evaluated for use to monitor the health of Eastern Beaufort Sea beluga (*Delphinapterus leucas*) in the Tarium Niryutait Marine Protected Area (TN MPA). Beluga body condition metrics collected from the community-based beluga monitoring program in the Inuvialuit Settlement Region from 2000-2015 were assessed. Body condition indicators based on the predicted values and residuals of fitted linear models for blubber thickness and girth were developed to account for variation in age, size, location, and timing of harvest. Statistically significant differences in condition were detected between regions of the TN MPA for three of the condition indices. The male blubber thickness indicator was found to increase during the summer harvest season. Long-term temporal analyses found that the male and female girth indicators led the temporal trends in male and female blubber thickness indicators. Lastly, two large-scale climatic variability metrics, Pacific Decadal Oscillation and sea ice minimum, were significantly negatively correlated to body condition trends. This research provides key recommendations for the Tarium Niryutait Marine Protected Area co-management boards on the use of beluga body condition indicators.

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Table of Contents

Abstract ii
Acknowledgments iii
List of Tables vii
List of Figures and Illustrations viii
Chapter One: **INTRODUCTION** 1
1.1 Rationale and Context 1
1.2 Thesis Objective 3
1.3 Thesis Structure 3
Literature Cited 5
Chapter Two: **BACKGROUND** 8
2.1 Ecological Indicators 8
2.2 Arctic Marine Management 10
2.3 EBS Beluga Whales 12
2.4 Body Condition Indicators 14
Literature Cited 17
Chapter Three: **DEVELOPING AN INDICATOR: UNDERSTANDING THE INFLUENCE OF HARVEST LOCATION AND HEALTH ON BELUGA WHALE BODY CONDITION.** 25
Abstract 26
3.1 Introduction 27
3.2 Methods 30
3.2.1 Study Area 30
3.2.2 Monitoring Data 31
3.2.3 Data Preparation 33
3.2.4 Body Condition Indicators 34
3.2.5 Spatial Variation 34
3.2.6 Entrapped Whale Condition 35
3.3 Results 37
3.3.1 Monitoring Data 37
3.3.2 Body Condition Indicators 37
3.3.3 Influence of Harvest Location 38
3.3.4 Comparison of Condition between Summer Harvests and Entrapped Belugas 41
3.4 Discussion 43
3.4.1 Influence of Harvest Location 45
3.4.2 Proposed Indicator Threshold 47
3.4.3 Comparison of Body Condition Indicators 48
Acknowledgements 51
Literature Cited 52
Chapter Four: **DEVELOPING AN INDICATOR PART II: UNDERSTANDING TRENDS AND VARIABILITY OF BELUGA WHALE BODY CONDITION AND INFLUENCE OF LARGE-SCALE CLIMATIC DRIVERS** 60
Abstract 61
4.1 Introduction 62
4.2 Methods 65
4.2.1 Data Collection 66

4.2.2 Body Condition Indicators 67
4.2.3 Temporal Trends and Variation 68
4.2.4 Indicator Correlation and Lag 69
4.2.5 Climate Variability 69
4.3. Results 70
4.3.1 Temporal Trends and Variation 70
4.3.2 Indicator Correlation and Lag 73
4.3.3 Climate Variability 74
4.4 Discussion 77
4.4.1 Seasonal Changes in Condition 77
4.4.2 Long-term Trends in Body Condition Indicators 77
4.4.3 Influence of Climate on Condition 80
4.4.4 Conclusion 82
Acknowledgements 82
Literature Cited 84
Chapter Five: **SUMMARY** 92
5.1 Findings 93
5.2 Conclusion & Future Work 96
Literature Cited 98

List of Tables

Table 3.1: Summary of beluga monitoring data used in analyses. Including belugas sampled as part of the summer harvest across the Beaufort Sea; TN MPA (left column), belugas sampled from Husky Lakes entrapments (right column). 37
Table 3.2: Models for body condition indicators as defined by AIC scores. Indicators marked by * were the selected models. 38
Table 3.3: Results of Tukey HSD tests of predicted values from condition indicators between belugas landed inside the three regions of the TN MPA (WES = Shallow Bay, CEN = East Mackenzie Bay, KUG = Kugmallit Bay) (see Fig. 3.4). Both Girth Male (GM) and Blubber Thickness Male (BM) differed ($p < 0.05$) between WES and both CEN and KUG and are marked by *... 40
Table 3.4: Results of Welch's t-test between predicted values from condition indicators of belugas landed inside the TN MPA to belugas landed outside the TN MPA (see Fig. 3.5). All four condition models found significant differences ($p > 0.05$) between belugas harvested in the TN MPA to outside the TN MPA and are marked by *. 41
Table 3.5: Best-fit models for body condition indicators as defined by AIC scores. Models marked by * were the selected indicators. 41
Table 3.6: Results of Welch's t-test between residuals of condition indicators for belugas landed in TN MPA to whales landed from entrapment events (see Fig. 3.6). 42
Table 4.1: The four sex-specific beluga body condition indicators used. See Chapter 3 (Table 3.6) for detail on indicator selection process. 67
Table 4.2: Proposed body condition thresholds for each of the four sex-specific beluga body condition indicators (Girth Male (GM), Girth Female (GF), Blubber Thickness Male (BM), Blubber Thickness Female (BF) derived in Chapter 3 69
Table 4.3: The results from the Welch's t-test for seasonal comparison for each of the four body condition indicators. Two of the indicators, Girth Female (GF) and Blubber Thickness Male (BM) found a significant difference ($p > 0.05$) between condition of whales landed PRE-and POST of the mid-harvest date (July 17^{th}) and are marked by *... 71
Table 4.4: Results of correlation and cross-correlation tests on four body condition indicators. The most significant relationships are shown. There is a significant correlation between Girth Male (GM) and Girth Female (GF) with no lag, and a significant correlation between Blubber Thickness Male (BM) and Blubber Thickness Female (BF) with no lag.. 73
Table 4.5: Results of linear regression of mean body condition (GM) and three climatic variations (PDO, SIM, AO) 76

List of Figures and Illustrations

Figure 2.1: Map of the three regions of the Tarium Niryuitat Marine Protected Area: Niaqunnaq (WES), Okeevik (CEN), Kittigaryuit (KUG). Community members from Aklavik, Inuvik, and Tuktoyaktuk travel to camps on the coast in the summer to hunt beluga in the three sub regions (DFO Oceans Program, 2018)... 12
Figure 2.2: Example of beluga monitoring form (2017) used by hunters and monitors across the ISR(provided by FJMC and DFO).. 14
Figure 3.1: Map of the Tarium Niryutait Marine Protected Area (pink) and the six communities located within the Inuvialuit Settlement Region: Aklavik, Inuvik, Tuktoyaktuk, Paulatuk, Sachs Harbour, and Ulukhaktok (DFO Oceans Program, 2018). 28
Figure 3.2: Three regions of the TN MPA (green, orange, and yellow areas) and common whaling camps (blue circles) (DFO Oceans Program, 2018). Note: Additional camps used by community members are not listed. 31
Figure 3.3: Harvest locations: organization of whaling camps in the TN MPA, outside the TN MPA, and Husky Lakes for body condition analyses.. 35
Figure 3.4: Comparison between three regions of the TN MPA for each of the four condition indicators predicted values (WES = Shallow Bay, CEN = East Mackenzie Bay, KUG = Kugmallit Bay). Box widths are proportional to the square root of the number of observations. There is a significant difference ($p > 0.05$) between WES and the other two areas (KUG and CEN) for both Girth Male (GM) and Blubber Thickness Male (BM) indicators and are marked by * (see Table 3.3) 39
Figure 3.5: Comparison between belugas landed in the TN MPA to belugas landed outside the TN MPA for each of the four condition indicators predicted values. Box widths are proportional to the square root of the number of observations. There is a significant difference ($p > 0.05$) between harvest locations for all indicators and are marked by *(see Table 3.4). 40
Figure 3.6: Comparison between belugas landed in the TN MPA (East Mackenzie and Kugmallit Bays from 2000-2015) to belugas landed from entrapment events (Husky Lakes from 1989,2006) using residuals from condition indicators (see Table 3.5). Box widths are proportional to the square root of the number of observations. A significant difference between two types of landings was found for all four body condition indicators (see Table 3.6). 42
Figure 4.1: The home range of the Eastern Beaufort Sea beluga. Figure modified from Loseto et al. (2018). 66
Figure 4.2: The day of year (Julien calendar) for whale landings from Kugmallit Bay (KUG) and East Mackenzie Bay (CEN) in the TN MPA from 2000-2015. The orange circle is the mean day of whale landings for each year. From 2000-2015, the mean day of harvest was 198...71
Figure 4.3: Inter-annual trends for Girth Male (GM), Girth Female (GF), Blubber Thickness Male (BM), Blubber Thickness Female (BF) as represented by yearly mean index values and 95% CI. The red lines represent the poor condition threshold proposed in Chapter 3 as developed from Husky Lakes entrapments in 1989 and 2006 (Table 4.2). 72
Figure 4.4: Inter-annual plots of mean PDO, SIM and AO (dotted black line) with mean GM plots and 95% CI (purple dots and lines).. 75

Figure 4.5: Results of cross-correlations between selected PDO, SIM and AO with mean GM. The most significant lag for body condition with PDO and SIM was zero years and two years (respectively). No statistically significant lag was found for AO within 10 years...... 76
Figure 4.6: Best fit correlations of the three environmental drivers to beluga whale body condition (girth male index). A: Pacific Decadal Oscillation (PDO) demonstrates a negative relationship at a zero-year lag ($p < 0.05$) B: Beaufort Sea (Canada) Sea Ice Minimum (SIM) demonstrating a negative relationship at a two-year lag ($p < 0.05$) and C: The Arctic Oscillation (AO) demonstrating non-significant relationship with a one year lag ($p = 0.43$). See Table 4.5 for regression details.. 76

Chapter One: **INTRODUCTION**

1.1 Rationale and Context

The management of marine protected areas (MPAs) requires monitoring programs that employ indicators. Indicators simplify an MPA into measureable variables that detect change and have established thresholds to be used for decision-making and management, but additional criteria may be applied when selecting indicators (Heink and Kowarik, 2010; Link et al., 2010; Niemi and Mcdonald, 2004; Rice and Rochet, 2005). The usefulness of an indicator can be determined by evaluating the data availability and quality, assessing trends and variation to determine sensitivity, and identifying the interactions and pressures that effect the indicator (Boldt et al., 2014; Link et al., 2010; Rice and Rochet, 2005). In Canada, the establishments of MPAs began with the passing of the Oceans Act in 1996 and the coverage of MPAs has continued to grow to meet a global commitment to protect at least 10% of Canada's marine waters by 2020 (Government of Canada, 2011). Canada's first Arctic MPA, the Tarium Niryutait MPA (TN MPA), was establish in 2010 in the Inuvialuit Settlement Region (ISR) (Oceans Act, TN MPA Regulations 2010). The TN MPA is developing a monitoring program that requires the selection of indicators to inform the co-management boards on how TN MPA is meeting the conservation objective to protect beluga and other marine species (fishes, seabirds, and waterfowl), and their supporting ecosystem (Loseto et al., 2010).

The Eastern Beaufort Sea (EBS) belugas are the focal species for the TN MPA, as it is their return to the Mackenzie Delta every summer in large aggregations that led to the establishment of the TN MPA (FJMC and DFO, 2013; Frost and Lowry, 1990; Harwood and Smith, 2002; Richard et al., 2001). Monitoring EBS beluga health is a high priority and body condition has been proposed as a TN MPA indicator because it can signal nutritional status or environmental stress, such as change in prey availability, presence of predators, disease or increased human activities such as shipping (Burek et al., 2008; Harwood et al., 2014; Koopman et al., 2002). Blubber thickness and girth measurements are two body condition indicators that have been used to monitor the health of cetaceans (ex: Bradford et al., 2012; George et al., 2015; Gómez-Campos et al., 2011; Joblon et al., 2014).

The EBS beluga whales are important to the Inuvialuit for subsistence harvests, a valuable cultural practice in itself and provides food security for communities (Harwood and Smith, 2002; Hoover et al., 2016). The subsistence harvest of the EBS belugas in the TN MPA have contributed to a long-term community-based beluga monitoring program and the Inuvialuit hunters are foundational in the annual collection of beluga morphometric data, tissue samples, and environmental observations (Harwood et al., 2002).

The EBS beluga whales are not listed as a special concern and the population is considered to be stable or increasing with an estimated population between 32,453 - 39,258 individuals (Allen and Angliss, 2014; COSEWIC, 2004). Harvested EBS belugas have been estimated to be as old as 57 and 49 years, for males and females respectively (Harwood et al., 2002). Since EBS belugas are long-lived predators and migrate between the Bering and Beaufort Seas, they will signal changes across their entire home range thus can be a sentinel species (Laidre et al., 2008; Moore, 2008). The Arctic is warming at twice the rate compared to elsewhere on the globe and impacts include warmer waters and declines in sea ice extent (ACIA, 2014; IPCC, 2014). The effects of climate change on Arctic marine mammal health include direct impacts such as temperature stress or indirect impacts such as changes in predator-prey interactions or increased shipping and resource exploration (Burek et al., 2008). Currently, there is a knowledge gap in understanding the measurability, sensitivity, and specificity of the EBS beluga body condition that inhibits the use of these indicators in monitoring the TN MPA.

1.2 Thesis Objective

The aim of this thesis is to improve the knowledge of EBS beluga whale body condition indicators for use in monitoring the TN MPA. Two body condition measurements collected as part of the long-term community-based beluga monitoring program in the ISR, blubber thickness and maximal half-girth, from 2000-2015 will be evaluated. First, body condition indicators based on the predicted values and residuals of fitted linear models were developed to account for variation in sex, age, size, location, and timing of harvest. The in-depth assessment of the EBS beluga body condition indicators was directed by four sub-objectives:
(1) Examine influence of harvest location on the variation of body condition indicators; (2) Compare the body condition of belugas harvested from summer hunts to belugas harvested from entrapment events, to propose indicator thresholds of health; (3) Assess body condition sensitivity by evaluating both seasonal variation and inter-annual variation; and (4) Assess the influence of large-scale climatic variability metrics on body condition trends and variation.

1.3 Thesis Structure

This thesis is presented and prepared in a manuscript format and is comprised of five chapters. In Chapter Two, I present a background of literature focused on the application of indicators, Arctic marine management, and the use of body condition indicators to evaluate marine mammal health.

Chapters Three and Four are written in manuscript style each containing an Abstract, Introduction, Methods, Results, Discussion, Acknowledgements, and Literature Cited. Chapter Three addresses thesis sub-objectives 1 and 2, examining the influence of harvest location on body condition indicators and assesses the condition of belugas harvested from summer hunts to those harvested from entrapment events. I am the corresponding author for the manuscript titled "Developing an Indicator: Understanding the Influence of Harvest Location and Health on

Beluga Whale Body Condition", that was submitted to Ecological Indicators August 25, 2018 and is currently under review. Co-authors contributed guidance with statistical analyses and advice in writing the manuscript.

MacMillan, K., Hoover, C., Iacozza, J., Peyton, J., Loseto, L. 2018. Developing an Indicator: Understanding the Influence of Harvest Location and Health on Beluga Whale Body Condition. Ecological Indicators (under review).

Chapter Four addresses thesis sub-objectives 3 and 4, which assesses the temporal trends in the body condition indicators at two scales, with a harvest season and between harvest seasons (2000-2015). This chapter also evaluates the influence of three large-scale climatic variables on the long-term trends of beluga body condition. This second manuscript, which I will be the corresponding author, is currently in preparation for submission to Polar Biology and expected for publication in early 2019. Co-authors contributed guidance with statistical analyses and advice in writing the manuscript.

MacMillan, K., Hoover, C., Iacozza, J., Peyton, J., Loseto, L. 2019. Developing an Indicator Part II: Understanding Trends and Variability of Beluga Whale Body Condition and Influence of Large-Scale Climatic Drivers Environmental Drivers. Polar Biology (in prep.).

Chapter Five concludes the thesis with a summary of research findings, contributions to knowledge of the EBS beluga whales, and identifies potential areas for future research

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Chapter Two: **BACKGROUND**

2.1 Ecological Indicators

The interest in conserving a species, sustainably using a resource, or maintaining an ecosystem requires mitigating human activities and impacts through management (Hayes et al., 2015; Jentoft, 1997). To evaluate the effectiveness of management requires data collection to determine if the management objectives, whether ecological, economical, governance, or other, are being met. Indicator-based approaches have been employed to monitor and manage both terrestrial and marine ecosystems (Girardin et al., 1999; Rice and Rochet, 2005). Indicators are tools that aim to tell a story by simplifying complex ecosystems, yet the wide application of indicators has resulted in numerous definitions regarding what exactly an ecological indicator is (Heink and Kowarik, 2010; Vandermeulen, 1998). Identifying indicators that are useful for management is a complicated process as it requires collecting salient information from the ecosystem that considers both the interactions within the ecosystem and stressors that act upon it, while also accounting for the interests and needs of the end-users (Bockstaller and Girardin, 2003; Hayes et al., 2015; Link et al., 2010). Another complication for indicator selection is that indicators are tools that sit at the interface between science and policy, a point that is evident when reviewing the wide range of definitions (Heink and Kowarik, 2010; McCool and Stankey, 2004). Criteria that are applied to indicators that are valuable to both the scientific and political domain include the need to simplify ecosystems while other criteria are more valuable to one domain over the other. For example, scientific criteria for indicators include but are not limited to: sensitivity, ability to capture a trend, inform on the state-of, and data availability (Bockstaller and Girardin, 2003; Boldt et al., 2014; Olsen et al., 1999; Rice and Rochet, 2005; Vandermeulen, 1998). Policy development requires additional criteria such as: identify thresholds for triggering actions or decisions, be cost-effective, easily understood by non-experts, and can be used for communication with decision-makers and the public (Boldt et al., 2014; Niemeijer, 2002; Rice and Rochet, 2005). When selecting indicators for monitoring, it is important to communicate the extent that the indicator meets both the scientific and political criteria. As a transboundary tool, it is important for indicators to be scientifically defensible when used to translate information from the environment to policy (Olsen et al., 1999), but acknowledging indicator limitations will avoid misuse and contribute to the continued development and improvement of indicators.

Marine ecosystems are dynamic and highly complex. Selecting a suite of indicators that simplify the complexity is a challenging task, compounded by the difficulty and cost in regularly accessing the marine waters to collect data (Boldt et al., 2014; Edwards et al., 2010). The literature is rich with proposed frameworks and recommendations to assist management with developing monitoring programs and selecting suites of indicators *a priori* (ex. Hayes et al., 2015; Niemeijer and Groot, 2008; Rice and Rochet, 2005). Alternatively, a data-driven approach can be used that evaluates indicators using the available data (Niemeijer, 2002). Three criteria that can be applied to data to determine if the indicator is useful are measurability, sensitivity, and specificity (Link et al., 2010). Measurability consider the existence of historical data to establish baselines that are subjective to temporal and spatial scopes, as well as the ability to continue collecting data (Dayton et al., 1998; Link et al., 2010; Rice and Rochet, 2005). Additional considerations for measurability include the method of data collection, bias, and precision (Olsen et al., 1999). Indicator sensitivity signifies if change is captured, whether a trend results from natural variation or environmental or anthropogenic forcing (Dayton et al., 1998). Lastly, indicator specificity describes what interactions, whether ecological interactions or human-driven activities are reflected in the indicator sensitivity (Boldt et al., 2014; Link et al., 2010). Two important considerations when assessing indicator specificity in a marine ecosystem are first, the challenge in isolating single stressors from a multi-stressor ecosystem and second, an indicator may have a lag in detection (Niemi and Mcdonald, 2004).

2.2 Arctic Marine Management

The primary reasons for establishing an MPA are analog to the reasons behind terrestrial protected areas, including the preservation of a species, ecosystem, and biotic diversity (Kelleher and Kenchington, 1992). Compared to terrestrial protected areas, MPAs require additional considerations as marine species may have extensive ranges and the needs of people to access coastal waters for resources and cultural practices (Kelleher and Kenchington, 1992). The biological, cultural and economic considerations are captured in the definition of MPAs used by Canada; "clearly defined geographical space which is recognized, dedicated and managed through legal and other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Government of Canada, 2011). One avenue in which MPAs can be established in Canada by federal authority under the Oceans Act, directed by the Minister of Fisheries and Oceans (Government of Canada, 2011). There are other avenues to "establish other effective means" of marine conservation, but MPAs under the Ocean Act can regulate all activities that may damage the MPA ecosystem, including oil/gas exploration, fishing, and shipping (Oceans Act, 1996). Currently, Canada has established eleven MPAs, each with monitoring programs in various stages of development (DFO, 2018a), along with eight Areas of Interest (AOIs) (DFO, 2018b). The established MPAs account for < 0.5 % of marine conservation coverage in Canada (DFO, 2018c). Each federal MPA is required to develop a monitoring plan, including identifying indicators, to ensure that the established MPAs are effective marine conservation tools (Government of Canada, 2011).

Understanding the governance structure of the region in which the Tarium Niryutait Marine Protected Area (TN MPA) was established is important when discussing monitoring and decision making. The TN MPA was established in the Inuvialuit Settlement Region (ISR) and MPAs in the ISR are managed differently than elsewhere in Canada. The ISR was established with the signing of the Inuvialuit Final Agreement in 1984 (DIAND, 1984), resulting in the co-management of the TN MPA between Fisheries and Oceans Canada (DFO) and the Fisheries Joint Management Committee (FJMC), that is supported by the Inuvialuit Game Council and advised by local community Hunters and Trappers Committees (Armitage et al., 2011; Fast et al., 2001). The TN MPA is composed of three sub regions, Naiqunnaq, Okeevik, and Kittigaryuit, which cover approximately 1800 km^2 of the Mackenzie Estuary (Fig. 2.1). A suite of indicators is recommended for the TN MPA due to the broad conservation objective, the complexity of the marine ecosystem, and the multiple stressors on ecosystem (Loseto et al., 2010). The health of the focal species of the TN MPA, the Eastern Beaufort Sea (EBS) beluga whale (*Delphinapterus leucas*), is one of the priority indicators. A proposed beluga health indicator is body condition and blubber thickness is the suggested metric, although it is not the only body condition indicator option (Loseto et al., 2010).

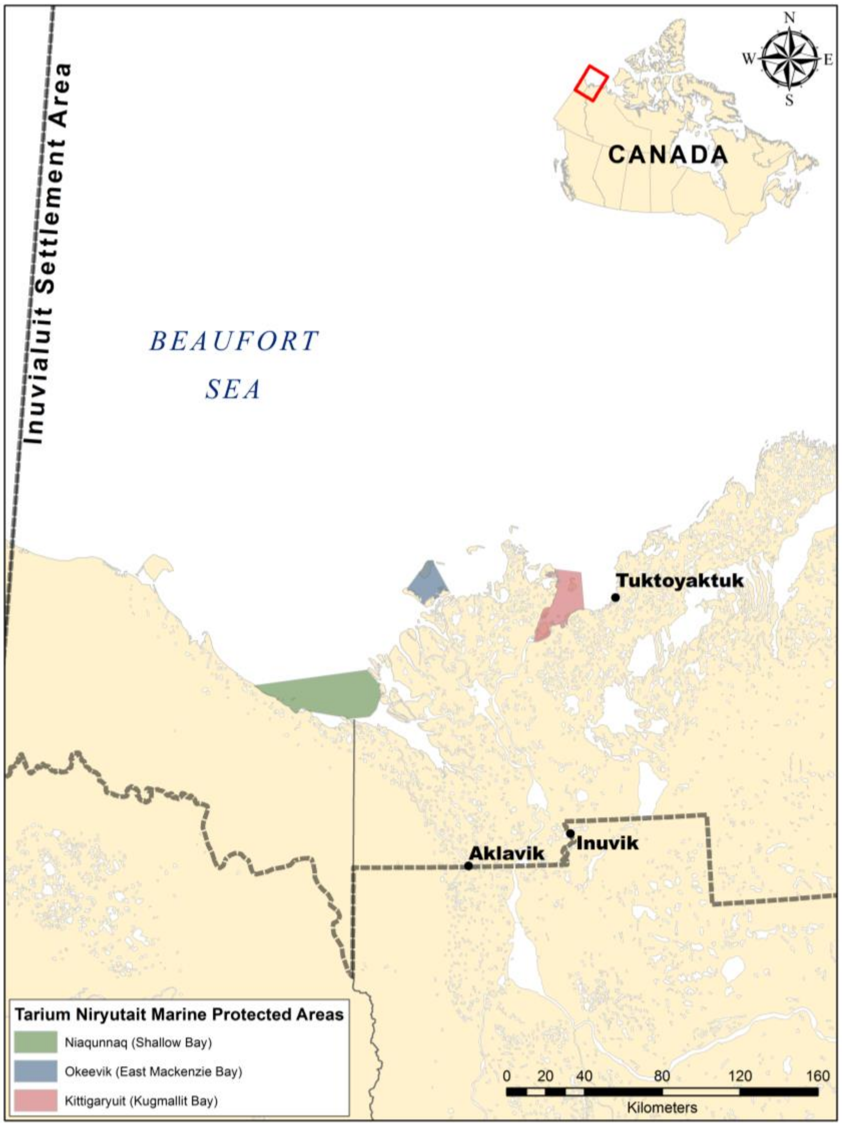


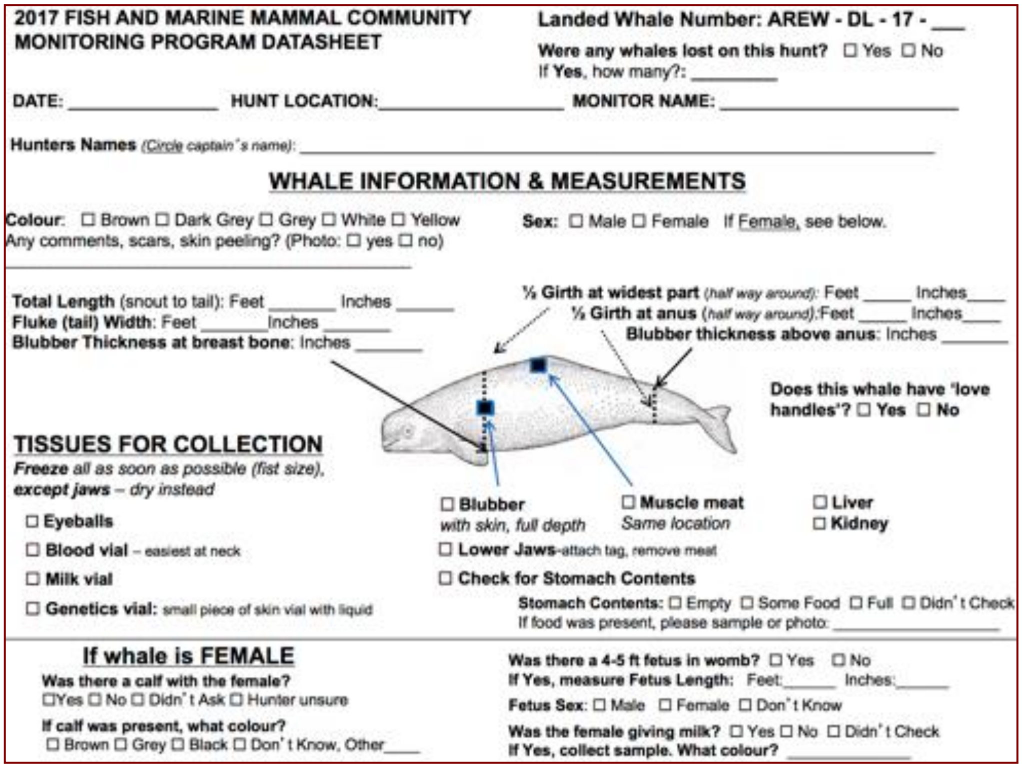
Figure 2.1: Map of the three regions of the Tarium Niryuitat Marine Protected Area: Niaqunnaq, Okeevik, Kittigaryuit. Community members from Aklavik, Inuvik, and Tuktoyaktuk travel to camps on the coast in the summer to hunt beluga in the three sub regions (DFO Oceans Program, 2018).

2.3 EBS Beluga Whales

Beluga whales have a circumpolar distribution across the Arctic. Specifically, the EBS beluga whale population migrates thousands of kilometers in early spring from their wintering waters in the Chukchi and Bering Seas to their summering waters the TN MPA, Mackenzie Estuary, and the surrounding Beaufort Sea and Amundsen Gulf (Citta et al., 2017; Frost and Lowry, 1990; Harwood and Smith, 2002; Richard et al., 2001). The observed aggregation of belugas in estuaries during summer months is not restricted to the EBS beluga population and there are numerous hypotheses for the yearly return of belugas to estuarine waters (COSEWIC, 2004). Proposed reasons for the annual use of estuaries by belugas include feeding, calving, and moulting (Frost and Lowry, 1990; Sergeant, 1973; St. Aubin et al., 1990). The EBS belugas enter the Mackenzie estuary once the landfast ice barriers break, and belugas are observed in the TN MPA from June to August (Carmack and Macdonald, 2002; Fraker, 1977; Harwood and Smith, 2002; Richard et al., 2001). The distribution of EBS belugas across the summering waters is segregated so that females with calves and smaller males select open water habitat close to mainland including the TN MPA, whereas larger males prefer ice-covered waters farther from the mainland (Loseto et al., 2006).

The return of the belugas is both culturally significant and provides food security for the Inuvialuit communities (Harwood and Smith, 2002; Hoover et al., 2016). Each summer families from Inuvik, Aklavik, and Tuktoyaktuk travel to traditional hunting camps along the Mackenzie estuary and Beaufort Sea shoreline to hunt (Harwood et al., 2002). The communities of Paulatuk, Ulukhaktok, and Sachs Harbour are located beyond the TN MPA boundaries also opportunistically harvest beluga (Harwood et al., 2002). The subsistence hunt of belugas is foundational to the long-term beluga monitoring program in the ISR, established in 1973 (Harwood et al., 2002). The monitoring program has alternated between being run by government agencies and industry-sponsored programs. Starting in 1987 and continuing to the present, FJMC directs the monitoring program (Fraker, 1977; Harwood et al., 2002). The monitoring program has evolved over the years; whereas the initial years recorded the size and timing of harvest, the program has expanded to include additional beluga measurements and tissue collection to monitor other biological parameters such as mercury exposure, stress hormones and persistent organic pollutants (Loseto et al., 2018, 2008; Smythe et al., 2018). From

2000 to present, the collection of body condition metrics of blubber thickness and girth has been regularly practiced, as directed by the beluga monitoring forms (Fig. 2.2).



2017 FISH AND MARINE MAMMAL COMMUNITY MONITORING PROGRAM DATASHEET

Landed Whale Number: AREW - DL - 17 - ___

Were any whales lost on this hunt? ☐ Yes ☐ No
If Yes, how many?: ________

DATE: ______________ HUNT LOCATION: ________________ MONITOR NAME: ______________________

Hunters Names (Circle captain's name): ____

WHALE INFORMATION & MEASUREMENTS

Colour: ☐ Brown ☐ Dark Grey ☐ Grey ☐ White ☐ Yellow
Any comments, scars, skin peeling? (Photo: ☐ yes ☐ no)
____

Sex: ☐ Male ☐ Female If Female, see below.

Total Length (snout to tail): Feet ______ Inches ______
Fluke (tail) Width: Feet _______ Inches ______
Blubber Thickness at breast bone: Inches ______

½ Girth at widest part (half way around): Feet _____ Inches ____
½ Girth at anus (half way around): Feet _____ Inches ____
Blubber thickness above anus: Inches ______

Does this whale have 'love handles'? ☐ Yes ☐ No

TISSUES FOR COLLECTION
Freeze all as soon as possible (fist size), except jaws – dry instead

☐ Eyeballs
☐ Blood vial – easiest at neck
☐ Milk vial
☐ Genetics vial: small piece of skin vial with liquid

☐ Blubber *with skin, full depth*
☐ Muscle meat *Same location*
☐ Liver
☐ Kidney
☐ Lower Jaws-attach tag, remove meat
☐ Check for Stomach Contents
Stomach Contents: ☐ Empty ☐ Some Food ☐ Full ☐ Didn't Check
If food was present, please sample or photo: ______________

If whale is FEMALE

Was there a calf with the female?
☐Yes ☐ No ☐ Didn't Ask ☐ Hunter unsure

If calf was present, what colour?
☐ Brown ☐ Grey ☐ Black ☐ Don't Know, Other____

Was there a 4-5 ft fetus in womb? ☐ Yes ☐ No
If Yes, measure Fetus Length: Feet:_____ Inches:_____
Fetus Sex: ☐ Male ☐ Female ☐ Don't Know
Was the female giving milk? ☐ Yes ☐ No ☐ Didn't Check
If Yes, collect sample. What colour? __________

Figure 2.2: Example of beluga monitoring form (2017) used by hunters and monitors across the ISR (provided by FJMC and DFO).

2.4 Body Condition Indicators

Body condition of marine mammals can be evaluated from morphometric measurements such as blubber thickness, maximal girth, weight, length, or indices such as Body Mass Index(BMI), or scored based on visual criteria (ex: George et al., 2015; Joblon et al., 2014; Moore et al., 2001). Body condition indicators aim to measure the energy stores of an individual, which reflect foraging effort and success, link to ecological fitness, and are used as a proxy for the health of the overall population (Aguilar and Borrell, 1990; Bradford et al., 2012; Burek et al., 2008; Koopman et al., 2002; Noren et al., 2015). Changes in body condition of marine mammals have been associated to changes in prey availability, disease, stress, and environmental change (Burek et al., 2008; George et al., 2015; Laidre et al., 2008; Moore, 2008). Blubber thickness is one common measure of body condition in marine mammals as blubber is a major deposit for lipids but maintaining blubber is also key for thermoregulation, buoyancy, streamlining (Koopman et al., 2002; Miller et al., 2011; Noren and Mangel, 2004; Ryg et al., 1993; Strandberg et al., 2008). A second recommended body condition indicator is girth, often a measure from the dorsal midline to ventral midline, because it has been suggested to be more sensitive as it measures change in blubber thickness as well as change in other lipid stores in the body (Choy et al., 2017; George et al., 2015, Rice and Wolman 1971).

Understanding the measurability, sensitivity, and specificity of EBS beluga body condition indicators is key when evaluating the usefulness for monitoring. Due to the long-term establishment of the ISR beluga monitoring program, historical data is available for this analysis, which is a rare occurrence for marine monitoring but highly valuable (Edwards et al., 2010; Harwood et al., 2002). Additional measurability considerations that were assessed include bias and precision of data collection (Rice and Rochet, 2005). The sensitivity of beluga body condition evaluates both spatial variation as well as temporal short-term and long-term variation and trends. For the EBS belugas, from 2000-2007 and 2011-2014, a slight decline in the blubber thickness has previously been detected (Choy et al., 2017; Harwood et al., 2014). From 2011-2014, no trend was apparent for a girth indicator for the EBS belugas (Choy et al., 2017). It is important to note that these two previous studies in EBS condition differ in their approach. Because of these methodological differences, an analysis on condition trends from 2000-2015 is required determine if the previous trends detected hold or whether they are examples of short-term variation. There is also a knowledge gap in the sensitivity of girth indicators and a need to evaluate the long-term girth condition trends. Lastly, the specificity of the body conditions will assist the co-management of the TN MPA to understand the drivers of change. Previously, it was observed that 2005 was the year with the thinnest blubber thickness for male EBS belugas, and during that same year, ringed seals in the nearby Amundsen Gulf also had the lowest body condition in two decades (Harwood et al., 2014). The low body condition of these two species in the Beaufort may be a result of changes of their common prey, Arctic Cod, as prey is an important consideration when assessing body condition (Harwood et al., 2014). Another proposed driver of beluga body condition is the ice coverage across the Beaufort Sea. Both 2011 and 2012 observed highs in both blubber thickness and girth indices, with 2012 as the year with lowest sea ice extent (Choy et al., 2017). These past studies have presented two potential drivers to explain the changes in beluga body condition and the continued evaluation of body condition specificity is key for TN MPA management.

The Arctic is experiencing climate change at both an increased rate and magnitude compared to elsewhere on the planet (ACIA, 2014; Johannessen and Miles, 2011). Changes occurring include increased water temperature, decreasing amounts of snow, reduced sea-ice extent, earlier melt season and later freeze-up (Arrigo et al., 2008; Barber et al., 2009; Stroeve et al., 2014). These changes are influencing marine ecosystems across the Arctic, including the distribution of the primary prey of belugas, Arctic Cod (Loseto et al., 2009; Quakenbush et al., 2015). Other predicted changes in the Arctic that may affect the health of belugas include the northward migration of predators and increased human activities such as shipping, tourism, and resource extraction (Carmack and Macdonald, 2002; Pizzolato et al., 2016). Examining body condition indicators is important for understanding population health and resilience to external stressors (Kershaw et al., 2017). Detailing the development of body condition indicators will provide the TN MPA management with a clear understanding of the benefits and limitations to each indicator, as well as understanding the spatial and temporal variation will aid in understanding future trends.

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Chapter Three: **DEVELOPING AN INDICATOR: UNDERSTANDING THE INFLUENCE OF HARVEST LOCATION AND HEALTH ON BELUGA WHALE BODY CONDITION.**

MacMillan, K., Hoover, C., Iacozza, J., Peyton, J., Loseto, L. 2018. Developing an Indicator: Understanding the Influence of Harvest Location and Health on Beluga Whale Body Condition. Ecological Indicators (under review).

Abstract

Selecting indicators for monitoring marine protected areas is a challenging process that requires simplifying complex marine ecosystems into a suite of indicators. Prior to selecting a final suite of indicators, it is key to understand the information captured by each proposed indicator. The Tarium Niryutait Marine Protected Area (TN MPA) located in the Inuvialuit Settlement Region, NWT is selecting indicators for monitoring. Proposed health indicators for the TN MPA species of interest, the Eastern Beaufort Sea (EBS) beluga, include the body condition metrics blubber thickness and girth. Sex-specific body condition indicators for both metrics were developed to account for beluga age, size, location, and timing of harvest from belugas harvested from 2000 to 2015. Indicators were tested to determine if spatial variation is detected in the condition of belugas between the three regions of the TN MPA and between belugas harvested inside to outside of the TN MPA. Lastly, we assessed belugas in good and poor condition to determine if thresholds of health could be developed. Three of the indicators (girth male, girth female, blubber thickness male) contain both temporal and spatial factors, indicating a significant influence of harvest location and year on condition. Male belugas harvested from the western region of the TN MPA had smaller mean girth and mean blubber thickness compared to the other two TN MPA regions, whereas there was no significant difference for females across the three TN MPA regions. There was a significant difference inside and outside the TN MPA for all four indicators, with smaller mean blubber outside the TN MPA, and females exhibiting larger mean girth inside the TN MPA, while males have a smaller mean girth inside the TN MPA. Indicators confirmed that entrapped belugas had significantly lower indicator residuals than summer harvest belugas.

3.1 Introduction

Marine protected areas (MPAs) are a management tool used worldwide to regulate activities and conserve biota in coastal and ocean waters (Wood et al., 2018). In Canada, MPA coverage is growing to meet a global commitment to protect at least 10% of Canada's marine waters by 2020 (DFO, 2010). MPA management includes the development and implementation of monitoring programs that involves the selection of indicators (Hayes et al., 2015; Rice and Rochet, 2005). Indicators are typically specific measurements that can be regularly collected and provide relevant data that can be used to derive trends and understand the state of and changes in an ecosystem (Schomaker, 1997; Vandermeulen, 1998). Since marine ecosystems are highly dynamic and complex, it is recommended that suites of indicators should be used for monitoring MPAs (Boldt et al., 2014, Rice and Rochet, 2005).

The Tarium Niryutait Marine Protected Area (TN MPA) was Canada's first Arctic MPA, established in 2010 in the Inuvialuit Settlement Region (ISR) (Fig. 3.1) (Oceans Act, TN MPA Regulations 2010). Prior to the establishment of the TN MPA, these waters were formally recognized by the Beaufort Sea Beluga Management Plan (BSBMP) as important Eastern Beaufort Sea (EBS) beluga summer habitat (FJMC and DFO, 2013b; Fraker, 1977; Frost and Lowry, 1990; Harwood and Smith, 2002; Richard et al,. 2001). The EBS beluga whale population migrate thousands of kilometers from their wintering waters in the Chukchi and Bering Seas to their summer waters in the TN MPA and the surrounding Beaufort Sea and Amundsen Gulf (Frost and Lowry, 1990; Harwood and Smith, 2002; O'Corry-Crowe et al., 1997; Richard et al., 2001). Beluga summer distribution is segregated by sex, age, and reproductive condition such that females with calves and smaller males select open water habitat close to mainland while large males select closed sea ice cover further from the Mackenzie Estuary (Loseto et al., 2006). The TN MPA not only protects key beluga habitat but also conserves subsistence practices and significant cultural traditions for the Inuvialuit (Fraker, 1977; Harwood et al., 2002)

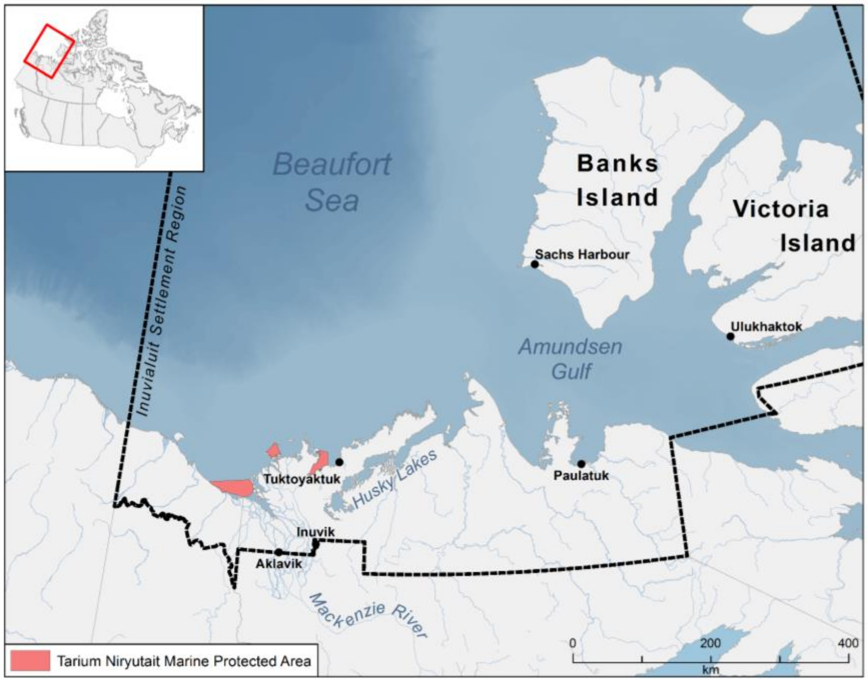

Figure 3.1: Map of the Tarium Niryutait Marine Protected Area (pink) and the six communities located within the Inuvialuit Settlement Region: Aklavik, Inuvik, Tuktoyaktuk, Paulatuk, Sachs Harbour, and Ulukhaktok (DFO Oceans Program, 2018).

The TN MPA management plan requires the identification of ecological, socio-economic, and governance indicators (DFO, 2010; FJMC and DFO, 2013b). Selecting ecological indicators for the TN MPA poses challenges as this ecosystem has high environmental variability and experiences accelerated rates of climate change (Barber et al., 2008; DFO 2010; FJMC and DFO, 2013b). The overall purpose of the indicators is to inform how well the TN MPA is meeting its conservation objective to "conserve and protect beluga whales and other marine species, their habitats, and their supporting ecosystem" (FJMC and DFO, 2013a). The highest priority ecological indicators are those that monitor the health of TN MPA species of interest, the EBS beluga whale (Loseto et al., 2010). The most prominent known effects impacting marine mammal health include disease, toxins, body condition, and the environment, and will have cumulative effects on overall health (Burek et al., 2008; Laidre et al., 2008). Specifically, changes in beluga body condition may impact reproduction rates, individual growth rates, and the survival of the population (Harwood et al., 2012; Kingsley and Byers 1998; Stirling, 2002; Harwood et al. 2012). Changes in body condition may reflect shifts in prey quality or abundance, an infection, or injury, which may be driven by environmental change (Burek et al., 2008; George et al., 2015; Laidre et al., 2008; Moore, 2008). Since the EBS belugas are a far-migrating and high trophic-level species, body condition is likely to be influenced by variation occurring outside the TN MPA boundaries and may capture long-term environmental changes (Loseto et al. 2010; Moore, 2008).

Body condition is a proposed health metric to monitor the EBS belugas, with blubber thickness and girth as optional metrics (DFO, 2010). These metrics have been used to monitor the health of other marine mammals including seals, polar bears, and walruses (Choy et al., 2017; George et al., 2015; Harwood et al., 2012; Kingsley and Byers, 1998; Stirling, 2002; Williams et al., 2013). Blubber is a complex tissue affected by diet, morphology, and the environment (Strandberg et al., 2008). Blubber serves as an energy reserve, has key thermoregulatory function, and assists with buoyancy and streamlining (Koopman et al., 2002; Noren and Mangel, 2004; Ryg et al., 1993 ; Strandberg et al., 2008). Girth, a measure of full or half body circumference, has been recommended as a body condition indicator for bowhead and beluga whales as it captures changes in blubber thickness as well as in other lipid storage layers and muscle mass (Choy et al., 2017; George et al., 2015).

The management of MPAs requires monitoring programs that use indicators known to capture both the current state and changes in an ecosystem (Rice and Rochet, 2005; Vandermeulen, 1998). Long-term data sets are important for this process of developing and selecting indices for monitoring, as they aid in capturing long-term patterns (Edwards et al., 2010). The EBS beluga monitoring program was initiated in the ISR in 1973, including the area that would become the TN MPA, and continues presently, forming the longest known beluga monitoring program (Fraker, 1977; Harwood and Smith, 2002). A thorough analysis of this long-term monitoring data will not only contribute to understanding the body condition variation that is captured by blubber thickness and maximal half-girth metrics, but will also contribute to understanding the limitations and benefits of these metrics as indicators. First, we develop sex-specific body condition indicators for two metrics of condition: blubber thickness and maximal half-girth measurements, hereafter referred to as girth. Second, we assess if there is spatial variation captured in the body condition indicators at two scales, within the three sub-areas of the TN MPA areas and between areas in the TN MPA and other areas of the summer habitat. Lastly, based on observations of good and poor condition of belugas from the summer harvest and from two entrapment events, we compare the body condition of these groups to determine if thresholds of health could be developed.

3.2 Methods

3.2.1 Study Area

Located in the Mackenzie Estuary, the TN MPA is comprised of three separate areas; Naiqunnaq (Shallow Bay), Okeevik (East Mackenzie Bay), and Kittigaryuit (Kugmallit Bay), covering nearly 1800 km^2 (Figs. 3.1 and 3.2) (FJMC and DFO, 2013b). Every summer, families from the communities of Aklavik, Tuktoyaktuk, and Inuvik spend time at hunting and fishing camps along the shores of the three sub-regions of the TN MPA (Fraker, 1977; Harwood et al., 2002a; Norton and Harwood, 1986). The remaining ISR communities of Paulatuk, Ulukhaktok, and Sachs Harbour are located beyond the TN MPA boundaries in the Beaufort Sea and Amundsen Gulf, but also participate in beluga harvest practices outside of the TN MPA

(Harwood et al., 2002). The majority of the beluga harvesting begins in early July and may last from 4-6 weeks (Fraker 1977; Harwood et al. 2002; Norton and Harwood, 1986). However, the beluga monitoring dataset reveals that there are also opportunistic hunts in June and August. There are two cases of beluga entrapments recorded in the beluga monitoring dataset in 1989 and 2006 occurring in Husky Lakes, that are directly connected to the Beaufort Sea (Fig. 3.1). It is thought that belugas move into the Husky Lakes during the summer months to feed (Kotokak and Bill, 2007), but in 1989 and 2006, they were not able to leave the lakes before the winter freeze-up.

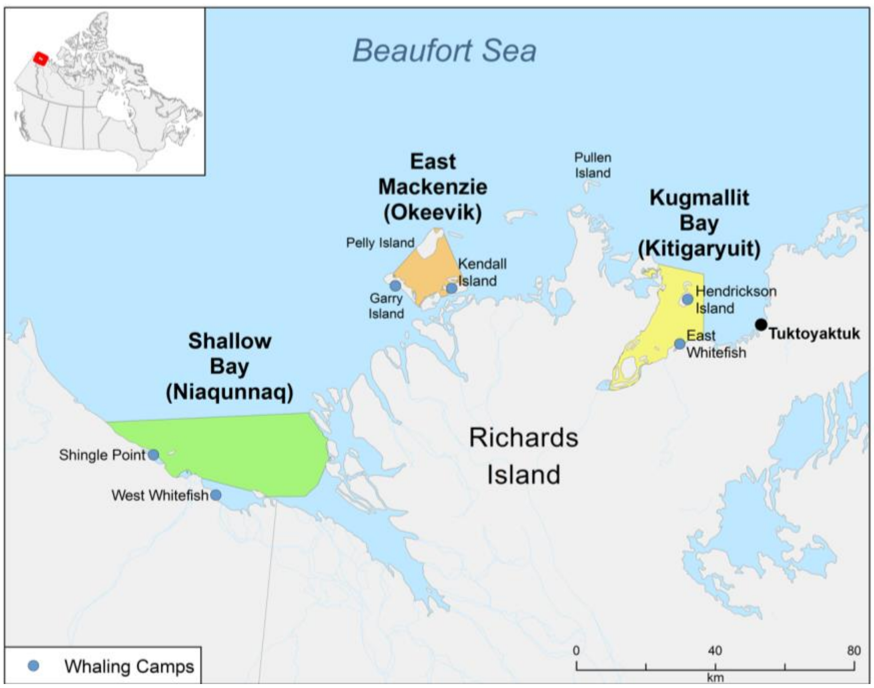

Figure 3.2: Three regions of the TN MPA (green, orange, and yellow areas) and common whaling camps (blue circles) (DFO Oceans Program, 2018). Note: Additional camps used by community members are not listed.

3.2.2 Monitoring Data

The EBS beluga monitoring program in the TN MPA provides an opportunity to regularly collect specific beluga measurements that contribute to a long-term dataset to determine potential indicators (Harwood et al., 2002). The Inuvialuit harvesters are instrumental partners in the monitoring program as they collect metrics and samples from harvested belugas and record environmental observations (Harwood et al., 2002). The beluga monitoring program data set is composed of data collected from 1974 to present. The protocol for morphometric and biological sampling collection was standardized in 1980 (Bell and Harwood, 2012). Blubber thickness and girth measurements were first recorded in 1989, collected from entrapped belugas in the Husky Lakes. Starting in the year 2000, the collection of blubber thickness and girth measurements were required as part of the monitoring program. The monitoring protocol has continued to evolve over the years to answer additional questions about the EBS beluga population regarding their diet and exposure to contaminants (Bell and Harwood, 2012; Loseto et al., 2015).

This analysis is focused on data collected from 2000-2015 (n = 1389) during the years when the collection of blubber thickness and girth measurements were standardized and beluga aging techniques were consistent. Blubber thickness is measured from the chest region, between the pectoral fins. Girth is measured behind the pectoral fins from mid-chest to the dorsal ridge. Beluga age was determined by counting dentinal growth layer groups (GLG) in sectioned teeth and was visually identified by two deposits (dark layer and light layer) (Harwood et al., 2014; Perrin and Myrick, 1980). In this study, as with previous studies on this beluga population (e.g., Harwood et al., 2014; Loseto et al., 2015; Luque and Ferguson, 2010) a single GLG group is equal to one year (Stewart et al., 2006). Additional variables used in this research collected from the monitoring program include: year, day of year, camp, standard length (snout to tail), fluke width, sex, and age.

3.2.3 Data Preparation

Morphometric data were examined thoroughly for outliers due to possible misreporting of measurements either from data collection or when the data were digitized. Hendrickson Island camp in Kugmallit Bay was identified as the monitoring camp with the most consistent protocols as the same beluga monitor lead the data collection (2001-2013) and often a secondary science crew was present (L. Loseto pers. comms.), therefore individual measurements farther than three standard deviations from these samples were flagged as possible errors and investigated individually. In addition, *t*-tests were performed for each morphometric parameter recorded at each camp with Hendrickson Island for every year, confirming that overall Hendrickson Island was not significantly different from the other camps, although there was year-to-year variation. Flagged entries were corrected using the original data sheets if possible. A total of 57 outlying belugas were removed.

The dataset was also investigated for the presence of immature belugas, potentially affecting body condition variability (Loseto et al. 2015; Robeck et al. 2005). The Gompertz growth curve (Eq.1) was used to investigate the non-linear growth of belugas and the derived asymptotic length has previously been used to represent mature EBS belugas (Harwood et al., 2002; Luque and Ferguson, 2010).

(Eq. 1) $$L_t = A * e^{(-e^{(-k \cdot (t - t_0))}}$$

Where L_t represents predicted standard length (cm), *A* represents asymptotic length which is the predicted maximum length (cm), *k* and t_0 are model constants, and *t* is the estimated age based on growth layers in teeth (Luque and Ferguson, 2010). Growth models for males and females derived similar asymptotic length values compared to previous research. Asymptotic lengths from 2000:2015 were 432.1 cm (males) and 372.9 cm (females). Previously derived values for

EBS belugas from 1988:1994 were 432.0 cm (males) and 386.2 cm (females) (Harwood et al., 2002), and EBS belugas sampled from 1993:2003 were 432.3 cm (males) and 381.5 cm (females) (Luque and Ferguson, 2010). Since EBS belugas sampled in this assessment aligned with previous growth research, we used the estimated age of sexual maturity for belugas to remove immature whales, which was age 15.9 for males and 11.9 for females (Robeck et al., 2005). There were 24 young male belugas and 1 young female beluga below these ages that were excluded from the analyses.

3.2.4 Body Condition Indicators

General linear models were used to create body condition indices, aligning with previous approaches for bowhead whales (George et al., 2015) and previous assessments for EBS beluga whales from 2011:2014 (Choy et al., 2017). Due to sexual dimorphism in belugas (Loseto et al., 2006), sex-specific body condition models were built resulting in four indicators; Girth Male (GM), Girth Female (GF), Blubber Thickness Male (BM), Blubber Thickness Female (BF). Pair plots were used to investigate the relationship and collinearity between morphometric parameters. A stepwise regression method (RStudio Team 2015, Version 0.99.903) was used to select the final 'best-fit' model based on the Akaike Information Criterion (AIC) scores.

3.2.5 Spatial Variation

Previous research has not investigated the influence of harvest location on EBS beluga condition. The three regions of the TN MPA are typically used by different ISR communities; but hunters and families may camp and harvest in any region of the TN MPA (Inuuvik Community Corporation et al., 2006). Representatives on the Fisheries Joint Management Committee raised the question about the influence of location on body condition metrics because of hunter selection and segregated use of the TN MPA (John Noksana Jr. pers. comms.). Thus, the influence of harvest location on body condition was assessed at two scales using the best-fitting indicators (GM, GF, BM, BF). A post-hoc Tukey HSD test was used to detect if there were significant differences in beluga condition among the three regions of the TN MPA for each indicator (Fig. 3.3). Second, a Welch's t-test was used to compare beluga condition between whales landed within the TN MPA to those landed outside of the TN MPA.

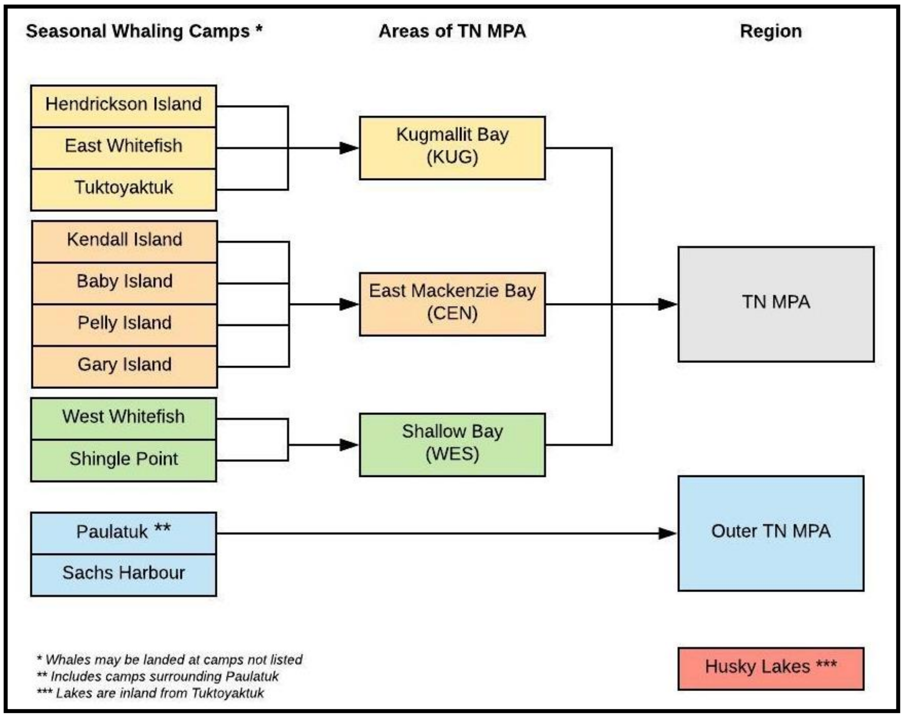

Figure 3.3: Harvest locations: organization of whaling camps in the TN MPA, outside the TN MPA, and Husky Lakes for body condition analyses.

3.2.6 Entrapped Whale Condition

To understand the utility of the condition metrics for use as an indicator, belugas harvested as part of the summer hunter in the TN MPA were tested against those harvested from entrapment events to assess if these two type of harvest events can be used as thresholds for body condition indicators. The assumption that belugas harvested from the TN MPA are in healthy or good condition is first based on the report that the EBS beluga population considered to be either stable or increasing in size with the last population maximum estimate in 1992 at 39,258 individuals (Allen and Angliss, 2014; COSEWIC, 2004; Harwood and Kingsley, 2013). Also, the majority of TN MPA sampled are harvested by hunters from the communities of Inuvik and Tuktoyaktuk, where it has been identified that hunters select healthy belugas to harvest (Ostertag et al., 2018). Although there have been observations from hunters and previous research has identified a slight decline in blubber thickness (2000-2007), overall harvested belugas are in good condition (Harwood et al., 2014; Waugh et al., 2018). EBS belugas harvested from the two entrapment events (1989 and 2006) in Husky Lakes were in the lakes for approximately 2-3 months (Harwood and Smith, 2002), and observation recordings from those harvests note that the whales appear to have poor body condition (n = 125) (Harwood and Smith, 2002; Kotokak and Bill, 2007). The cortisol concentration in the blubber of the 2006 entrapment belugas were seven times higher compared to the summer harvest belugas from 2006 and 2007 (Trana et al., 2016).

For this analysis four sex-specific body condition indicators were developed using only morphometric variables (standard length, fluke width, and age). The exclusion of temporal and spatial predictors is required to develop an indicator that could be used to compare the two assigned body condition groups because the poor condition group is restricted to a single location and limited years. Indicators were built using data from belugas harvested in the TN MPA, and then tested using data from Husky lakes to identify if belugas of similar standards (age, length, fluke-length) showed significant differences in blubber thickness or girth measurements. Again, step-wise regression models were selected based on AIC scores prior using a Welch's t-test to compare the two condition groups.

3.3 Results

3.3.1 Monitoring Data

A summary of the selected beluga monitoring data used in these analyses is found in Table 1. Overall 89.9% of the sampled belugas were harvested within the TN MPA. Of those belugas, 69.0% were harvested from KUG, 25.7% were harvested from CEN, and 5.3 % were harvest from WES.

Table 3.1: Summary of beluga monitoring data used in analyses. Including belugas sampled as part of the summer harvest across the Beaufort Sea; the TN MPA (left column), belugas sampled from Husky Lakes entrapments (right column).

Beaufort Sea Summer Harvests		**Husky Lake Entrapments**	
Total number of samples	1389	Total number of samples (1989 and 2006)	125
Mean number sampled each year and SD	84.6 ± 21.8		
Year with highest number of samples	2004 (n= 131)		
Year with lowest number of samples	2008 (n=74)		
Percent Male	75.2% (n=1045)	85.6 % (n=107)	
Percent Female	19.0% (n=264)	13.6 % (n=17)	
Mean and SD Girth (M)	109.79 ± 18.50 cm	98.58 ± 14.31 cm	
Mean and SD Girth (F)	95.81 ± 16.94 cm	83.77 ± 8.52 cm	
Mean and SD Blubber Thickness (M)	8.85 ± 2.61 cm	3.55 ± 1.32 cm	
Mean and SD Blubber Thickness (F)	7.15 ± 2.13 cm	3.60 ± 0.91 cm	
Mean and SD Age (M)	28.75 ± 9.03	26.77 ± 14.30	
Mean and SD Age (F)	37.48 ± 12.54	37.23 ± 16.58	

3.3.2 Body Condition Indicators

The two variables standard length and fluke width are correlated (r = 0.65, *p*-value < 0.001), thus these two variables were substituted for each other during the step-wise regression analyses. The four final best fitting body condition indicators selected by lowest AIC score along with the stepwise selection for each body condition indicator are listed in Table 2. The final indicators use different sample sizes, as all measurements were not always recorded for each beluga. For GM, the significant factors are year, area, length, and age. For GF, the significant factors are year, area, and length. For BM, the significant factors are year, camp, and length. For BF, the significant factor is fluke width. The male condition indicators (GM and BM) are moderately correlated (r = 0.33, p-value < 0.001), and both female condition indicators (GF and BF) are also moderately correlated (r = 0.39, p-value < 0.001).

Table 3.2: Models for body condition indicators as defined by AIC scores. Indicators marked by * were the selected models.

Body Condition Indicator	Variables	*p*-value	AIC	df	Adjusted R^2
GM	*** Year + Length + Age + Area**	**< 0.001**	**2948.38**	**587**	**0.4986**
	Year + Length + Age	< 0.001	+ 21.47		
	Year + Length	< 0.001	+ 38.35		
	Year	< 0.001	+ 155.73		
GF	*** Year + Length + Area**	**< 0.001**	**671.34**	**121**	**0.5696**
	Year + Length	< 0.001	+ 8.03		
	Year	< 0.001	+ 22.84		
BM	*** Length + Year + Area**	**< 0.001**	**957.00**	**577**	**0.1896**
	Length + Year	< 0.001	+ 3.72		
	Length	< 0.001	+ 43.39		
BF	*** Fluke Width**	**< 0.001**	**184.78**	**129**	**0.1128**
	Length	0.001	+ 13.94		

3.3.3 Influence of Harvest Location

The location of harvest factor is included in three of the four body condition indicators (GM, GF, BM). The Tukey HSD test results show that within the TN MPA the WES sub-area was significantly different from both CEN and KUG sub-areas for males (GM, BM: Fig. 3.4), with belugas from the WES subarea having smaller mean girth and mean blubber thickness.

However, there was no significant difference between the three TN MPA sub-regions for females (GF, BF: Fig 3.4). Tests comparing inside vs. outside the TN MPA reveal there was a significant difference between the two regions for all four indicators (BM, BF, GM, and GF: Fig. 3.5), with smaller mean blubber thickness occurring outside the TN MPA. Females exhibit larger mean girth inside the TN MPA, while males have a smaller mean girth inside the TN MPA (Fig. 3.5).

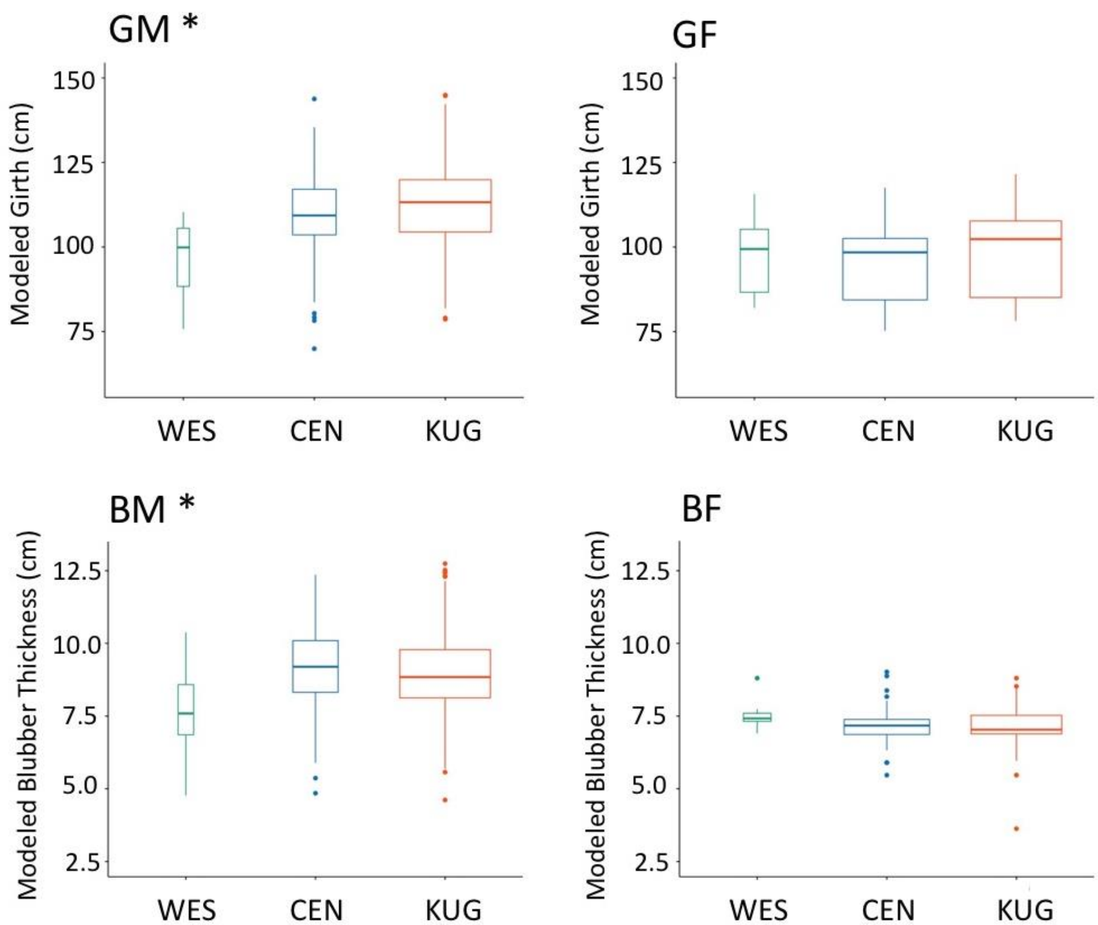

Figure 3.4: Comparison between three regions of the TN MPA for each of the four condition indicators predicted values (WES = Shallow Bay, CEN = East Mackenzie Bay, KUG = Kugmallit Bay). Box widths are proportional to the square root of the number of observations. There is a significant difference ($p > 0.05$) between WES and the other two areas (KUG and CEN) for both Girth Male (GM) and Blubber Thickness Male (BM) indicators and are marked by * (see Table 3.3).

Table 3.3: Results of Tukey HSD tests of predicted values from condition indicators between belugas landed inside the three regions of the TN MPA (WES = Shallow Bay, CEN = East Mackenzie Bay, KUG = Kugmallit Bay) (see Fig. 3.4). Both Girth Male (GM) and Blubber Thickness Male (BM) differed ($p < 0.05$) between WES and both CEN and KUG and are marked by *.

Areas Tested	GM Diff. in Means (cm) (*p*-value)	GF Difference between Means (cm) ((*p*-value)	BM Difference between Means (cm) (*p*-value)	BF Difference between Means (cm) (*p*-value)
WES - CEN	13.36 (0.008*)	1.70 (0.89)	1.49 (< 0.001*)	0.38 (0.99)
WES - KUG	15.55 (0.009*)	1.41 (0.92)	1.25 (< 0.001*)	0.37 (0.13)
CEN - KUG	2.30 (0.20)	3.11 (0.13)	0.24(0.10)	0.001 (0.13)

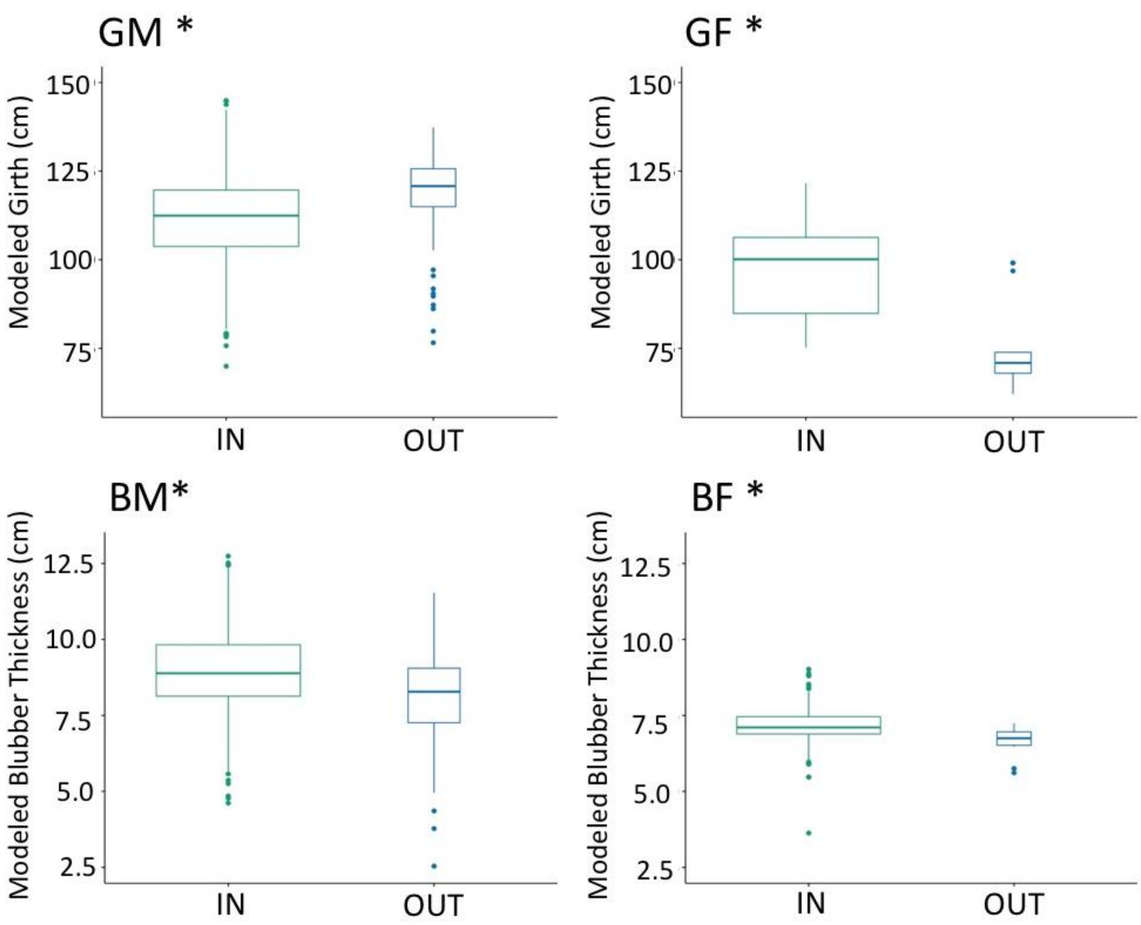

Figure 3.5: Comparison between belugas landed in the TN MPA to belugas landed outside the TN MPA for each of the four condition indicators predicted values. Box widths are proportional to the square root of the number of observations. There is a significant difference ($p > 0.05$) between harvest locations for all indicators and are marked by * (see Table 3.4).

Table 3.4: Results of Welch's t-test between predicted values from condition indicators of belugas landed inside the TN MPA to belugas landed outside the TN MPA (see Fig. 3.5). All four condition models found significant differences ($p > 0.05$) between belugas harvested in the TN MPA to outside the TN MPA and are marked by *.

IN vs OUT	t	df	*p*-value
GM	-2.36	58.59	<0.05 *
GF	6.15	14.38	<0.05 *
BM	6.32	130.42	<0.05 *
BF	3.28	12.66	<0.05 *

3.3.4 Comparison of Condition between Summer Harvests and Entrapped Belugas

Entrapped belugas were compared to whales harvested from East Mackenzie Bay (CEN) and Kugmallit Bay (KUG), as these two areas were not significantly different from each other for both males and females, and previously noted that hunters from these communities select healthy whales for harvest. Assessing only morphometric variables, the best-fitting models for each body condition indicator are listed in Table 3.5. For GM_2 and BM_2 the significant factors are length and age. For GF_2 and BF_2, the significant factor is fluke width. The four best-fitting models used different sample sizes, as measurements were not always taken for each whale.

Table 3. 5: Best-fit models for body condition indicators as defined by AIC scores. Models marked by * were the selected indicators.

Body Condition Indicators	Variables	*p*-value	AIC	df	Adjusted R^2
GM_2	*** Length + Age**	**< 0.001**	**2947.26**	**546**	**0.18**
	Length	< 0.001	+ 19.34		
GF_2	*** Fluke Width**	**0.002**	**689.66**	**124**	**0.063**
	Length	0.003	+ 12.36		
BM_2	*** Length + Age**	**< 0.001**	**909.94**	**538**	**0.12**
	Length	< 0.001	+ 5.44		
BF_2	*** Fluke Width**	**< 0.001**	**169.32**	**120**	**0.11**
	Length	0.007	+ 17.23		

The results of the Welch's t-test between whales from summer harvest to entrapment harvests found that each indicator (GM_2, GF_2, BM_2, BF_2) had a significant difference between the two groups, with whales from Husky Lakes having smaller girth residuals and smaller blubber thickness residuals when compared to whales of similar length or fluke width from the TN MPA (Fig. 3.6).

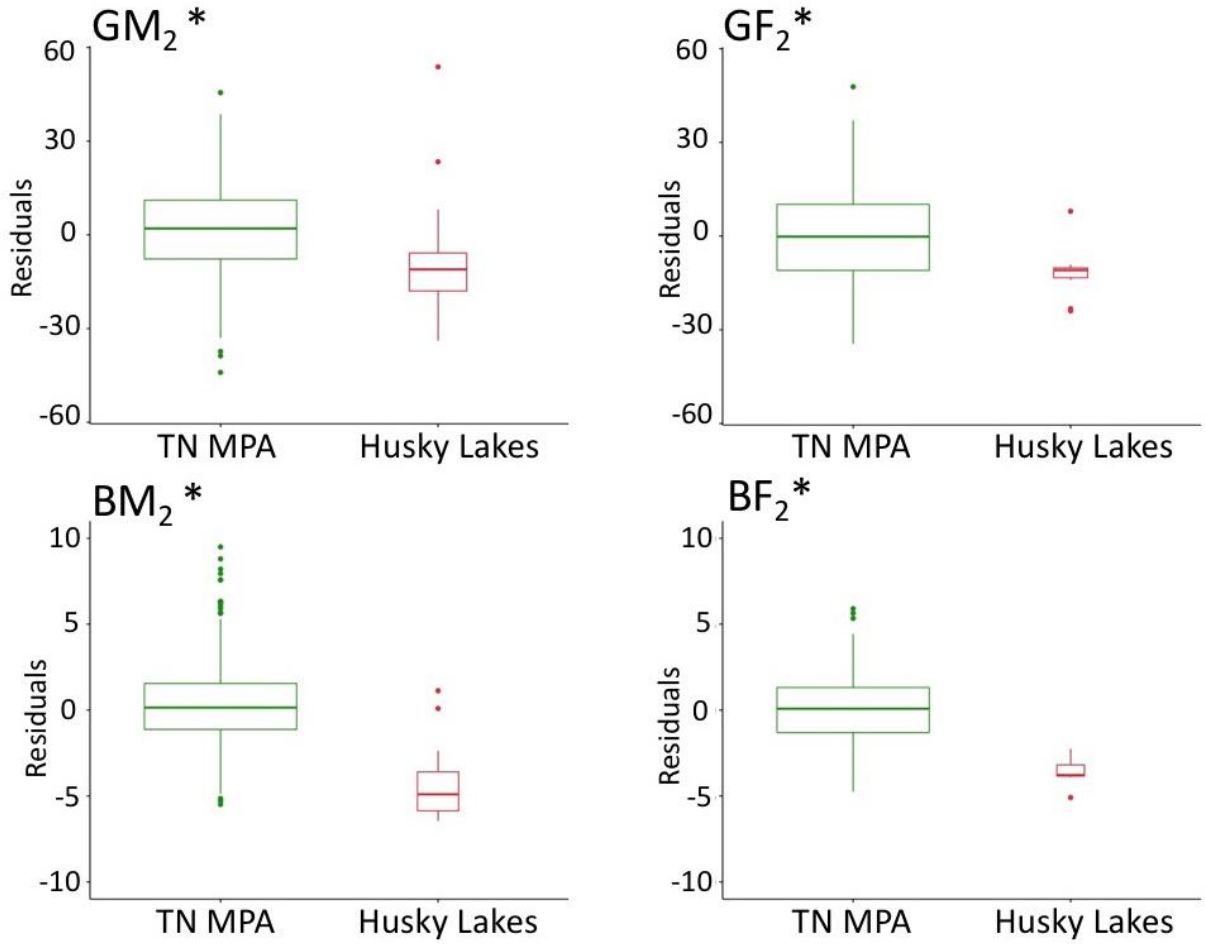

Figure 3.6: Comparison between belugas landed in the TN MPA (East Mackenzie and Kugmallit Bays from 2000-2015) to belugas landed from entrapment events (Husky Lakes from 1989,2006) using residuals from condition indicators (see Table 3.5). Box widths are proportional to the square root of the number of observations. A significant difference between two types of landings was found for all four body condition indicators (see table 3.6).

Table 3.6: Results of Welch's t-test between means of body condition indicator residuals for belugas landed in TN MPA to whales landed from entrapment events (see Fig. 3.6).

TN MPA vs HUSKY LAKES	t	df	*p*-value
GM_2	8.32	117.11	< 0.05 *
GF_2	4.50	14.00	< 0.05 *
BM_2	16.82	50.06	< 0.05 *
BF_2	10.47	8.33	< 0.05 *

3.4 Discussion

The two body condition indicators, blubber thickness and girth, were evaluated to better understand their use as indicators for monitoring the EBS beluga whales harvested in the ISR. The four indicators account for beluga age, size, location, and timing of harvest in determining the variation of blubber thickness and girth. Three of the indicators, GM, GF, and BM contain both temporal and spatial factors, indicating a significant annual and harvest location influence on condition. Harwood et al. (2014) identified that annual patterns were important when evaluating blubber thickness and found a slight decrease in the yearly mean blubber thickness for male belugas whales harvested within the TN MPA from 2000-2007. Choy et al. (2017) compared blubber thickness and girth condition indicators for EBS whales harvested from two regions of the TN MPA (KUG and CEN) and one outside of the TN MPA from 2011-2014, and found annual changes in both indices. Our findings align with these previous findings; however, our findings also reveal that location of harvest is important for GM, GF, and BM. In contrast, the BF indicator only includes a morphometric factor, fluke width. Fluke width was correlated to standard length in this study as well as in sampled belugas from West Greenland (1985-1992) (Heide-Jørgensen and Teilmann, 1994). All body condition indicators included a morphometric measurement to account for the influence of overall size on blubber thickness and girth measurements in keeping with Choy et al. (2017), who also included identified length as a significant covariate for blubber thickness and girth. Although fluke width was selected for BF, it can be substituted by length recognizing that the adjusted linear model has a slightly lower fit compared to fluke width.

Limitations in data and body condition indicators are important to consider in terms of how they affect the results and use of these metrics as indicators. First, both data exploration and field experience found that when blubber thickness and girth are recorded, these measurements are often rounded to the nearest quarter inch. This rounding of blubber thickness measurements has a relative error that is approximately 0.072% for male belugas. In comparison, the rounding of girth has a relative error that is 0.006% for male belugas. The rounding of blubber thickness impacts the overall indicator fit as demonstrated by the relatively low adjusted R^2 and hatched residuals compared to the girth indicators, that have a higher adjusted R^2 and normal residuals. Although we cannot correct the rounding, it is an important consideration that future monitoring collect blubber thickness in smaller length increments to improve the ability of this metric to capture change.

Second, due to hunter preference, 75.2 % of beluga whales sampled are male in our dataset (Table 3.2), which has been noted in previous research (e.g. Bell and Harwood, 2012; Harwood et al., 2002). Thus, the male body condition indicators use more samples than females, and contribute to better indicator fits as demonstrated by the R^2 values for GM and BM (Table 3.4). However, monitoring female belugas for changes in condition is highly important because a decline in body condition may signal current or future changes in reproduction rates, which would impact the entire EBS population (Laidre et al., 2008; Stirling, 2002). The lower sampling of females may affect the robustness of condition indicators and changes may not be captured or the interpretation of long-term condition trends will lack confidence.

Third, the number of sampled beluga whales across the three regions of the TN MPA are uneven (Table 2). Kugmallit Bay (KUG), accounts for 69.0 % of the sampled beluga whales within the TN MPA (Table 2), that is the location for both Hendrickson Island and East Whitefish and is often used by hunters from Tuktoyaktuk and Inuvik. These sites have an established co-monitoring program between FJMC and DFO that lends to the consistent sampling at these sites. In contrast, the community of Aklavik, who harvest in the western region (WES) of the TN MPA, is experiencing a decline in beluga harvests compared to the other two regions (FJMC, 2013). Detailed information on this complex issue can be found in a study requested by the community (Worden, 2018). Continued sampling from the western region of the TN MPA as well as outside the TN MPA boundaries will allow future research to test if these differences detected hold true or if they are the results of limited sampling. Overall, the recognition of all these limitations of the data contribute to the development of indicators, as managing bodies will be informed about the benefits and caveats of using these condition metrics.

3.4.1 Influence of Harvest Location

The influence of harvest location for both GM and BM was significant, as belugas harvested from the WES area of the TN MPA were significantly smaller from both CEN and KUG areas (Table 3.4, Fig. 3.4). One potential driver for the variation in condition between the TN MPA areas may be linked to hunter selection as each region is often used by specific communities (Inuuvik Community Corporation et al., 2006). The community of Aklavik typically utilizes camps in WES, the community of Inuvik typically utilizes camps in CEN and both communities of Inuvik and Tuktoyaktuk typically utilize camps located in KUG (Inuuvik Community Corporation et al., 2006). There are many external factors that influence the hunter selection of belugas and we are not able to quantify their effects on beluga selection in this paper. A few examples of such factors include differing subsistence needs and the difference in access to the hunting waters by each community (Harwood et al., 2002). In addition, environmental factors such as weather, storms, and wind will impact the ability to hunt and select belugas (Harwood et al., 2002).

The difference of EBS beluga condition within the TN MPA may also be influence by environmental factors such as the difference in spring time arrival of the belugas into the three areas (Hornby et al., 2016). The movement of sea ice including fractures and breaking up of landfast ice effect when belugas are observed to enter the TN MPA (Fraker, 1977; Hoover et al., 2016; Hornby et al., 2016; Loseto et al., 2018). Past observations suggested that belugas enter the TN MPA areas approximately at the same time (Fraker, 1977). However, from 1972-1984, the average day that the western ice barriers, which block access to Mackenzie Bay and Shallow Bay, broke are June 24-25, which is 1 week before they break above Kugmallit Bay on July 2-3 (Norton and Harwood, 1986). The Arctic, including the Beaufort Sea and Mackenzie Estuary, is a region impacted by climate change, and one change is the timing of sea ice breakup (Barber et al., 2008, 2012). From 2011 to 2013, the ice barriers broke earlier across the TN MPA, the approximate break day in Shallow Bay was June 21- 22, while the approximate break day in Kugmallit was June 24-28th (Hoover et al., 2014; Hornby et al., 2014). The observed earlier ice break-up over the Mackenzie Estuary may be driven by local spring warming and decline in snowfall (Lesack et al., 2014), and continued climate change in the region will continue to impact beluga access to the TN MPA. We are not able to determine whether human, environmental or other factors are driving the difference in EBS beluga condition across the TN MPA, but location must be considered for male belugas for developing condition indicators. In contrast, both indicators for females blubber thickness and girth revealed that there was not a significant difference in either condition metric between belugas landed across the three regions. Thus, all females landed in the TN MPA can be assessed together to develop condition indicators.

The second spatial variation test was between belugas landed within the TN MPA and those landed outside the TN MPA boundaries. We found that all indicators GM, GF, BM, and BF were significantly different between the two areas. The mean indicator value for BM, GF, and BF were less than those from whales harvested outside the TN MPA, compared to whales harvested inside the TN MPA. Whereas the mean indicator value for GM was larger for whales harvested outside the TN MPA compared to TN MPA harvested whales. Loseto et al. (2006) found that EBS belugas are segregated by age, size, and reproductive groups while summering in the Beaufort Sea, that support the variation in condition across the two regions. Beluga harvested in communities beyond the TN MPA (Sachs, Ulu and Paulatuk) occur less frequently, but these belugas provide additional information about this population. Beluga whales are considered 'sentinel species' and although the monitoring program is specific to the TN MPA, EBS whales are not restricted to those waters (Moore, 2008). Monitoring belugas outside of the TN MPA is an opportunity to capture additional changes in individual condition. Also, continued opportunistic sampling of harvested belugas beyond the TN MPA will be valuable for monitoring the health of the overall population. Due to the influence of location on condition on all four indicators, it is recommended to use belugas harvested from the CEN and KUG regions to develop indices, as the location of harvest on these belugas does not influence body condition from 2000-2015.

3.4.2 Proposed Indicator Threshold

The rare occurrence of belugas sampled from entrapment events provided an opportunity to compare the condition of these whales to belugas from the regular, summer harvest. Both GM_2 and BM_2 indicators had length and age as the two significant factors, similar to Choy et al. (2017) who found a blubber thickness indicator that included length and age. The most significant predictor for both GF_2 and BF_2 was fluke width. For all four indicators, we confirmed that the entrapped whales have a significantly smaller mean blubber thickness and mean girth (Figure 6, Table 6). There appears to be a greater overlap between the good and poor condition for the girth indicators compared to the blubber thickness indicators, which is expected as girth metrics will capture changes across blubber thickness, muscle, and other lipid storage layers. Importantly, these two condition groups can be used to develop thresholds for condition indicators, recognizing the assumption that whales harvested from 2000-2015 represent good condition.

3.4.3 Comparison of Body Condition Indicators

Many papers address the importance of first developing criteria to select indicators for monitoring, referred to as a top-down approach because management determines needs (Hayes et al., 2015; Rice and Rochet, 2005; Vandermeulen and Cobb, 2004). Summaries of the wide-range of potential criteria to be used to select indicators (e.g: Boldt et al., 2014; Niemeijer and Groot, 2008) demonstrate that although indicators themselves are meant to be simple measurements, even the process to select the 'best' indicators can be complicated from the onset. The TN MPA Monitoring Plan (2013) refers to three criteria for selecting indicators; 1) simplification of more complex situations; 2) quantification and qualification of state or trends based on thresholds/limits; 3) and communication of complex information in a simple set of metrics (FJMC and DFO, 2013a). We will use the first two criteria to assess blubber thickness and girth metrics as potential indicators for the TN MPA.

The assessment of beluga body condition is a simplification of the overall beluga health, and changes in condition indicators may reflect changes in prey, an injury or illness, or another environmental change (Burek et al., 2008; George et al., 2015 ; Laidre et al., 2008; Moore, 2008). But alone these simple measurements of blubber thickness and girth do not explain why changes in condition are occurring, thus to understand changes in condition requires additional information (Loseto et al., 2018). Blubber thickness is a common measure for body condition of marine mammals (Burek et al., 2008; George et al., 2015; Harwood et al., 2015; Noren et al., 2015; Strandberg et al., 2008; Williams et al., 2013). Blubber serves many roles for marine mammals such as a storage site for lipids, regulates body temperature, and assists with streamlining (Koopman et al., 2002; Noren and Mangel, 2004; Ryg et al., 1988; Worthy and Edwards, 1990). However, the metabolism of blubber may not occur evenly throughout a marine mammal, as certain areas such as the chest region, may be metabolized prior to other body regions (Koopman et al., 2002; Noren et al., 2015; Ryg et al., 1988). Also, marine mammals may limit the metabolism of lipids in blubber, to ensure that the blubber does not lose thermoregulatory capacity, by metabolism of other sites of lipids such as around organs (Noren and Mangel, 2004). Therefore, girth is an alternative measure, since it will capture changes in blubber thickness as well as other lipid sites, and muscle (George et al., 2015). Both blubber thickness and girth simplify overall health of an EBS beluga based on body condition, although they may not capture the same trends since the body condition indicators (GM, GF, BM, BF) are only moderately correlated.

Second, these analyses included data from ten years of monitoring prior to the establishment of the TN MPA and five years' post-establishment. This range provides a sufficient range of data to begin to identify trends. The assessment that compared 'good condition' belugas to 'poor condition' belugas supports the observations that the entrapped belugas have a significantly poorer condition for blubber thickness and girth metrics, regardless of sex. Also, these two condition groups can be used to develop thresholds. However, the difference between condition groups is smaller for girth compared to blubber thickness. Thus, thresholds for blubber thickness index may be easier to interpret. Lastly, the GM and GF indicators both had higher adjusted R^2 values compared to BM and BF, that suggests that overall, both girth indicators are better fits for the data than blubber thickness. We have already addressed one reason for the lower fit for blubber thickness indicators, that is an artifact from the rounding of blubber thickness measurements during collection. In summary both metrics have limitations and benefits, blubber thickness thresholds are easier to interpret, yet girth indicators are better explained by the predictor variables.

This paper has taken steps towards developing condition indicators to be used to monitoring the health of the EBS beluga by looking at the factors that influence the variability of blubber thickness and girth and identifying thresholds. However, in the process, mirroring the challenge with developing indicators is the ability to narrow complex ecosystems and interactions into a simple metric. Indicators sit at the interface of science and policy, and the requirement to act as a transboundary tool between these two frames only contributes to the challenge in selecting appropriate metrics (Eijsackers et al. 2007; Link, 2005). Other suggested indicators of health for EBS belugas in the TN MPA includes monitoring containments, disease, parasites, abnormalities, stress, and fatty acids (Loseto et al., 2010). These may be useful in conjunction with body condition to explain changes in condition. However, there is a unique opportunity to improve the use of condition indices by assessing trends along with other beluga health research in the region that involve traditional and local Inuvialuit knowledge. Ostertag et al. (2018) have identified indicators used by hunters to determine the health of a harvested beluga within the ISR that include observing diving behaviour, texture and colour of blubber, texture of meat, and the condition of other organs. There is an opportunity to unite both simple condition metrics with hunter and traditional knowledge for an overall better understanding of beluga health. The TN MPA beluga monitoring program was founded with the interest of bringing together local Inuvialuit knowledge with scientific knowledge, and the success of the long-term program is due to the joint involvement of local harvesters, the Fisheries Joint Management Committee, Fisheries and Oceans Canada, and the local Hunters and Trappers Committees (Bell and Harwood, 2012; Harwood and Smith, 2002). By bringing these complementary ways of understanding beluga health together, monitoring of the belugas will be meaningful to both the local harvesters, communities, and managing agencies (Loseto et al., 2018).

Belugas are moderately sensitive marine mammals because they have the flexibility to cope with changes in sea ice and diet (Laidre et al., 2008). But as a long-living species that migrates over long distances, changes detected in condition may inform management about specific changes their migration, over-wintering grounds, or previous summers (Moore, 2008). Not yet resolved is the temporal variation detected by the body condition indicator and if variation can be linked to environmental changes. These next steps will provide more information for the co-management boards to select a EBS health indicator for beluga whale body condition in the TN MPA.

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Chapter Four: **DEVELOPING AN INDICATOR PART II: UNDERSTANDING TRENDS AND VARIABILITY OF BELUGA WHALE BODY CONDITION AND INFLUENCE OF LARGE-SCALE CLIMATIC DRIVERS**

MacMillan, K., Hoover, C., Iacozza, J., Peyton, J., Loseto, L. 2019. Developing an Indicator Part II: Understanding Trends and Variability of Beluga Whale Body Condition and Influence of Large-Scale Climatic Drivers. Polar Biology (in preparation).

Abstract

The development of indicators for marine management is a challenging task due to ecological complexities and the managerial desire for simplification. Describing trends captured by indicators is a key step in determining their usefulness. This research uses previously developed body condition indicators, blubber thickness and girth to assess body condition trends over time from harvested Eastern Beaufort Sea belugas (*Delphinapterus leucas*) from 2000 to 2015 to: (1) examine both the harvest season and inter-annual trends of EBS beluga body condition; (2) compare trends between each body condition index; and (3) test climate variability metrics (Pacific Decadal Oscillation (PDO), sea-ice minimum (SIM), and (Arctic Oscillation) that may impact the EBS belugas across their home range for potential influence on body condition. Results indicate that there is a significant decrease in the female girth index and a significant increase in the male blubber thickness index over a harvest season. Both girth indices (male, female) and blubber thickness indices (male, female) are highly correlated to each other, demonstrating that condition changes hold across sexes. However, there are differences between condition indices for the same sex, as male blubber thickness index lags the girth index by 2 years and the female blubber thickness index lags the girth index by 3 years. The male girth index was selected as the body condition indicator to test with climate variability metrics. EBS beluga body condition has a significant negative relationship with both PDO and SIM. Overall, body condition is a simple measure collected on harvested whales but understanding the information captured by these metrics is complicated. It is important that body condition indicators are assessed with other indicators of health including hunter observations and bio tracers, to better understand the changes captured by beluga body condition indicators.

4.1 Introduction

"An indicator, no matter how good, presents only a part of a part of the picture." F. Khan (2014)

In recent decades, there has been growing interest and research around the management potential of ecological indicators because of the need to make informed decisions on highly complex ecosystems (Hirvonen, 1992; Niemi and Mcdonald, 2004). The diverse application of indicators has resulted in a wide breadth of definitions, complicating what exactly an indicator is or can be (Heink and Kowarik, 2010). However, the range and adaptability of definitions enables indicators to employ flexibility in their application. Ecological indicators can either be a measurement from a single variable or a combination of many variables from the ecosystem, that are used to signal or simplify complex processes and assist with decision-making (Bernstein, 1992; Bockstaller and Girardin, 2003; Girardin et al., 1999). Indicators can provide a current-state measure that may be used as an early-warning system or to assist with determining the cause of change in the variable of interest (Dale and Beyeler, 2001; Nusser et al., 1998). In general, the indicator, whether an abiotic or biotic feature of the ecosystem should represent information beyond what is being measured and a carefully selected suite of indicators is recommended to avoid over-simplification (Dale and Beyeler, 2001; Hayes et al., 2015; Rice and Rochet, 2005).

One aim of an ecological indicator is the ability to capture a trend; but assessing indicator trends has been criticized due to the need to meet both ecological and statistical requirements (Bernstein, 1992; Dixon et al., 1997; Stow et al., 1998). These concerns can challenge the application and the use of indicators for monitoring and management (Dale and Beyeler, 2001). For instance, when examining long-term trends for indicators derived in ecological systems, the impacts of seasonal variation, multi-year trends, anthropogenic forcing and a lag in detection must be considered (Bernstein 1993; Dayton et al., 1998; Dixon et al., 1997). In addition, determining baseline values for indicators can be a challenge because for some indicators, it is a subjective decision for what is normal (Niemeijer, 2002). One suggestion for research is to focus on describing the trends and uncertainty of the indicator rather than being deployed for hypothesis testing (Dixon et al., 1997). Overall, detailed descriptions of the steps taken during indicator development and trend assessment should be noted because this process will move indicator development forward from realm of theoretical frameworks proposed in the literature to the more practical application in the field (ex: Boldt et al., 2014; Hayes et al., 2015; Rice and Rochet, 2005) Here, we detail the process in developing an indicator for the Tarium Niryutait Marine Protected Area (TN MPA).

The TN MPA, located in the Inuvialuit Settlement Region (ISR), was established in 2010 and is one of many newly established MPAs in Canada. While MPAs are usually faced with unique monitoring challenges resulting in the lack of long-term data that hinders the ability to establish baseline or long-term trends (Edwards et al., 2010), the TN MPA is home to a community-based monitoring program established in 1973 (Harwood et al., 2002). The TN MPA was established to protect the areas in Mackenzie estuary where large aggregations of the Eastern Beaufort Sea (EBS) belugas (*Delphinapterus leucas*) return to each summer (Harwood et al., 1996). The TN MPA also protects the highly important subsistence harvest of EBS belugas for the Inuvialuit from oil and gas development (Harwood et al., 2002). Indicators that inform about EBS beluga health are a high interest for TN MPA management (FJMC and DFO, 2013). Of the original 82 prioritized indicators proposed to monitor the TN MPA in 2010, 16 focused on the health of EBS beluga, including a body condition indicator: blubber thickness (DFO, 2010).

Body condition refers to the size of energy stores of an individual and has been used to assess the health of Arctic marine mammals such as seals, polar bears, walruses, and bowhead whales (George et al., 2015; Harwood et al., 2012; Kingsley and Byers, 1998; Stirling, 2002; Williams et al., 2013), and changes in condition have been linked to changes in prey, disease, stress, or an environmental change (Burek et al., 2008; George et al., 2015; Laidre et al., 2008;

Moore, 2008). Specifically, blubber thickness had been used as a measure of body condition (Choy et al., 2017; George et al., 2015; Harwood et al., 2014; Ryg et al., 1988; Williams et al., 2013), and serves as an energy store for marine mammals, but is important for thermoregulation, buoyancy, streamlining (Koopman et al., 2002; Noren and Mangel, 2004; Ryg et al., 1993; Strandberg et al., 2008). Girth, a measure of the circumference around a specified region of the body, has been recommended as an alternative metric of body condition for bowhead and beluga whales. This is because it not only captures changes in blubber, but also changes in the muscle and other lipid storage sites within the body (Choy et al., 2017; George et al., 2015).

A slight decline in the mean blubber thickness of adult male EBS belugas was detected from whales harvested in the TN MPA from 2000-2007 and 2011-2014 (Choy et al., 2017; Harwood et al., 2014). Choy et al. (2017) also developed a body condition index for EBS beluga maximal-girth that did not detect a decline from 2011-2014. An analysis of the long-term trends is required to determine if the previous blubber thickness decline is part of a long-term trend or inter-annual variation. There is also a need to compare the long-term temporal trends of maximal-girth and blubber thickness to determine if the dissimilarity in trends found by Choy et al. (2017) continues.

It is valuable to establish if trends captured by indicators are influenced by natural, climatic factors or from anthropogenic forcing (Bernstein, 1992; Dayton et al., 1998). Links between ecosystems and climatic conditions have been established (Saether, 1997); for example, shifting climatic regimes have been hypothesized as the driver in the population decline of the North Pacific Steller sea lion (*Eumetopias jubatus*) by affecting sea lion growth and body condition by altering prey availability (Benson and Trites, 2002; Trites et al., 2007). Large-scale climatic variability impacts marine ecosystems through complex mechanisms that link variables such as temperature and precipitation with biological communities (Benson and Trites, 2002;

Mantua et al., 1997). Climate variability metrics were selected from across this home range to assess for relationships since the EBS belugas spend most of their lives outside of the TN MPA (Loseto et al., 2018b). Research indicates that the growth and survivorship of the EBS belugas are not affected by large-scale climate variations, supporting the belief that belugas are less sensitive to environmental change (Laidre et al., 2008; Luque and Ferguson, 2009). If a response in an EBS beluga body condition is detected, the exact ecological mechanisms driving the response are likely to remain unknown because responses can be cumulative between natural and human influences or may be delayed in detection (Beckerman et al., 2002; Benson and Trites, 2002; Francis et al.,1998; Moore, 2008).

Since previous assessments on blubber thickness (Harwood et al., 2014), seven more years have been added to the long-term monitoring dataset and the linear model approach demonstrated by Choy *et al.,* (2017) accounts for variation in beluga size and age. Building upon the analyses on EBS beluga body condition in Chapter 3, here we aim to assess the temporal in body condition trends from harvested EBS belugas from 2000 to 2015 to: (1) examine both the harvest season and inter-annual trends of EBS beluga body condition; (2) compare trends between each body condition index; and (3) test three climate variability metrics that impact the EBS belugas across their home range (Pacific Decadal Oscillation (PDO), sea-ice minimum (SIM), and (Arctic Oscillation) for potential influence on body condition.

4.2 Methods

Every summer, thousands of EBS belugas return to their summering waters in the Beaufort Sea, including the Mackenzie Estuary and the TN MPA. This genetically distinct population has an estimated maximum of 39,258 individuals and are one of the farthest migrating population of the five populations that are believed to winter in the Bering Sea (Fig.

4.1) (Allen and Angliss, 2014; Citta et al., 2017; O'Corry-Crowe et al., 1997). The EBS belugas begin their journey in early April, passing through the Bering Strait and migrating through the Chukchi Sea along the Alaskan coast (Citta et al., 2017; Richard et al., 2001). They arrive to the Beaufort Sea, where many pass through the Mackenzie Delta from late June to early August (Hornby et al., 2014; Richard et al., 2001). The return of the EBS beluga to the Mackenzie Delta is important for both traditional practices and provides food security for Inuvialuit communities, and was the motive for the establishment of Canada's first Arctic marine protected area (Harwood et al., 2002)

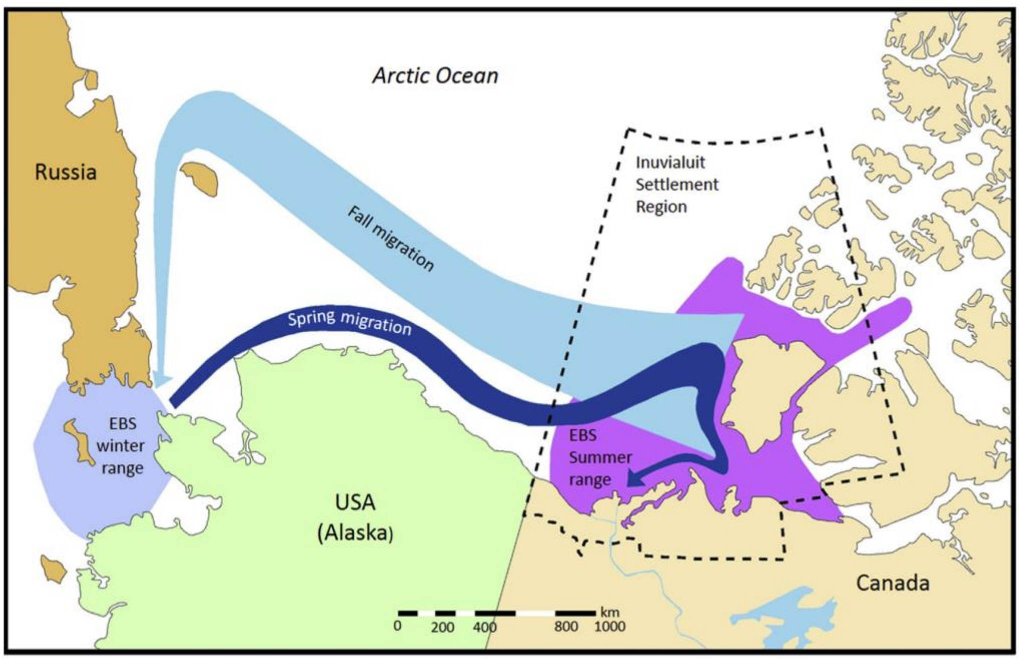


Figure 4.1: The home range of the Eastern Beaufort Sea beluga. Figure modified from Loseto et al. (2018).

4.2.1 Data Collection

The data used in this study were collected as part of community-based beluga monitoring program in the TN MPA established in 1973 (Harwood et al., 2002). The Inuvialuit hunters are foundational in the implementation of the program, the recording and collecting EBS beluga data, and the recording environmental observations (Harwood et al., 2002). Blubber thickness and maximal half-girth measurements, hereinafter referred to simply as girth, have been collected as part of the beluga monitoring program since 2000. Blubber thickness is measured at the center of the chest between the pectoral fins. Girth is measured from the mid-chest to the dorsal ridge behind the pectoral fins. Significant spatial differences in beluga body condition metrics were detected in Chapter 3 between the three regions of the TN MPA. Whales sampled from the Okeevik (East Mackenzie Bay) and Kittigaryuit (Kugmallit Bay), which are the central and eastern regions of the TN MPA, were selected for the following analyses because the body condition belugas sampled from these two regions were not significantly differently. These two regions of the TN MPA have numerous hunting camps within them, but most hunters that land belugas within these regions are from two of the Inuvialuit communities, Inuvik and Tuktoyaktuk.

4.2.2 Body Condition Indicators

In Chapter Three, multiple linear regressions were used to develop four sex-specific EBS beluga body condition; girth male (GM), girth female (GF), blubber thickness male (BM), and blubber thickness female (BF), using morphometric and age variables (Table 4.1). A stepwise regression method was used to select the final four model based on the Akaike Information Criterion (AIC) scores (Table 4.1).

Table 4.1: The four sex-specific beluga body condition indicators used. See Chapter 3 (Table 3.6) for detail on indicator selection process.

Sex-Specific Body Condition Index	Linear Model Predictors
Girth Male (GM)	Length+ Age
Girth Female (GF)	Fluke Width
Blubber Thickness Male (BM)	Length + Age

Blubber Thickness Female (BF)	Fluke Width

4.2.3 Temporal Trends and Variation

Variation and trends in EBS beluga body condition was assessed at two temporal scales, within a season and across seasons. Hunters from three ISR communities (Inuvik, Tuktoyaktuk, and Paulatuk) use blubber thickness as an indicator of beluga health (Ostertag et al., 2018). Also, we were recommended to assess blubber thickness for seasonal changes by hunters because they use ‘mid-July’ as the date during the EBS beluga harvest in which whales landed after that date should be fatter (i.e. have thicker blubber) (John Noksana Jr. pers. comms). We tested these observations to determine if this seasonal change in EBS beluga condition is captured by the blubber thickness indices, as well as both girth indices although this metric was not directly referenced by hunters. We first tested harvest dates to determine if the mean-day of harvest aligns with the hunter observed mid-July date. Whales were divided into two groups, whales landed before the mean-day of harvest were labeled as ‘Pre’ and belugas harvested on and after this date were labeled as ‘Post’. Welch’s t-tests were performed on each of the four condition indicators (GM, GF, BM, BF) between ‘Pre’ and ‘Post’ belugas and statistical significance was considered at a p value < 0.05 for all analyses.

The interannual trends for each of the four indicators were visually examined by developing plots that used the annual mean and 95% confident intervals from 2000-2015 for GM, GF, BM, BF. Included on each plot was the proposed poor condition threshold that was previously derived in Chapter 3. This proposed poor condition threshold, which is specific to each body condition indicator, was included to evaluate whether it was passed in any year.

Table 4.2: Proposed body condition thresholds for each of the four sex-specific beluga body condition indicators (Girth Male (GM), Girth Female (GF), Blubber Thickness Male (BM), Blubber Thickness Female (BF) derived in Chapter 3.

Husky Lakes	Mean	Lower Confidence Interval	Upper Confidence Interval
GM	-10.56	-13.12	-7.99
GF	-11.67	-13.50	-9.84
BM	-4.50	-4.88	-4.13
BF	-3.60	-3.79	-3.41

4.2.4 Indicator Correlation and Lag

To examine the relationships between the four body condition indicators, cross-correlation tests were used using the HMISC package and rcorr function (RStudio Team 2015, Version 0.99.903). First Pearson's product-moment correlation was used to evaluate temporal trends between males and females of the same index (GM, GF and BM, BF). Next, we tested temporal trends between condition indices for the same sex (GM, BM and GF, BF). Lastly, cross-correlation tests were performed between the four condition indicators to examine if any lag between condition trends can be detected using the ccf function (RStudio Team 2015, Version 0.99.903).

4.2.5 Climate Variability

Our third research objective was to examine three climate variability metrics that influence the home range of the EBS beluga, from their wintering waters to summering waters. The climate metrics selected were Pacific Decadal Oscillation (PDO) from the previous 12 months (July - June) and the winter average (December - March) of the Arctic Oscillation (AO) (https://www.esrl.noaa.gov/psd/data/climateindices/), as well as sea-ice minimum (SIM) for the

Canadian Beaufort Sea (https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/climatology/beaufort-sea-coverage-graph-1968-2016.html). The three climatic variability metrics were tested to determine if an association or lagged associations occurs with the beluga body condition trends. Changes in the PDO index has been linked to shifts in the distribution of species in the North Pacific and to EBS beluga mercury trends (Benson and Trites, 2002; Grebmeier et al., 2006; Loseto et al., 2015). Sea ice affects beluga whale habitat and sea ice conditions have been linked to changes in EBS beluga body condition from 2011-2014 (Choy et al., 2017; Heide-Jorgensen et al., 2010, Hornby et al. 2016). Lastly, although the influence of the AO index on sea ice in the Beaufort Sea is changing, the AO has been linked to changes in species distributions in the Arctic (Aanes et al., 2002; Stroeve et al., 2011). Cross-correlation between environmental drivers and condition were tested using the ccf function (RStudio Team 2015, Version 0.99.903).

4.3. Results

4.3.1 Temporal Trends and Variation

The mean Julian day of harvest was found to be day 198, which coincides as July 17th (July 16th on a leap year) (Fig. 4. 2). Belugas that were landed before day 198 were labelled as ‘Pre’ and whales landed on and after day 198 were labelled as ‘Post’. The seasonal comparison of condition indicators GF and BM found there was a significant difference within a season, while no significant difference was found for GM and BF (Table 4.3). Male belugas landed after day 198 had a slightly larger mean blubber thickness index compared to earlier in the season (Table 4.3). Female belugas landed after day 198 had a slightly smaller mean girth index compared to earlier in the season (Table 4.3).

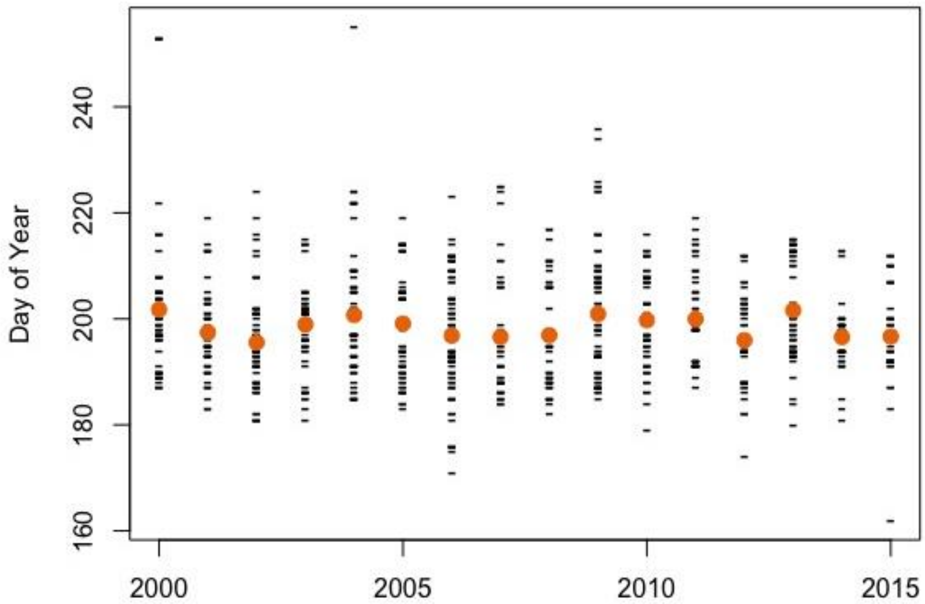
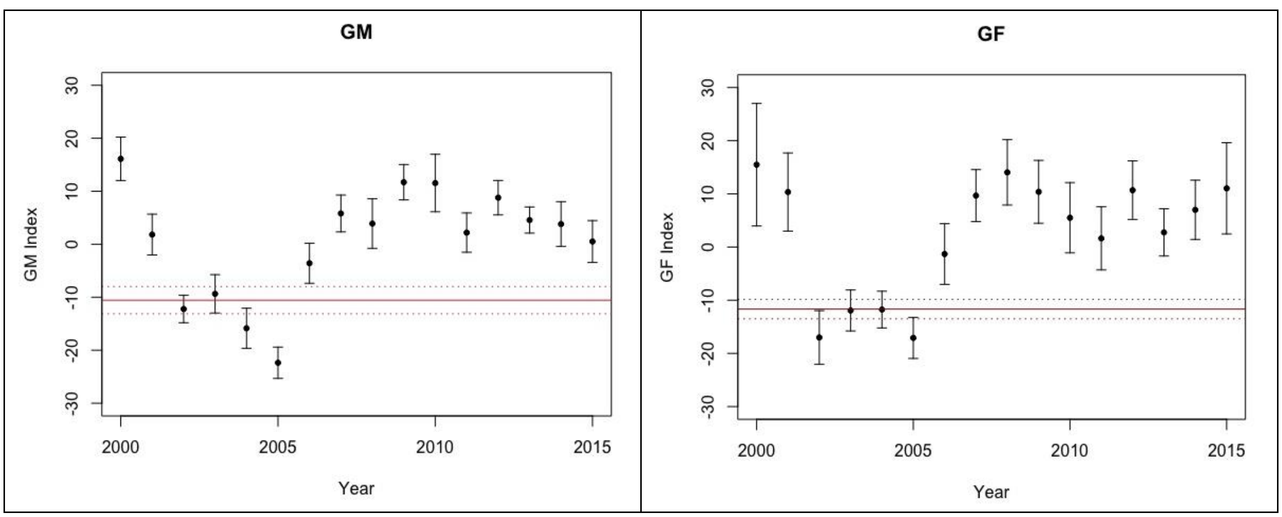


Figure 4.2: The day of year (Julien calendar) for whale landings from Kugmallit Bay (KUG) and East Mackenzie Bay (CEN) in the TN MPA from 2000-2015. The orange circle is the mean day of whale landings for each year. From 2000-2015, the mean day of harvest was day 198.

Table 4.3: The results from the Welch's t-test for seasonal comparison for each of the four body condition indicators. Two of the indicators, Girth Female (GF) and Blubber Thickness Male (BM) found a significant difference ($p > 0.05$) between condition of whales landed PRE-and POST of the mid-harvest date (July 17th) and are marked by *

Body Condition Indicators	GM	GF *	BM *	BF
t	+ 0.84	- 2.11	+ 2.25	+ 0.29
df	528.37	199.38	493.99	197.47
p-value	0.402	0.036 *	0.025 *	0.770
Mean in group PRE	- 0.43	+ 2.43	- 0.18	- 0.04
Mean in group POST	+ 0.59	-2.27	+ 0.26	+ 0.04
Overall Change in Group Mean	0	-	+	0

The indicators for males and females suggest a decline in girth from 2000 to 2005 (GM) or 2002 (GF) (Fig. 4.3). From 2002-2005, both girth indices from fall within the poor condition threshold. Following this period, both girth indices recover and remain above the poor condition threshold for the remaining years (Fig 4.3). The male girth index revealed high condition values in 2000, 2008, and 2009 that were not significantly different from each other. The female girth index revealed high condition values in 2000, 2008, 2012, 2015, but with the exception of the year 2000, the confidences intervals do not distinguish these highs from years occurring immediately prior or after. No overall linear trend was evident for either GM (adj. R^2: 0.03 *p* 0.23) or GF (adj. R^2: 0.06 *p* 0.18). The male blubber thickness index remains above the poor condition threshold throughout the sampling period (Fig. 4.3). The male blubber thickness index revealed two periods of high condition in 2002-2003 and 2009-2011, and low condition in 2000, 2005, and 2014. The female blubber thickness index reveals condition highs in 2000 and 2009-2011. The female blubber thickness index revealed two lows in 2007 and 2014, the latter which crossed into the poor condition threshold (Fig. 4.3). No overall linear trend was apparent for BM (adj. R^2: -0.07 *p* 0.89) or BF (adj. R^2: -0.05 *p* 0.70).



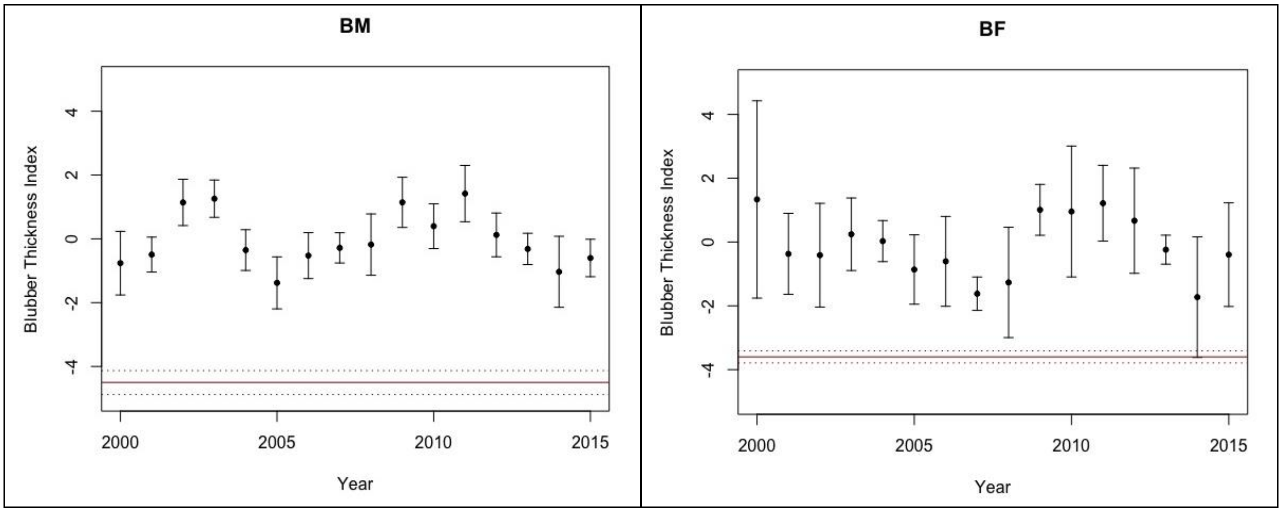


Figure 4.3: Inter-annual trends for Girth Male (GM), Girth Female (GF), Blubber Thickness Male (BM), Blubber Thickness Female (BF) as represented by yearly mean index values and 95% CI. The red lines represent the poor condition threshold proposed in Chapter 3 as developed from Husky Lakes entrapments in 1989 and 2006 (Table 4.2).

4.3.2 Indicator Correlation and Lag

Tests show that trends in condition indicators are correlated between sexes, whereas condition indicators for the same sex are not significantly correlated (Table 4.4). Cross-correlation tests to determine lag between male indicators and between female indicators show that BM lags GM by 2 years, although the *p* value is 0.6. Lastly, BF lags GF by significant 3 years (Table 4.4).

Table 4.4: Results of correlation and cross-correlation tests on four body condition indicators. The most significant relationships are shown. There is a significant correlation between Girth Male (GM) and Girth Female (GF) with no lag, and a significant correlation between Blubber Thickness Male (BM) and Blubber Thickness Female (BF) with no lag.

Indicators Tested	Correlation value (r)	*p* value	Lag *(Years)*
GM -> GF	0.89	< 0.05	0
BM -> BF	0.52	< 0.05	0
BM -> GM	0.51	0.06	2
BF -> GF	0.65	< 0.05	3

4.3.3 Climate Variability

Each of the climatic variability metrics (PDO, AO, SIM) were plotted against EBS beluga body condition (Fig 4.4) and cross-correlations were calculated (Fig 4.5). Only one of the four proposed body condition indicators were selected to this test, based on the above results. We selected GM as the representative body condition indicator as it can represent change across all four condition metrics. The cross-correlation plot between PDO and body condition shows that best-fit was a zero-year lag with a negative relationship (Fig. 4.5.A). The regression plot between a zero-year lagged PDO and body condition was significant (R^2= 0.21 and p=0.042) (Fig 4.6.A). The cross-correlation plot between SIM and body condition shows that best-fit was a two-year lag with a negative relationship (Fig. 4.5.A). The regression plot between a two-year lagged SIM and body condition was significant relationship (R^2= 0.31 and p=0.015) (Fig 4.6.B). The cross-correlations between GM and AO reveals that the best-fit was a one-year lag with a positive relationship (Fig 4.5.C). The regression plot between a one-year lagged AO and body condition was non-significant (R^2= -0.02 and p=0.43) (Fig 4.6.C)

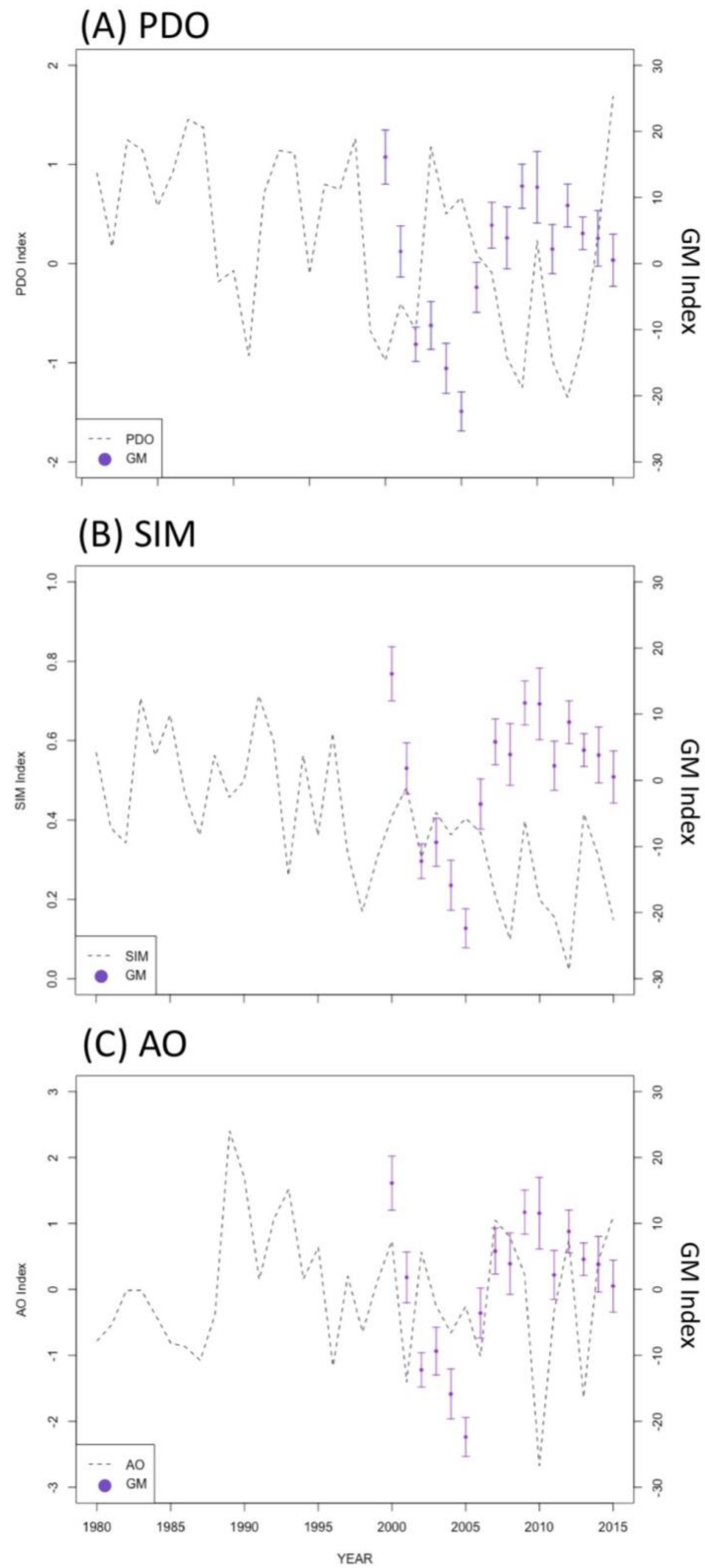


Figure 4.4: Inter-annual plots of mean PDO, SIM and AO (dotted black line) with mean GM and 95% CI (purple dots and lines).

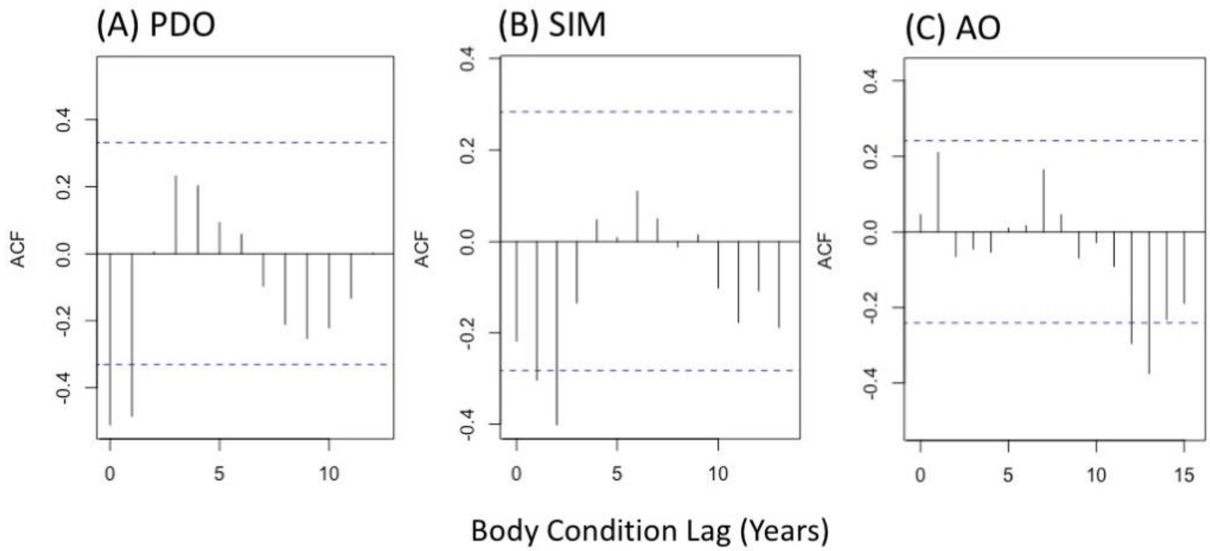


Figure 4.5: Results of cross-correlations between selected PDO, SIM and AO metrics with mean GM. The most significant lag for body condition with PDO and SIM was zero years and two years (respectively). No statistically significant lag was found for AO within 10 years.

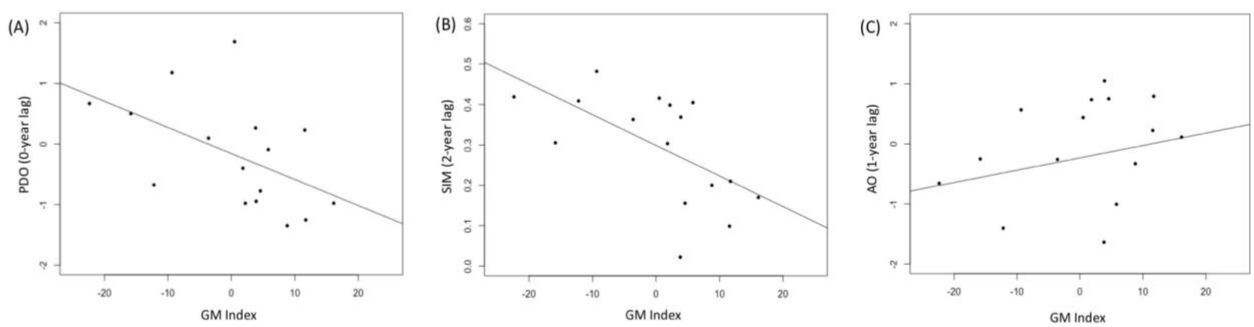


Figure 4.6: Best fit correlations of the three environmental drivers to beluga whale body condition (girth male index). A: Pacific Decadal Oscillation (PDO) demonstrates a negative relationship at a zero-year lag ($p < 0.05$) B: Beaufort Sea (Canada) Sea Ice Minimum (SIM) demonstrating a negative relationship at a two-year lag ($p < 0.05$) and C: The Arctic Oscillation (AO) demonstrating non-significant relationship with a one year lag ($p = 0.43$). See Table 4.5 for regression details.

Table 4.5: Results of linear regression and correlation between mean body condition (GM) and three climatic variations (PDO, SIM, AO)

	Most significant lag	Slope	Intercept	Adjusted R^2	*p*-value	Pearson's correlation (r)
PDO	0	- 0.04x	- 0.16	0.21	0.042	- 0.51
SIM	2	- 0.007	+ 0.3	0.31	0.015	-0.6
AO	1	+ 0.02	- 0.23	-0.02	0.43	0.21

4.4 Discussion

This research is the second stage in the development of body condition indicators to monitor beluga health from harvested whales in the TN MPA. We found significant seasonal trends in two body condition indices; male blubber thickness and female girth, and revealed the long-term temporal trends in the four body condition indices. We also found that two of the three large-scale climatic variability metrics, PDO and SIM, correlated with beluga body condition from 2000-2015.

4.4.1 Seasonal Changes in Condition

The male blubber thickness index had a significant increase from early to late season, supporting observations made by hunters from three ISR communities, two of which harvest within the TN MPA, Inuvik and Tuktoyaktuk. These hunters observe that blubber thickness changes throughout the season, with thinner blubber thickness observed in early July and thicker blubber thickness observed in late July (Ostertag et al., 2018), verifying the seasonal trend captured by blubber thickness indicator. The seasonal increase in blubber thickness suggests that whales harvested in the TN MPA later in the season, may reflect those who had longer time to feed in the summering waters and able to increase their condition relative to earlier arrivals (Lockyer,1987). Seasonal fluctuations in beluga blubber thickness have also been observed by hunters from the eastern Arctic in Nunavik (Breton-Honeyman et al., 2016). The opposing trend captured by the female girth index is puzzling and worth future investigations.

4.4.2 Long-term Trends in Body Condition Indicators

A key step in the development and assessment of indicators is the evaluation of long-term trends or patterns, and it has been recommended to describe these trends and the uncertainty observed (Bernstein, 1992; Niemi and Mcdonald, 2004). The following descriptions are general observations that simplify the complicated interannual variation captured by each indicator. Both male and female girth indices revealed declines that cross the poor condition threshold from 2002-2005 that then recovered in 2006 to remain above the poor condition threshold for the remaining years. Previous research on the EBS belugas has not noted the decline in the girth of harvested belugas from 2002-2005 (ie: Choy et al., 2017; Harwood et al., 2014; Inuuvik Community Corporation et al., 2006; Luque and Ferguson, 2010). The female girth index has wider, overlapping confidence intervals, making it difficult to assess the indicator sensitivity. It would be valuable for future investigations to review both past hunter observations and speak with community members about these years. A long-term trend is not apparent for either girth index, but continued monitoring will help to understand the annual variation captured by both indices. It is also important to note that both girth indices recovered after the period of poor condition, signalling the potential of belugas to recover after changes in the environment as noted by Laidre et al., (2008).

The male blubber thickness index revealed two lows in 2005 and 2014 that did not cross the poor condition threshold. Again, these two lows have confidence intervals that do not distinguish themselves from surrounding years, but they do have the lowest mean value. The female blubber thickness index revealed two lows in 2007 and 2014, the latter which crossed into the poor condition threshold. The female blubber thickness index reveals condition highs in 2000 and 2009-2011. The confidence intervals for each year of the female blubber thickness index overlap for many of the years, again challenging the ability to significantly distinguish years apart. Our findings align with Harwood et al., 2014, who noted 2005 low blubber thickness for male EBS belugas and 2002 and 2003 high blubber thickness, thus validating our index. Additionally, Inuvialuit hunters observed that in 2005, EBS belugas who were harvested in later in the season had thin blubber thickness (Inuuvik Community Corporation et al., 2006). The year

2014 has also previously been noted as a year with low blubber thickness index value for EBS belugas (Choy et al., 2017). Again, there is no apparent long-term trends for either blubber thickness index, although the variation suggests a cyclical pattern may emerge with continue monitoring. Temporal changes in the body condition of other Arctic marine mammals in the Beaufort Sea have been detected, including declines in the condition of adult and sub-adult ringed seals while an increase in the condition of sub-adult bowheads has been detected (George et al., 2015; Harwood et al., 2014). Although no overall trends are apparent in the body condition indices for the EBS belugas, the variation captured by each index indicate that body condition is sensitive, although the mechanisms driving the change are not resolved.

The temporal trends captured by both blubber thickness and girth metrics hold between male and females, but there is a lag in both sex-specific blubber thickness indices from the respective sex-specific girth indices, suggesting that girth indices are more responsive to change than blubber. Girth has been suggested for both the EBS belugas and bowheads in the Beaufort Sea and the EBS belugas as an ideal body condition indicator (Choy et al., 2017; George et al., 2015). Our expanded temporal analysis builds upon the previous research on EBS beluga condition and demonstrates that girth indices are more responsive than blubber thickness indices. Blubber in marine mammals such as belugas acts not only as an energy reserve, but is important for insulation, buoyancy, and streamlining (Koopman et al., 2002; Noren et al., 2015; Ryg et al., 1993). Thus, maintaining blubber thickness is important for survival, and the lag between girth and blubber thickness indices for the EBS whales suggests that the EBS belugas, like other marine mammals, will use other energy stores in the body to maintain blubber thickness and the other functions blubber supports (Irvine et al., 2017; Noren and Mangel, 2004). Additionally, the girth index for EBS belugas (2011-2014) was a significant predictor for the fatty acid signatures that inform about prey selection (Choy et al., 2017).

4.4.3 Influence of Climate on Condition

We tested three large-scale climate variables in the Bering and Beaufort Seas to assess whether they affected the male girth index, which was selected as the proxy for body condition. Both male indices were correlated to the female indices, and cross-correlation index suggests that the male girth index leads temporal trend for the blubber thickness index by two years. In addition, the girth male index appears to be more sensitive because it crossed the poor-condition threshold from 2002-2005 whereas the male blubber thickness index did not. The statistical measures of correlation between large-scale climatic variability and condition indices of a long-lived predator do not define causation, but do provide some insight into the relationship that changes in the environment may have on beluga condition. Our findings show that EBS beluga body condition lags both PDO index and SIM metric with a significant negative relationship. On the other hand, the AO index does not have a significant relationship to beluga body condition index, which aligns with previous research on lack of influence of AO on mercury temporal trends in the EBS belugas (Loseto et al., 2015).

The most significant negative relationship between body condition and SIM occurs at a 2-year lag. A lower SIM value indicates more open water in the Beaufort Sea and correlates to a higher body condition index value. Changes in body condition may signal shifts in access to prey or quality of available prey (Harwood et al., 2014). As the Beaufort Sea trends to increasing open water, a change in the marine ecosystem is expected (Overland and Wang, 2013; Stroeve et al., 2007; Wood et al., 2013). One such change may alter the distribution of the primary prey selected by the EBS belugas, Arctic Cod, an ice-associate fish (Choy et al., 2017; Loseto et al., 2009; Quakenbush et al., 2015). There was a unique harvest in 2014 from the ISR community of Ulukhaktok, which is located outside of the TN MPA boundaries harvested whales had predominately Sandlace in their stomach contents, which is thought to indicate alternative foraging (Loseto et al., 2018a). Belugas are hypothesized to be less sensitive to environmental change because they are able to adapt to the changing oceanographic conditions and prey distribution (Laidre et al., 2008; Moore, 2008; Stafford et al., 2016). The year 2014 was also low index value for blubber thickness for whales harvested in the TN MPA; however, it would be expected to lag a low girth index by two years but 2012 was a high for the girth index. The Ulukhaktok harvest is a demonstration of a shift in distribution resulting from prey selection that challenges the assumptions of the body condition indicator and is an important example to note for future assessments.

The most significant negative relationship between body condition and PDO occurs at a 0-year lag, whereby a positive PDO index is correlated to a lower body condition index. As a far-migrating species, changes in EBS beluga condition may reflect ecosystem changes occurring in their overwintering waters, the Bering Sea (Grebmeier et al., 2006). Recorded sea surface temperatures from the south-eastern Bering Sea shelf note that this region experienced a warm event during 2000–2005, which aligns with the years where the body condition index decreases and crosses the poor condition threshold. The poor condition of EBS belugas during those years indicates that the state of the Bering Sea directly influence EBS belugas harvested the following summer in the TN MPA. The PDO has been found to influence another marine mammal population, the Steller sea lion, along the Alaskan coast (Trites et al., 2007). However, the Bering Sea influences the state of the Beaufort Sea, thus it is important that future research investigates whether changes in the Beaufort, Bering or both are driving the changes captured by the body condition index (Carmack and Macdonald, 2002). Although temporal variation is captured by the EBS condition index, we cannot address how those trends have impacted the overall population.

4.4.4 Conclusion

This research builds upon previous work to better understand the use of body condition as an indicator to monitor the EBS belugas by assessing the temporal trends and variation captured four different indices. This analysis examined both the seasonal and long-term variation as well as the influence of large-scale environmental variability metrics. The detailed procedure is a demonstration of the considerations required when assessing the trends and variation of a proposed indicator. Although the process to develop beluga body condition indicators is specific to the TN MPA, we hope that this paper can be a useful tool for other MPA management trying to develop indicators for monitoring. The last step in developing an indicator is for it to be validated by end-users, in this case include the TN MPA co-management boards, including Inuvialuit hunters (Bockstaller and Girardin, 2003). We can recommend the use of one indicator, male girth index, to inform about the condition of the population due its correlation to the female girth index and the 2-year lead on blubber thickness index trends. Measuring blubber thickness is an important health indicator used by hunters when harvesting a whale and is important to continue monitoring, especially since it signals seasonal change (Inuuvik Community Corporation et al., 2006; Ostertag et al., 2018). Our recommendation of a girth index to be used as a body condition indicator for the TN MPA refers to its ability to capture long-term change in blubber thickness as well as other fat-reserves in the body and muscle mass. Overall, the final decision for selecting an EBS beluga body condition indicator for the TN MPA will be left to the co-management boards.

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Chapter Five: **SUMMARY**

To improve our understanding of Eastern Beaufort Sea (EBS) beluga body condition indicators for use to monitor the Tarium Niryutait Marine Protected Area (TN MPA), indicators were first developed from the predicted values and the residuals of fitted linear models for both blubber thickness and girth metrics. Data used in the analyses were collected from harvested belugas within the Inuvialuit Settlement Region (ISR), as part of the long-term community-based beluga monitoring program. A stepwise regression method was used to select the final indicators. Sex-specific indicators were developed for ease of interpretation by TN MPA management and ISR community members. Two approaches were taken when developing the sex-specific body condition indicators: the first approach used morphometric, spatial, and temporal variables whereas the second approach used only morphometric variables. The first approach was key in determining the influence of harvest location and year of harvest on body condition indicators (Chapter 3); however, the second approach was necessary to develop indicator threshold (Chapter 3) and perform analyses on temporal variation (Chapter 4).

The assessment of the measurability, sensitivity, and specificity of the four sex-specific body condition indicators was guided by four sub-thesis objectives. The first objective (Chapter 3) examined the variation in body condition of whales based on the location of harvest at two scales. The first spatial assessment tested for significant difference between the condition of harvest belugas within the three regions of the TN MPA, the second assessment tested between whales harvested within the TN MPA and belugas harvested outside the TN MPA. The second objective (Chapter 3) evaluated belugas harvested in the TN MPA to those harvested from entrapment events in 1989 and 2006 to determine if body condition thresholds could be established. The third objective (Chapter 4) assessed the four sex-specific body condition indicators for seasonal variation and inter-annual variation and trends. Lastly, the fourth objective (Chapter 4) explored the influence of large-scale climatic variability on beluga body condition.

5.1 Findings

The results presented in Chapter Three found that harvest location should be considered for both blubber thickness and girth indicators. Specifically, the western TN MPA region (WES), was significantly different from the other two regions (CEN and KUG), for both male body condition indicators. The second spatial test found that for all four body condition indicators, belugas landed inside the TN MPA had a significantly different condition from belugas landed outside the TN MPA. One potential cause for the spatial difference in body condition may be due to hunter preference, as hunters from each community tend to consistently harvest from the same region of the TN MPA (Inuuvik Community Corporation et al., 2006). As these hunters continue to use the same region, their personal and community preference will influence their beluga selection, which may explain the patterns we see. A second potential cause in the spatial difference of body condition is that EBS belugas exhibit spatial segregation across their summering waters in the ISR (Loseto et al., 2006). Currently, we are not able to determine whether human, environmental or other factors are driving the spatial differences in condition. This information is important for TN MPA management because belugas harvested from two of the regions (KUG and CEN) are not significantly different and can be selected to create an indicator that does not need a spatial variable in the model. Belugas that are harvested outside of these two TN MPA regions (WES) and outside of the TN MPA boundaries should continue to be monitored because these whales can represent an aspect of the EBS population that is not captured by the TN MPA beluga monitoring program (Loseto et al., 2006).

Chapter Three compared the condition of whales harvested in the TN MPA that were not significantly different (KUG and CEN) to belugas harvested from two entrapment events in 1989 and 2006 in the Husky Lakes to evaluate body condition thresholds. All four body condition indicators found that the entrapment harvests had significantly lower indicator residuals compared to the TN MPA summer harvests. The fundamental assumption in this assessment is that the TN MPA harvested belugas represent good condition and that the entrapped Husky Lakes whales represent poor condition. By testing this assumption, a threshold can be established for beluga body condition for all four indicators. A threshold is an important aspect for an indicator as it assists with understanding trends, variation, and can trigger action from decision-makers (Hayes et al., 2015; Link, 2005; Rice and Rochet, 2005).

The result presented in Chapter Four first examine the temporal trends and variation. A significant change in condition over a harvest season was found for two of the body condition indicators: male blubber thickness and female girth. Hunters use blubber thickness as an indicator for health during the harvest season and the beluga monitoring data has also captured the trend that supports their observations that belugas have thicker blubber as the season progresses (Ostertag et al., 2018). The increase of blubber thickness over a feeding season has been noted in other cetaceans as well (ex: Breton-Honeyman et al., 2016; Lockyer 1987). The long-term temporal plots have provided key observations which have contributed to understanding the trends and variation captured by each indicator. First, linear regression is not significant for any of the body condition indicators and the fifteen years of data suggest a cyclical or sinusoidal pattern, however more years are required to verify this observation. Each of the temporal plots includes the proposed poor condition threshold developed from the entrapped beluga condition in Chapter Three. Both male and female girth indicators crossed the poor condition threshold from 2002-2005, whereas the only other instance that the threshold was crossed was by female blubber thickness in 2002, indicating that the girth indices may be more sensitive than blubber thickness indices as previously suggested (George et al., 2015; Gómez-Campos et al., 2011; Rice and Wolman, 1971). The male girth indicator was strongly correlated to the female girth indicator with no lag, and that the male blubber thickness indicator was correlated to the female blubber thickness indicator with no lag. Also, the male girth indicator led male blubber thickness indicator by two years and the female girth indicator led female blubber thickness indicator by three years. Due to the relationships of the four indices and individual model fits, the male girth indicator was selected as the body condition indicator to assess the influence of large-scale climatic variability. Both the Pacific Decadal Oscillation (PDO) and Beaufort Sea Ice Minimum (SIM) had significant negative correlations that lead the beluga body condition by zero and two years respectively. When there is a positive PDO index, the Bering Sea has warmer sea surface and these conditions are correlated to poorer beluga body condition, suggesting that environmental conditions in the overwintering waters do influence the beluga condition in the summer. A lower SIM value indicates more open water in the Beaufort Sea and these conditions correlate to a higher beluga body condition, suggesting that as the Beaufort Sea continues to trend to more open water in the summer, that the EBS beluga will benefit in regards to their condition. However, the statistical measures of correlation between these large-scale climatic variability metrics and body condition of the EBS beluga do not define causation but do provide insight into how environmental change may affect beluga condition. As the Arctic trends towards lower sea ice extent, a shift in the Arctic ecosystem include greater pelagic marine productivity, reduction in benthic prey, decreased ice, and increased air and water temperatures (Barber et al., 2012; Grebmeier et al., 2006). Further analyses are required to determine how these multi-stressors and increased human activities simultaneously affect beluga body condition.

5.2 Conclusion & Future Work

The marine ecosystems in the Bering and Beaufort Seas are expected to shift with changing environmental conditions in the Arctic (Grebmeier et al., 2006; Wood et al., 2013). The northern Bering Sea is changing from an Arctic to sub-Arctic ecosystem (Grebmeier et al., 2006) and the Beaufort Sea is experiencing accelerated sea-ice loss, increased warming in the spring, and decreasing snowfall (Lesack et al., 2014; Wood et al., 2013) In addition to the environmental and ecosystem changes, the Arctic is predicted to see an increase in human activities such as shipping (Pizzolato et al., 2016). The EBS belugas pass through these changing waters from the Bering Sea to the Beaufort Sea and understanding how these changes affect their health is key for TN MPA management (Citta et al., 2017; Loseto et al., 2010).

The first key insight about the beluga body condition indicators is that both blubber thickness indicators had a lower model fit compared to the girth indicators. One reason for the lower fit is that blubber thickness has a short range and the measurements are often rounded to the nearest quarter inch in the field. This results in a binning effect that is apparent from the fitted model residuals. The second key insight is that both girth indicators lead the blubber thickness indicators, suggesting that girth is more sensitive than blubber thickness. However, only male blubber thickness indicator exhibits a seasonal change, which is used hunters to determine beluga health. Lastly, the exploration in large-scale climatic variables provided insight into links between the state of the ecosystem with beluga body condition. Both the PDO and sea ice extent effects pelagic marine productivity in the marine ecosystem (Barber et al., 2012; Grebmeier et al., 2006; Wood et al., 2013) and influences the distribution of beluga's primary prey, Arctic cod (Choy et al., 2017; Loseto et al., 2009). In addition, environmental changes may lead to the introduction of southern species in the EBS beluga range, which may result in competition or predation (Grebmeier et al., 2006). Although the exact mechanisms between changes in the atmosphere to an upper trophic species remain unknown, it is valuable to examine these relationships while the beluga population is assumed to be overall healthy and stable (COSEWIC, 2004).

Together, Chapter Three and Four establish important considerations for the use of both blubber thickness and girth body condition indicators for monitoring the TN MPA. Although body condition is a metric that can easily be collected from harvested whales due to the partnership with hunters, it can reflect a multitude of stressors or changes. The main goal of indicators is to simplify the complex marine ecosystem and body condition does simplify beluga health into a single measurement. However, the challenge with simplifying any aspect from an ecosystem, including beluga health, is that over-simplification can render an indicator useless. Although 2000-2015 may be sufficient to be determined as baseline trends, much remains unknown about body condition trends, variation, and drivers. This research has contributed to filling a knowledge gap in understanding how body condition performs as an indicator for monitoring the health of the EBS beluga and the TN MPA. Since questions remain about trends and variation capture by beluga body condition indicators, assessing fatty acids, stress hormones, disease, and local Inuvialuit knowledge will assist in understanding changes in body condition (ex: Choy et al., 2017; Loseto et al., 2018b; Ostertag et al., 2018; Smythe et al., 2018). One last step is the need for the end-users, TN MPA management as represented by FJMC and DFO, to evaluate body condition indicators as decision-making tools (Rice and Rochet, 2005).

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