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Improved Wildlife Health and Disease Surveillance through the Combined Use of Local Knowledge and Scientific Knowledge

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Improved Wildlife Health and Disease Surveillance through the Combined Use of Local Knowledge and Scientific Knowledge

by

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Abstract

Effective health and disease surveillance of wildlife populations is necessary for evidence-based wildlife management and conservation, as well as for the protection of human and animal health. Wildlife surveillance, however, is often challenging to undertake due to numerous limitations associated with gathering and interpreting field data from free-ranging populations. This thesis illustrates a novel approach to wildlife health surveillance which overcomes these limitations by capitalizing on the experiential-based knowledge of resource users documented with participatory methods and applied in combination with conventional surveillance methods. This participatory approach was developed and applied in – and with the active participation of – the community of Cambridge Bay in the Canadian Arctic to improve veterinary surveillance of muskoxen (*Ovibos moschatus*). In the North, harvesting muskoxen improves food security, the local economy and is connected to local indigenous culture and traditions. In Cambridge Bay, an accurate understanding of muskoxen health was urgently needed due to local concerns of possible declines and disease emergence. A participatory surveillance program composed of different activities which drew on both local knowledge and scientific knowledge was developed. Semi-structured interviews of key informants applied participatory epidemiology techniques to document local knowledge on muskox health, while scientific knowledge was generated by testing samples collected through collaboration with hunters, field investigations, and available archives. Local knowledge of key informants proved critical for filling historic and contemporary knowledge gaps on muskox health, including data on demography, morbidity, mortality and body condition, highlighting its potential to serve as an early warning system for detecting changes in wildlife health. Local knowledge informed the design of targeted scientific studies, and when combined the two knowledge systems reduced the overall uncertainty of the surveillance output. Participation of local resource users throughout the study enabled development of a surveillance adapted to the local context and needs, including customization of surveillance interventions. In addition to producing important information for Cambridge Bay and the local muskox population, this thesis develops the field of participatory wildlife surveillance by illustrating the broader applicability of this approach for enhancing the capacity for health surveillance of other wildlife species, both harvested and not, and in other settings.

Preface

This thesis is composed by manuscripts that have been published, submitted for publication, or are considered for publication. Matilde Tomaselli designed and performed this research and wrote the papers with guidance from her thesis committee and other collaborators. All authors contributed important intellectual content and provided critical review of the papers. Written permission for reproduction of the articles included in this thesis has been obtained in its entirety from the publishers and all co-authors.

Published manuscripts

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Chapter 3 – Tomaselli M, Kutz S, Gerlach C, Checkley S. 2018b. Local knowledge to enhance wildlife population health surveillance: conserving muskoxen and caribou in the Canadian Arctic. *Biological Conservation, 217:337-348.*

Chapter 4 – Tomaselli M, Dalton C, Duignan P, Kutz SJ, van der Meer F, Kafle P, Surujballi O, Turcotte C, Checkley S. 2016. Contagious Ecthyma, Rangiferine Brucellosis, and Lungworm Infection in a Muskox (*Ovibos moschatus*) from the Canadian Arctic, 2014. *Journal of Wildlife Diseases, 52(3):719-724.*

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Ethical note

This research was approved by the Kitikmeot Inuit Association, the Ekaluktutiak Hunters and Trappers Organization, the Conjoint Faculties Research Ethics Board at the University of Calgary (REB14-0646 and renewals), and the Nunavut Research Institute (license 04 017 14N-M and renewals). The muskox sampling was undertaken under the Wildlife Research Permits issued by the Department of Environment of the Government of Nunavut (2014-053, 2015-068 and 2016-058). Historical samples included in this research were collected under the University of Calgary Animal Care and Use Permit (AC13-0121) and Wildlife Research Permits issued by the Department of Natural Resources of the Government of Northwest Territories. The sample collection was in compliance with the standards for animal care, biosafety and biosecurity recommended by the University of Calgary.

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which I hope will inspire many projects to come helping both people and wildlife

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List of Symbols, Abbreviations and Nomenclature

Abbreviation	Definition
BPAT	Buffered plate agglutination test
BQCMB	Beverly and Qamanirjuaq Caribou Management Board
°C	Degree Centigrade
CB	Cambridge Bay
cELISA	Complement enzyme-linked immunosorbent assay
CF	Country food
CFT	Complement fixation test
CI	Confidence interval
CINE	Centre for Indigenous Peoples' Nutrition and Environment
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWHC	Canadian Wildlife Health Cooperative
CWD	Chronic wasting disease
DU	Dolphin and Union
DNA	Deoxyribonucleic acid
ECCC	Environment and Climate Change Canada
EDTA	Ethylenediaminetetraacetic acid
EHTO	Ekaluktutiak Hunters and Trappers Organization
EVK	Ethnoveterinary knowledge
FMD	Foot and Mouth Disease
FP	Filter paper
GIS	Geographic Information System
H&E	Hematoxylin and eosin stain
HPAI	Highly pathogenic avian influenza
iELISA	Indirect enzyme-linked immunosorbent assay
IQR	Interquartile range
KIA	Kitikmeot Inuit Association
KU	Kugluktuk
LK	Local knowledge
µm	Micrometers
NRI	Nunavut Research Institute
NU	Nunavut
NWT	Northwest Territories
OD	Optical density
OIE	World Organization for Animal Health (Office International des Epizooties)
ORFV	Orf virus
P	Plasma

PCR	Polymerase chain reaction
PDS	Participatory disease surveillance
PE	Participatory epidemiology
PENAPH	Participatory Epidemiology Network for Animal and Public Health
PPR	Peste des petits ruminants
PRA	Participatory rural appraisal
PS	Participatory surveillance
R^2	Coefficient of determination
RVF	Rift Valley fever
S	Serum
SARS	Severe acute respiratory syndrome
SD	Standard deviation
SH	Sachs Harbour
SK	Scientific knowledge
SPSS	Statistical Package for the Social Sciences
STAT	Standard tube agglutination test
UL	Ulukhaktok
%P	Percentage of positivity

Chapter 1. Introduction: literature review and thesis overview

This PhD research is a valuable contribution to ongoing efforts to enhance the capacity for wildlife health and disease surveillance. It provides specific means for improving the processes of data gathering and interpretation by fostering participation of local stakeholders, while promoting the development of programs and interventions that are relevant locally. This thesis demonstrates how the use of local knowledge (LK) and its application with scientific knowledge (SK) can improve the veterinary surveillance of wildlife populations. It illustrates how this approach was successfully applied in the Canadian Arctic to the surveillance of free-ranging muskoxen (*Ovibos moschatus*), which was urgently needed due to local concerns of possible declines and disease emergence, including zoonoses (Kutz et al., 2013a; 2015). Lessons learned from this work will enable implementation of a similar participatory and transdisciplinary approach in other settings and for other wildlife species. The remainder of this introduction provides necessary background context and rationale for this thesis, including an overview of the chapters that follow.

1.1. Wildlife health and disease surveillance: concepts, challenges and opportunities

It is well accepted that the study of wildlife disease and wildlife health plays a critical role for the conservation of biodiversity, wildlife management, and the protection of the health of domestic animals and humans (Daszak et al., 2000; Deem et al., 2001; Gortázar et al., 2007; Smith et al., 2009; OIE, 2010; Hanisch et al. 2012; Peterson and Ferro, 2012; Stephen, 2014). Continued collection of epidemiological data from wildlife populations through either monitoring or surveillance programs is the first step in developing an appropriate level of understanding of the health and disease status of wildlife (Mörner et al., 2002). Although monitoring and surveillance are often used interchangeably, these two terms differ; collecting epidemiological data for monitoring does not entail a specific purpose other than detecting temporal trends, while surveillance refers to a more systematic form of data collection and analysis in which results directly inform policy and management actions (Artois et al., 2009). Therefore, even though monitoring efforts can also produce data valuable for informing a large array of interventions (e.g., for public health protection, livestock disease management, or wildlife conservation) (Artois et al., 2009), surveillance efforts are specifically designed to support decision-making and to influence management through programs in which processes of data gathering, analyses, and communication are clearly defined (OIE, 2010).

Despite the recognized importance of wildlife surveillance and the increasing efforts to establish surveillance programs in many countries (e.g., Leighton et al., 1997; Mörner et al., 2002; Artois et al., 2009; Kuiken et al., 2011), its implementation continues to often be insufficient or inadequate (Kuliken et al., 2005; Grogan et al., 2014). For example, Kuliken et al. (2005) highlighted that insufficient capacity for wildlife surveillance both in developing and developed countries led to delays in the detection and control of emerging zoonotic infections, such as severe acute respiratory syndrome (SARS coronavirus) and highly pathogenic avian influenza (HPAI viruses), with negative consequences for both human and domestic animal health. Similarly, Grogan et al. (2014) highlighted how the lack of effective wildlife surveillance contributed to global biodiversity loss through the delayed recognition and control of "biodiversity diseases". The slow characterization of and response to the emergence of chytridiomycosis (*Batrachochytrium dendrobatidis*) in amphibians and white-nose syndrome (*Pseudogymnoascus destructans*) in bats contributed to devastating population effects, including major declines and species extinctions (Lips et al., 2006; Skerratt et al., 2007; Foley et al., 2011; Grogan et al., 2014).

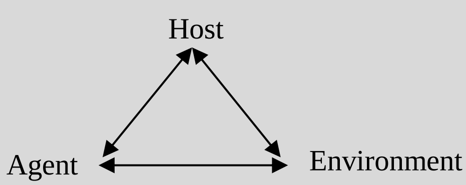
Undertaking wildlife surveillance, however, is a challenging task, beginning from the initial data acquisition (Stallknecht, 2007; Ryser-Degiorgis, 2013). Diagnostic data derived through the submission of cases discovered by the general public (i.e., animals found dead or ill) is the most common source of surveillance information for wildlife and is known as passive, general or scanning surveillance (Stallknecht, 2007; OIE, 2010). Data derived through scanning surveillance are influenced not only by the probability of case detection, which is time sensitive and species/setting specific, but also by complex decision-making processes (Stallknecht, 2007). Scanning surveillance is the most important component of a national wildlife health program as it enables the discovery of new pathogens, including emerging diseases (e.g., chronic wasting disease - CWD - in ungulates, *Mycoplasma gallisepticum* in house finches and West Nile virus in avian species in North America; Stallknecht, 2007), and the detection of disease outbreaks (OIE, 2010), however it can be insufficient unless coupled with awareness campaigns and incentives (OIE, 2014). Therefore, the information generated by scanning surveillance is likely to reflect patterns and trends in motivations for reporting rather than true patterns and trends of disease (OIE, 2014). It can also lead to systematically underestimating or failing to detect mortality of wildlife in remote areas, or mortality of animals that are quickly removed from the environment by scavengers and decomposition (Stallknecht, 2007; Wobeser, 2007; Sleeman et al., 2012). Additionally, scanning surveillance provides only a limited extent of information regarding changes in wildlife populations and, implemented alone, is inadequate for achieving a comprehensive understanding of wildlife health which is inclusive of sustainability and resilience (Deem et al., 2001; Hanisch et al., 2012; Stephen, 2014; Box 1.1).

Box 1.1. Wildlife health and disease, evolving concepts

Over the years, there has been an evolution in how we think about and articulate the meaning of wildlife health, diseases and pathogens, recognizing that "health is not the mere absence of disease" and disease and pathogens are not fixed concepts themselves but move along a continuum (Ryser-Degiorgis, 2013). Consequently, measuring health and disease is a complex endeavor.

A cornerstone of these discussions is the recognition that disease is not restricted to infectious aetiologies and can be multifactorial. According to Wobeser (1997), disease in wildlife is *"any impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as nutrition, toxicants, and climate; infectious agents; inherent or congenital defects, or combinations of these factors"*.

Recognizing that parasites (both macro and micro) are a normal component of ecosystems has led to a shifting view of disease as the outcome of the interaction of features related to the host, the parasite (or agent), and the environment in which this relationship occurs (Wobeser, 2007).



Schematic often used to refer to the interaction between host, agent, and the environment, also referred to as the "epidemiologic triad".

Therefore, disease can be better described as the outcome of multiple factors interacting within a causal web (Wobeser, 2007). However, despite the recognition that the "one agent-one disease" approach is largely inadequate to describe and understand diseases, this over-simplistic approach continues to be applied (Wobeser, 2007; Ytrehus et al., 2015).

In response to the need for promoting effective wildlife conservation, the definition of disease in wildlife has evolved towards a population-centric definition, which recognizes disease as *"those impairments"*, as previously described by Wobeser (1997), *"that negatively affect the long-term persistence of populations and the ability of healthy populations to fulfill their ecological role in an ecosystem"* (Deem et al., 2001).

More recently, in the effort to move from a disease-centered approach to a health-centered approach, the discussion has focused on the need for a modern reconceptualization of wildlife health (Hanisch et al., 2012). Although this discussion remains ongoing, the adoption of a holistic approach is prevailing, with wildlife health viewed as a "*dynamic and adaptive process to cope"* with cumulative changes which drive population "*vulnerability and resilience"* over time (Hanisch et al., 2012; Stephen, 2014). Infectious and non-infectious diseases are therefore one determinant of wildlife health among other biological, social and environmental factors that influence population productivity and sustainability (Stephen, 2014).

This continued ontological discussion about wildlife health is relevant for realizing improvements to the scope and effectiveness of wildlife health surveillance and health management, ultimately helping to conserve wildlife more effectively.

In veterinary surveillance for domestic animals, elements of active or targeted surveillance are often combined with scanning surveillance to gather more complete and reliable data to meet specific needs (OIE, 2014). This is also true for wildlife surveillance (OIE, 2010), in which focused epidemiological studies are performed to better understand wildlife health and disease outcomes (Mörner, 2002; Mörner et al., 2002; Stallknecht, 2007; Artois et al., 2009; Ryser-Degiorgis, 2013). Authors agree that impediments to achieving this understanding are primarily related to challenges for sample and data collection in the field, as well as interpretation of field data (Wobeser, 2007; Stallknecht, 2007; Artois et al., 2009; Ryser-Degiorgis, 2013). For example, difficulties in defining and achieving an adequate sample size, limited ability to obtain samples that are representative of the population under surveillance (i.e., selection bias), limited availability of diagnostic assays that are validated for wildlife species (i.e., misclassification bias), and difficulties with implementing study design beyond the cross-sectional are some of the significant impediments to wildlife epidemiological studies that can undermine generation of trustworthy surveillance outputs (Wobeser, 2007; Stallknecht, 2007; Artois et al., 2009; Ryser-Degiorgis, 2013; Gilbert et al., 2013; OIE, 2014; Walton et al., 2016). Moreover, logistical and financial restrictions can pose additional constraints to wildlife surveillance, especially in remote and resource-scarce areas of the world (Wobeser, 2007; Ryser-Degiorgis, 2013). These areas, despite the additional challenges, are often the ones where wildlife surveillance is also most urgently needed. This is true for example in remote settings characterized by the presence of subsistence-oriented societies based on hunting wild game where healthy wildlife populations contribute directly to healthy communities (e.g., in the Arctic; Myers et al., 2005; Meakin and Kurvitz, 2009), and in low-income countries where many areas are considered the "hotspots" for emerging zoonotic pathogens from wildlife (Jones et al., 2008; Morse et al., 2012) and there are strong ecological interactions between people, wildlife, and livestock.

The numerous unique challenges presented by wildlife health surveillance and the interrelatedness between animal, human and ecosystem health necessitate collaboration across multiple disciplines (Aguirre et al., 2002; Ryser-Degiorgis, 2013). The application of a plethora of tools and methods covered by disciplines within both natural sciences and health sciences is well established and advocated for to enhance wildlife health surveillance and research, as well as disease management (Daszak et al., 2004; Artois et al., 2009; Ryser-Degiorgis, 2013). For example, Skerratt et al (2010) emphasized the contribution of combined cross-disciplinary investigations in pathology, epidemiology, microbiology and ecology both in the field and in experimental settings to better understand disease dynamics and the global impact of chytridiomycosis in amphibians and to better formulate control strategies; Capelle et al. (2010) combined environmental modeling through remote sensing and aerial population estimates to predict the seasonal spatial distribution of wild waterbirds in the wetland of the Inner Niger Delta of Mali to better target areas for active surveillance of avian influenza; recently, the PREDICT program enhanced surveillance of viruses in a diversity of wildlife hosts by combining predictive modeling to find high-risk interfaces for disease emergence with innovative non-invasive sampling methods and cutting-edge molecular tools (Kelly et al., 2017).

Collaborations between wildlife professionals and a range of local stakeholders have also contributed to improving wildlife health surveillance through a broad number of initiatives, ranging from hunter-based and community-based programs to citizen science initiatives. For example, in the sparsely populated Sahtu Settlement Region of the Northwest Territories in northern Canada, the health of caribou and moose have been monitored though a community-based and hunter-driven program, which originated in response to local concerns about wildlife health in 2003; throughout the years, this program has also contributed to building local capacity for participation in wildlife health monitoring and management (Brook et al., 2009; Carlsson et al., 2016). In Finland, since 2007 the food safety authority developed a surveillance program in cooperation with hunters for infectious diseases and contaminants in wild cervids, which also contributed to the delivery of hunter education on biology, disease and meat safety (Tryland et al., 2012). Engaging with the general public has also provided opportunities to improve wildlife surveillance through programs that have capitalized on existing citizen science networks (Lawson et al, 2015). Two examples (among others) include the Garden Wildlife Health program (www.gardenwildlifehealth.org), which seeks to identify emerging threats to garden wildlife in Britain and the FeederWatch program (www.feederwatch.org), through which the emergence of house finch conjunctivitis (*Mycoplasma gallisepticum*) was first identified in 1994 in North America and has since contributed to its monitoring.

Finally, in recent years amongst the veterinary wildlife community there has been increasing awareness of the opportunities afforded by social sciences applied to wildlife health surveillance and research, particularly of participatory research that capitalizes on experiential-based knowledge of "local experts" (Ryser-Degiorgis, 2013; Goutard et al., 2015). Although in the published literature there are examples in which LK has been applied to explore different aspects of wildlife health (see next section), the application of LK for wildlife surveillance is in its infancy at present. However, people who earn their livelihoods from natural environments and from animal-based farming have long been recognized as contributing valuable ecological knowledge for the management and conservation of wildlife populations and valuable ethnoveterinary knowledge (EVK) for the surveillance of livestock diseases, respectively. Ecologists and wildlife managers on one side and livestock veterinarians and veterinary epidemiologists on the other side have been combining LK with data obtained through "conventional" methods to address specific questions that often focus on applied issues in the respective fields. Lessons learned from these two fields of study can guide significant advances in wildlife health and disease surveillance.

1.2. Recognition of local knowledge as a management tool for wildlife

There are several names that refer to experiential-based knowledge driven by local resource use and practices, including general names such as local and traditional ecological knowledge, indigenous knowledge, technical knowledge, folk knowledge and wisdom, and more specific names that connote specific groups, for example *Inuit Qaujimajatuqangit* or Inuit knowledge. This local and experiential-based body of knowledge is herein conjointly referred as LK. This "way of knowing" is not only a prerogative of indigenous ethnicity, however, it is more likely to be a feature of those societies that have maintained subsistence-based resource use and practices (Berkes et al., 2000). Local knowledge is typically passed on through oral tradition and can be encoded in different forms, ranging from empirical experiences of everyday life to cultural practices (Berkes et al., 2000; Usher, 2000; Huntington, 2011). As such, LK comprises multiple epistemological dimensions, including historical and contemporary observations of ecological processes that shape the environment and the wildlife within it, and cultural-based values and cosmology that influence the knowledge system itself (Usher, 2000; Berkes et al., 2000). In subsistence-oriented societies, LK systems are evolving with LK being documented and transmitted through different means.

Since the 1980s, there has been increasing interest in utilizing LK for adaptive management of natural resources and co-management of wildlife (Gadgil et al., 1993; Berkes et al., 2000; Usher, 2000; Davis and Wagner, 2003; Brook and McLachlan, 2008), recognizing that LK offers a different perspective which is often complementary to SK (Berkes et al., 2000; Rist and Dahdouh-Guebas, 2006). The two knowledge systems, when combined, can achieve an improved understanding of natural systems, gaining broader insights of environmental processes and their impacts (Huntington et al., 2004a, b; Box 1.2). Additionally, the effort of combining LK with SK can produce collaborative partnerships between scientists and LK holders that allow for an improved understanding of each other's perspectives, building trust, resolving conflict and ultimately enhancing overall management (Huntington et al., 2004a; Kendrick and Manseau, 2008; Berkes, 2009; Huntington, 2011). Finally, from a practical perspective, capitalizing on the activities of resource users that are already occurring also reduces the need for undertaking expensive field work for conventional scientific research (Moller et al., 2004; Anadón et al., 2009).

Box 1.2. Local knowledge and scientific knowledge

Local knowledge is a holistic body of knowledge (i.e., all elements are viewed as interconnected) that is based on observations and experience of the natural environment acquired through a process of trial and error, typically "local" in spatial scale and acquired over a long time period, including many generations (Berkes et al., 2000; Huntington et al., 2004a; Rist and Dahdouh-Guebas, 2006). Scientific knowledge, also referred to as western science or western knowledge, is disaggregated or compartmentalized into specialized disciplines, typically has a strong numerical component and aims for generalization in space and time with observations usually lacking time depth (Berkes et al., 2000; Huntington et al., 2004a; Rist and Dahdouh-Guebas, 2006). Both methods for acquiring and interpreting information have uncertainties of their own; the combination of the two knowledge systems as independent sources of information can reduce overall uncertainty and increase confidence and depth of knowledge (Huntington et al., 2004a).

Methods to document LK are flexible and include the use of open-ended semi-structured interviews, which are used more frequently, and collaborative fieldwork, workshops, and questionnaires, which are rarely used because they are more structured and pose limitations to new discovery but are sometimes preferred for quantification (Huntington, 1998; Huntington, 2000). In documenting LK identifying "who knows" or the "key informants" (i.e., people recognized to be the expert on the topic of inquiry) is critical and influences the reliability of the information (Huntington, 2000; Davis and Wagner, 2003).

North America and in particular the Arctic - an area where including LK of indigenous groups in science is strongly encouraged and in some cases (e.g., wildlife co-management) made mandatory by land claims agreements (Usher, 2000; Wendzel, 2004) - has been at the forefront of the development of this field (Berkes et al., 1991; Berkes et al., 2000; Huntington, 2000; Davis and Wagner, 2003; Brook and McLachlan, 2008). In the current literature, many examples highlight how LK from a variety of key informants has contributed critical information to manage and monitor wildlife populations. For example, in the early 1980s knowledge of Alaskan native whalers informed locations and timing for population estimates of bowhead whales, which had been previously undertaken by scientists alone and proved to be based on false assumptions; this led to an increase of the population estimate from 2000-3000 animals to 6000-8000 (Huntington, 2000). In the coastal communities of northern Alaska, Huntington et al. (2016) documented hunters' observations of extensive changes in sea ice and weather and the effect both are having on the migration of various marine mammal species. In a comparative study undertaken over a 12-year period, Parlee et al. (2014) documented knowledge of elders and harvesters of the Łutsël K'é Dene First Nation in Northern Canada that highlighted local changes in the availability of caribou and moose, coupled with observations of range shift for both species and new sightings of white tail deer, with this posing concerns about possible northward expansion of the prion disease CWD present among the white tail deer population at southern latitudes.

Local knowledge has also been valuable for exploring intraspecific interactions between wildlife and livestock that may facilitate pathogen transmission. For example, Brook and McLachlan (2009) combined knowledge collected from farmers and data derived from radio-collared elk to elucidate interactions between elk and cattle that can facilitate pathogen transmission at the edge of a provincial park in southern Canada. While in Switzerland, Casaubon et al. (2012) and Wu et al. (2012) relied on knowledge of game wardens and farmers to elucidate intraspecific interactions between various species of wild ungulates and cattle in alpine pastures, and between wild boars and outdoor domestic pigs, respectively.

Finally, LK of a variety of key informants has also been used for detecting and describing wildlife morbidity and mortality. For example, Madslien et al. (2011) relied on hunters' observations to estimate the prevalence of alopecic syndrome (*Lipoptena cervi*) in Norwegian moose; Chen et al. (2012) used participatory epidemiology to understand prevalence and patterns of sarcoptic mange (*Sarcoptes scabiei*) in wild Formosan serow in the range of indigenous communities in Taiwan; more recently, Iverson et al. (2016) and Henri et al. (2018) relied on the knowledge of Inuit hunters to document recent and historical mortality outbreaks associated, or possibly associated, with avian cholera (*Pasteurella multocida*) in Common Eiders in the Eastern Arctic.

The range of ecological observations about wildlife captured by LK include movements and abundance of animals, behavior and body condition, morbidity and mortality, and interspecies interactions, as well as biotic and abiotic features of the environment in which animals live. These cumulative and holistic observations are relevant for understanding wildlife health and for its continuous assessment. Despite the promising examples illustrated above, the potential for applications of LK for wildlife health assessment has not been fully explored and the systematic use of this body of knowledge for wildlife health surveillance is still lacking. Experiences offered by the application of LK as a veterinary surveillance tool for livestock diseases will be a valuable contribution to advancing the application of LK for wildlife health assessment.

1.3. Recognition of local knowledge as a veterinary surveillance tool

Qualitative participatory approaches to veterinary epidemiological research and disease surveillance, referred to as participatory epidemiology (PE) and participatory surveillance (PS), respectively, have contributed to significant improvements for the understanding and control of livestock diseases in low-income countries (Catley and Mariner, 2002; Catley, 2003; Jost et al, 2007; Mariner et al, 2011; Catley et al, 2012; Goutard et al., 2015; Allepuz et al., 2017). These approaches originated in the 1990s as the veterinary application of participatory rural appraisal (PRA) (Catley et al., 2012), which evolved a decade earlier from rapid rural appraisal (RRA) as a bottom-up multidisciplinary strategy to improve rural development through community empowerment (Chambers, 1983; 1994a, b, c; Pretty, 1995).

Participatory epidemiology and PS (formerly referred as PDS, participatory disease searching or surveillance) access community knowledge systems, particularly the knowledge of livestock owners about the diseases affecting their animals, including clinical presentation, gross pathology, epidemiological features of disease and associated risk factors, as well as treatment (knowledge collectively referred to as ethnoveterinary knowledge or existing veterinary knowledge - EVK) (Mariner and Paskin, 2000). This knowledge is gathered in the field through a combination of multiple participatory appraisal techniques and tools, ranging from open-ended semi-structured interviews (individual and group) to interactive scoring and visual exercises and direct observations, which allow for generation of both qualitative and quantitative "epidemiological intelligence" (Mariner and Paskin, 2000). The techniques are applied in a flexible way through an appraisal supported by iterative analyses which make the assessment progressively more relevant to the local context or situation (Jost et al., 2007). Similarly to PRA, PE relies on the process of "triangulation", or cross-checking information using multiple methods and sources, to improve data quality and reliability (Pretty et al., 1995; Mariner and Paskin, 2000; Jost et al., 2007; Catley et al., 2012). Triangulation is applied both "within-method" and "across-method", including through the use of conventional veterinary assessments and diagnostics (i.e., clinical and pathological examinations, field and laboratory testing) (Mariner and Paskin, 2000; Catley et al., 2012; OIE, 2014).

Much of the early development and application of PE and PS were associated with efforts to eradicate rinderpest, a severe viral disease of even-toed ungulates (i.e., artiodactyls) causing up to 100% mortality in immunologically naïve cattle and water buffalo and considered the animal disease with the greatest impact on human livelihoods (Mariner et al., 2012). Participatory surveillance was essential in locating the last foci of rinderpest in remote pastoralist areas of East Africa where conventional surveillance had failed to disclose disease, and to guide targeted control for eradication (Mariner and Roeder, 2003). Subsequently, PS was utilized as a tool to confirm the absence of clinical disease in a number of countries of Africa and Asia (Roeder, 2011; Mariner et al., 2012). Building from that experience, PE and PS have then been used in both rural and urban settings in Africa and Asia to improve the surveillance and control of other livestock diseases that have an impact on people's well-being; related examples include: peste des petits ruminants (PPR) and foot and mouth disease (FMD) in Pakistan (Hussein et al., 2008; Anjum et al., 2006), Rift Valley fever (RVF) in Kenya and Tanzania (Jost et al., 2010), and HPAI in Indonesia (Azhar et al., 2010). The use of PS proved to be cost-effective for targeted studies compared to conventional surveillance, as well as sensitive and timely for detection of different types of disease situations, ranging from rare or emerging diseases to prevalent but under-reported diseases, the latter which PE contributed up to a tenfold increase in case detection (Jost et al., 2007; Mariner et al., 2011). Furthermore, the participatory process has enabled local stakeholders to have a greater role in shaping disease control programs that align with local priorities (Jost et al., 2007; Mariner et al., 2011; Catley et al., 2012).

Since its application, PE, either in the form of surveillance or epidemiological research, has contributed to addressing important knowledge gaps about livestock diseases in marginalized areas, to prioritizing disease and guiding better control strategies, to unravelling aetiology of complex syndromes (Catley et al., 2001; 2004), and to informing models for disease transmission (Mariner et al., 2005; 2006 a, b), including zoonoses (Grant et al., 2016). In the past two decades, PE has been increasingly used and its applications have broadened to include participatory risk analysis, impact assessment, veterinary public health, evaluation tools for surveillance, including hunter-based surveillance (e.g., Schulz et al., 2016), and training, among others (see Catley et al., 2012; Allepuz et al., 2017). As evident from the recent review by Allepuz et al. (2017), PE activities continue to be implemented mainly in Africa and Asia and to be largely centered on livestock systems.

The use of PE for wildlife is still largely underrepresented, with disease transmission at the wildlife-livestock and wildlife-human interfaces being more common. For example, Catley et al. (2002), while studying bovine trypanosomiasis in Kenya, found that Orma pastoralists considered contact with wild buffalo a risk factor for FMD in their cattle, with contact between livestock and wildlife more likely to occur in the Orma season "*bona hageiya*", from January to mid-March. Coffin et al. (2015) explored interactions between people and wildlife at the edge of a national park within a study focused on anthrax

(*Bacillus anthracis*) management in Western Uganda. In the project “Lawa model”, an EcoHealth approach that has been ongoing for 10 years for the control of the foodborne carcinogenic parasitic disease opisthorchiasis (*Opisthorchis viverrini*) endemic in the Lawa Lake region of Thailand, PE has largely been implemented to unravel complex socio-ecological interactions; these interactions include the human-wildlife interface, given the disease is transmitted through the consumption of undercooked wild fish (*Cyprinid* species) (Sirpa et al., 2017). Only one study in the published literature appears to apply PE methods directly to wildlife, in an assessment which was limited to one endemic disease (Chen et al., 2012). Tellingly, in the most recent guide for animal health surveillance of the World Organization for Animal Health (OIE), PS is presented as a surveillance tool limited to livestock diseases (OIE, 2014). However, given their strong reliance on LK, PE and PS are promising approaches for significantly enhancing effectiveness of wildlife health surveillance, monitoring and research. In fact, as highlighted in the preceding sections, there is strong evidence that knowledge from local wildlife experts can contribute to improving both disease detection and the broader understanding of health outcomes and their underlying ecological processes, which can be difficult to capture with SK alone.

Goutard et al. (2015) recently emphasized that lessons learned and associated advances in the field of livestock surveillance can guide methods for enhancing wildlife surveillance and the possibilities afforded by LK for providing critical eco-epidemiological information and EVK on wildlife species. The work presented in this thesis moves in such a direction, providing insights into practical applications of these approaches for health surveillance of muskoxen in the Canadian Arctic and identifying lessons learned to enable their implementation in other settings and for other wildlife species.

1.4. Integrating lessons learned from other fields of study to improve wildlife health surveillance

From the preceding sections, it appears clear that the way LK is applied by ecologists and wildlife managers on one side (ecological knowledge) and by livestock veterinarians and epidemiologists on the other side (ethnoveterinary knowledge) and the insight LK is providing in those respective fields of application are highly relevant for wildlife health surveillance. These two fields of study – LK applied to wildlife co-management and LK applied to livestock disease surveillance – can be combined by capitalizing on their strengths to create a novel and holistic approach to wildlife health surveillance, while ensuring direct participation of those who are most affected by changes in wildlife health and by decision-making on wildlife.

The Canadian Arctic, where this research was undertaken, provides an ideal setting for applying such a novel approach owing to: the availability and depth of knowledge of local residents regarding the natural ecosystem and its wildlife; the importance of sustainable and healthy wildlife for food security (Myers et al., 2005; Meakin and Kurvitz, 2009) and the need for understanding and effectively monitoring health of wildlife given the rapid changes occurring in the environment (e.g., climate change), which are already altering host-parasite systems (McCarty, 2001; Altizer et al., 2013; Kutz et al., 2014); the inherent logistical and financial challenges for implementing wildlife surveillance through conventional methods; and finally, the legislated requirement of including *Inuit Qaujimajatuqangit* in wildlife co-management (e.g., Nunavut Wildlife Act, 2003).

For wildlife health surveillance, PE and PS can provide the framework for the collection of LK and its combination with SK. In the field of wildlife co-management, Huntington et al. (2004a) emphasized that LK and SK should be viewed as *"independent sources of information"* that *"brought together increase confidence and depth of knowledge"*; however, much work is still needed to facilitate the co-application of LK and SK in co-management systems (Gagnon and Berteaux, 2009). The principle of across-method triangulation, which is a key process in PE, although often overlooked (Catley et al., 2012), provides the means for facilitating the combination of LK with SK. However, triangulation should not be viewed as a process to "validate" results by contrasting the two knowledge systems against one another, but rather as a process to achieve greater insights by comparing and combining results from knowledge systems that compensate for each other's uncertainty (see Huntington et al., 2004a).

In wildlife co-management, another challenge for the combination of LK with SK is associated with the difficulty to effectively use qualitative data within typically quantitative systems. In PE, the use of participatory visualization and diagramming techniques provides means for better sharing, displaying and integrating qualitative animal health data within conventional quantitative systems. In LK studies applied to wildlife co-management, mapping is the most utilized tool; however, many other participatory tools (e.g., proportional piling, ranking and scoring, Venn diagrams) could be applied to unravel complex ecological interactions, while facilitating engaged participation of LK holders and immediate co-analysis of information with participants.

A "challenge" common to both fields of study lies in the flexibility of methods. Although flexibility is also a strength of participatory approaches, often it has been mistakenly intended as utilizing qualitative methods and techniques in a loose way and with a lack of transparency in reporting methods applied (see Brook and McLachlan, 2008). For instance, in the literature on LK applied to wildlife co-management, there are examples in which LK improperly collected or interpreted has led to the dismissal of LK as untrustworthy and requiring validation by SK (Gilchrist et al., 2005; Brook and McLachlan, 2005). Clearly, this can lead to conflicts. Similarly, conflicts may arise if we were to apply to wildlife surveillance the PRA principle of optimizing trade-offs between cost of learning and usefulness of information, also referred to as "optimal ignorance" and "appropriate imprecision" (Chambers, 1994a). This principle, which the PE tradition often refers to, can be appropriate in the context of rural development and action oriented research, but might not be appropriate if we aim at producing rigorous accounts for understanding and assessing wildlife health.

Therefore, more emphasis on methods will be required for ensuring data quality and reliability and to avoid the information that is generated being dismissed as anecdotal and failing to be integrated into decision-making. Qualitative methods should be applied using "scientific rigor", meaning that a rigorous process of data collection and analyses will be necessary to produce credible and rigorous accounts (Murphy and Dingwall, 2003; Green and Thorogood, 2014a). This aspect is critical for promoting the transdisciplinary application of qualitative and quantitative disciplines for wildlife health and avoiding the risk of producing further separation between them. Finally, the use of rigorous methods will allow for comparability and combination of results across localities, which will be important for health surveillance of wildlife populations with large home ranges that intersect multiple communities and groups of key informants.

By applying and adapting concepts and methods derived from the use of LK in wildlife co-management and the fields of participatory epidemiology and livestock surveillance, this thesis offers a valuable contribution to developing the emerging field of participatory wildlife health surveillance and it illustrates methods and techniques that can be transferred beyond the specific locality and wildlife species this research focused on.

1.5. Thesis overview

1.5.1. Thesis aim and objectives

The overarching aims of this research were to investigate how LK can contribute to improving wildlife health and disease surveillance, and how the combination of LK with SK within a participatory framework can improve the output of wildlife surveillance. This investigation was undertaken utilizing the muskox as a study species, and the LK and assistance of the residents of the community of Cambridge Bay in the Canadian Arctic as a study system.

The primary objectives of this research were to:

1. Design and implement surveillance activities to collect and interpret LK and SK on muskox health and diseases in the study area;

2. Evaluate how LK and SK alone and combined contributed to understanding health and disease outcomes of muskoxen in the study area and to quality attributes of the surveillance (qualitatively assessed);

3. Based on the lessons learned from the previous objectives, develop a participatory framework that combined LK and SK to improve veterinary surveillance for harvested and non-harvested wildlife in settings characterized by the presence of local informants.

1.5.2. Study system

This research program took place in the community of Cambridge Bay, also referred to by its traditional Inuinnaqtun name of Iqaluktutiaq, located on Victoria Island, Nunavut in the Canadian Arctic (Fig. 6.1). Cambridge Bay, like many other Arctic communities, is remote and can generally be accessed only by plane (recognizing there is also periodic access by ocean-going vessels such as cruise ships and barges during the limited open-water period).

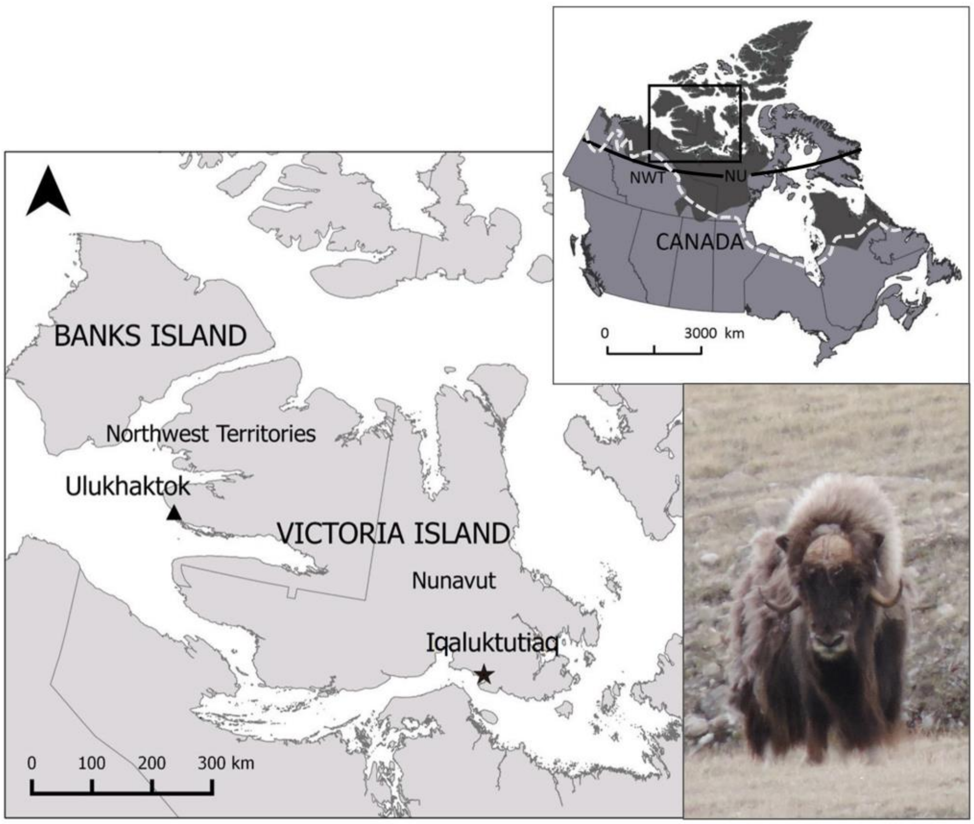


Figure 1.1. Map of Victoria Island in the Canadian Arctic Archipelago showing the only two settlements established on the island, Iqaluktutiaq, or Cambridge Bay, Nunavut (study area) and Ulukhaktok, Northwest Territories (approximately 1700 and 400 people, respectively; Statistics Canada, 2016). Victoria Island has a surface area of approximately 217 km^2 (Natural Resources Canada, 2018), a similar size to that of the United Kingdom. At top right, Victoria Island is georeferenced within Canada (squared box); the current known distribution of muskoxen in Canada is shown in dark grey (information from Kutz et al., 2017); the Arctic Circle is marked with a black solid line (above which temperatures remain well below 0°C for most of the year and limited, or lack of, sunlight characterizes the lengthy winter season); and the "tree line" (line above which trees do not grow) is indicated with a dashed white line. At bottom right the picture of an adult male muskox from Victoria Island. Map generated in QGIS 2.8.9 and modified from Tomaselli et al. (2018a).

Goods, including all store-bought foods and fresh produce, are imported regularly by plane and once-seasonally by marine resupply vessels. Harvesting of local wildlife species, including muskoxen, occurs throughout the year and contributes significantly to local food security, provides means for revenue through organized sport-hunts and creation of crafts, and is deeply ingrained in maintenance of local indigenous culture and traditions (see Chapter 2). While this research was focused on muskoxen, the study design also allowed for collection of relevant LK on the seasonally sympatric caribou of the Dolphin and Union herd (*Rangifer tarandus groenlandicus*).

Muskoxen are cold-adapted ungulates that live year-round in the Arctic (Box 1.3). They were almost extinct in the early 1900s and active management of the species (ban of hunting) lead to their recovery (Lent, 1999; Gunn and Adamczewski, 2003). Today muskoxen are found on the Arctic mainland and Archipelago, including Victoria Island (Fig 6.1). In Canada, as a function of the population increase, right to hunt muskoxen was progressively re-established since the 1970s. Today muskoxen are co-managed and hunting is regulated under a quota system (Dumond, 2006).

Box 1.3. Brief overview of muskox ecology

Muskoxen are non-migratory and in the study area are found year-round (Gunn and Adamczewski, 2003; Dumond, 2006), contrary to the caribou of the Dolphin and Union herd, which migrate seasonally between the ‘calving grounds’ on Victoria Island (summer) and the ‘wintering grounds’ on the mainland (Dumond et al., 2013). Muskoxen typically live in mixed sex and age herds; adult males are found also in small bachelor herds or alone. Muskoxen feed on sedges, grasses, and willows. When the vegetation is covered by snow (September to June), they access the forage by digging craters through the snow cover with the forehooves (Gray, 1987; Gunn and Adamczewski, 2003). Muskoxen display a conservative breeding strategy, meaning that a high threshold of fat reserves is required for a cow to conceive. Breeding behavior and mating occur in the summer and calves are born from April to June (Gray, 1987; Gunn and Adamczewski, 2003). Arctic wolves are the primary natural predators of muskoxen; other predators include grizzly bears and polar bears. Muskoxen display a group defense strategy against predators, they stand their ground by forming a tight defensive circle with the bigger animals facing outwards (Gray, 1987; Gunn and Adamczewski, 2003).

The community of Cambridge Bay and muskoxen as the selected wildlife species offered specific advantages for this research: there was the need to understand muskox health and disease outcomes resulting from local concerns of possible declines and disease emergence, including zoonoses (Kutz et al., 2013a, 2015), and conventional veterinary surveillance and monitoring efforts for muskox health that existed in the area prior to this study offered valuable comparative knowledge for the historical data generated by this research. Specific features of the study system are further offered in Chapters 2, 3 and 6.

1.5.3. Chapter overview

This thesis is comprised of the following five main chapters: "Iqaluktutiaq voices: local perspectives about the importance of muskoxen, contemporary and traditional use and practices" (Chapter 2); "Local knowledge to enhance wildlife population health surveillance: conserving muskoxen and caribou in the Canadian Arctic" (Chapter 3); "Contagious ecthyma, rangiferine brucellosis, and lungworm infection in a muskox (*Ovibos moschatus*) from the Canadian Arctic, 2014" (Chapter 4); "*Brucella* in muskoxen of the western Canadian Arctic 1989-2016, a transdisciplinary approach" (Chapter 5); and "Wildlife surveillance: from global challenges to local solutions, learning from the muskox project in the Canadian Arctic" (Chapter 6).

Chapter 2 presents results from individual semi-structured interviews that were undertaken with residents of Cambridge Bay with the aim to explore their relationships and interactions with muskoxen. This research specifically focused on exploring the importance of muskoxen, their contribution to local food security, the description of practices related to harvesting, butchering and consuming muskoxen, and community concerns mainly associated with muskoxen. This initial study provides a thorough description of the local context, setting the stage for the work that follows. Information generated is beneficial for the development of the surveillance program, the interpretation of surveillance data, and for shaping public health and wildlife co-management interventions. Understanding the human-wildlife relationships is a required first step for designing programs, which deliver improved outcomes for both people and wildlife (Decker et al., 2012). Information presented in this chapter emphasizes how the careful examination of the local context – how people interact with and value wildlife and what their concerns are with respect to wildlife – through local perspectives can improve wildlife surveillance through the development of programs that are locally relevant and should be considered as an essential part of participatory wildlife surveillance systems.

Chapter 3 discusses how qualitative research methods and participatory epidemiology concepts and techniques were adapted and applied to gather knowledge from local resource users of Iqaluktutiaq to assess the health and population status and trends of muskoxen and caribou in the area. This research highlights how LK can contribute to a holistic understanding of wildlife health by providing critical PE data on wildlife demography, population parameters (i.e., body condition status), morbidity, and mortality; moreover, it provides important considerations for the interpretation of LK on wildlife health and diseases; finally, recommendations are provided to guide the systematic use of LK for wildlife health and disease monitoring and surveillance. Information presented in this chapter emphasizes how LK can provide early warning for detecting and understanding changes in wildlife populations and can help identify research/surveillance priorities, while facilitating the co-management process.

This part of the research contributed to identifying and quantifying major population declines for muskoxen that were characterized by a decreased proportion of young, and provided an extensive dataset on health, morbidity and mortality, helping to generate hypotheses to explain changing demographics. For example, harvesters' observations supported the hypotheses that orf virus might have emerged and *Brucella* might have increased in the study area since the start of the decline. These pathogens are known to influence population dynamics of ungulates through decreased recruitment (Thorne, 2001; Vikøren et al., 2008). At the time of our study, little or no scientific information was available about those pathogens in the study area.

In participatory surveillance applied to livestock diseases, conventional veterinary diagnostics are used to triangulate (i.e., cross-check) PE data with the intent to confirm and further characterize pathogens (Mariner and Paskin, 2000; Catley et al., 2012). Triangulation with laboratory diagnostics was applied in this research by using biological samples obtained through a hunter-based sampling program for muskoxen that has been organized and coordinated in the community since 2014, field disease investigations that had been undertaken following the report of morbidity or mortality cases, and available archived collection. The following chapters provide two examples that illustrate how SK and LK were combined, leading to improvement of the surveillance output.

<u>Chapter 4</u> presents results derived by a field disease investigation that was triggered by observations recorded through the hunter-based sampling program. Within one harvested muskox this field disease investigation enabled the laboratory confirmation of pathogens hypothesized to be present in the study based on PE data, including orf virus (i.e., first laboratory confirmed case in a muskox in the study area and in the Canadian Arctic) and *Brucella suis* biovar 4 (i.e., second confirmed case in a muskox in the study area after the first isolation in 1998). Finding orf virus and B. *suis* biovar 4 not only corroborated the observations made by local knowledge holders but also added an important public health dimension to this case given the zoonotic potential of both pathogens. This case together with the available LK created questions about the role of orf virus and *B. suis* biovar 4 in the documented population decline. This work exemplifies the importance of thorough wildlife disease investigations undertaken by qualified health professionals in collaboration with local residents and harvesters.

<u>Chapter 5</u> presents the results from a targeted survey that was undertaken to evaluate status and trends of *Brucella* exposure and to summarize information on *Brucella* infection in muskoxen of the study area from 1989 to 2016. This work includes information that goes beyond the Cambridge Bay area and provides a summary of the available knowledge on *Brucella* in muskoxen of the Canadian Artic. In this research, the data available for the Cambridge Bay area are interpreted and discussed in light of the PE data previously gathered (summarized in Chapter 3). "Special problems" that limit the ability to identify disease in wildlife have been highlighted by several authors (e.g., Wobeser, 2007; Godfroid et al., 2010; Gilbert et al., 2013; Ryser-Degiorgis, 2013; OIE, 2010, 2014). This chapter illustrates the numerous challenges that exist for inferring disease status of wildlife based on diagnostic testing of samples (e.g., absence of validated tests, missing information on the study population, inadequate sample sizes or sampling methods) and highlights the value of triangulating SK with LK to improve this understanding.

Finally, **<u>Chapter 6</u>** summarizes the overall surveillance program piloted for muskoxen in Cambridge Bay. This chapter integrates the findings from the overall PhD research and discuss lessons learned in the broader context of participatory surveillance applied to free-ranging wildlife. Based on the knowledge and experience gained, the final natural step of this doctoral research is proposing a participatory framework that combines LK with SK and can contribute to enhancing health and disease surveillance for both harvested and non-harvested wildlife in those settings characterized by the presence of local informants.

Rapid unprecedented environmental changes worldwide create an urgent need for understanding and monitoring wildlife health for effective management and conservation of wildlife populations (Deem et al., 2001; Stephen, 2014), as well as for the protection of human and animal health (Kuliken et al., 2005; Stephen and Duncan, 2017). This research is a valuable and timely contribution to help address such needs through the development of the field of participatory wildlife health surveillance.

1.5.3.1. Chapter contributions

Chapter 2 and 3: MT designed the studies. MT conducted field data collection, transcription of the interviews and analyses. SC, CG, SK contributed to study design. MT wrote the manuscripts under revision of and discussion with SC, CG, SK, who also edited the manuscripts.

Chapter 4: MT organized and undertook the disease investigation in the field and coordinated further laboratory analyses. MT, PD conducted detailed pathological and histological examination of tissues; CD performed the confirmatory PCR for diagnosis of orf virus and assisted with phylogenetic analyses on *Parapoxvirus* sequences; OS, CT performed serology, microbiology, and PCR testing for *Brucella*; PK assisted with morphological and PCR analyses of protostrongylid larvae retrieved in fecal samples. MT wrote the manuscript, which was edited by all co-authors.

Chapter 5: MT, BE, SK, SC ideated the study. MT coordinated the hunter-based sample collection and organized field disease investigations from 2014 onwards. BE, TD, MB, MD, SC collected samples prior to 2014. Historical analyses were coordinated by BE and JH summarized the information. IN performed A/G iELISA analyses. MT compiled, analysed and interpreted results and wrote the manuscript. All co-authors edited the manuscript.

Chapter 6: MT ideated and wrote the manuscript under revision and discussion with SC, SK, CR. MT led all components of the research summarized in this chapter.

Chapter 2. Iqaluktutiaq voices: local perspectives about the importance of muskoxen, contemporary and traditional use and practices

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Abstract

Understanding human-wildlife relationships and interactions is crucial to implementing policies and practices related to wildlife and public health that are locally relevant and adapted to local communities and needs. With the goal to inform a community-based participatory muskox health surveillance system in the community of Iqaluktutiaq (Cambridge Bay) on Victoria Island, Nunavut, Canada, we explored the importance of muskoxen for community residents, their relevance for local food security, and the relationships and interactions between *Iqaluktutiamiut* and muskoxen. We investigated these themes through individual interviews of 30 community members identified as muskox experts by local organizations. Results were finalized and refined with 26 interviewees in feedback sessions. For Iqaluktutiaq residents, muskoxen have nutritional, economic, sociocultural and environmental importance. The decline of muskoxen documented locally has a multidimensional impact on the community, with negative effects on all the domains explored, from food security to the integrity of the cultural system. Description of subsistence and commercial harvesting and butchering practices are an asset for the successful implementation of participatory muskox health surveillance activities (e.g., hunter-based sampling), as well as interpretation of derived data (e.g., local knowledge on muskox diseases). Knowledge of specific harvesting practices that might increase exposure to zoonotic agents is also relevant for designing targeted strategies to mitigate public health risks. This research underlines how careful examination of the human-wildlife context through local perspectives can benefit wildlife health surveillance, public health and wildlife co-management outcomes.

Keywords: co-management, food security, hunting, Inuit knowledge, traditional and local knowledge, participatory research, public health, risk communication, risk perception, wildlife health surveillance, *Ovibos moschatus*, Cambridge Bay.

2.1. Introduction

In the Arctic, the health and sustainability of wildlife populations directly influence the nutritional and social health of individuals and communities and contribute to the health and resilience of local social-ecological systems. Wildlife, as a source of traditional foods or ‘country foods’, play an important role in promoting both food security and the health of northern people (Kuhnlein et al., 2001, 2009; McGrath-Hanna et al., 2003; Berner and Furgal, 2005; CINE, 2005; Myers et al., 2005; Loring and Gerlach, 2009) in an area particularly vulnerable to food insecurity (Meakin and Kurvits, 2009; ICC, 2012). One assessment for Nunavut, Canada’s northernmost territory, with about 37 400 inhabitants (Nunavut Bureau of Statistics, 2017), suggests 68.8% of households are food insecure, and this rate is expected to increase as the population continues to grow (Rosol et al., 2011). The income-in-kind or replacement value from country foods and the collateral cash economy associated with traditional food harvesting (e.g., selling of pelts and associated manufactured products) are significant, although difficult to capture analytically (Myers et al., 2005). For instance, it has been estimated that the replacement value of caribou meat harvested each year from the Qamanirjuaq herd alone was $15.1 million (BQCMB, 2013). Finally, and equally importantly, wildlife harvesting activities are intrinsically connected to Indigenous social and cultural identity (Myers et al., 2005), and they contribute to shaping local knowledge systems (Berkes et al., 2000; Usher, 2000).

The alterations that northern ecosystems are facing under the pressure of rapid environmental and socio-economic changes are an increasing concern for the negative impact they may have on wildlife populations (Meakin and Kurvits, 2009). For instance, shifts in the geographic distribution of species (McCarty, 2001; Parmesan, 2006; Post et al., 2009; Kashivakura, 2013; Kutz et al., 2013a), altered host-parasite interactions (Harvell et al., 2002; Kutz et al., 2005; Altizer et al., 2013; Gallana et al., 2013), and ‘mismatch’ between the availability of resources and physiological needs of wildlife species can pose a threat to the health, sustainability, and resilience of Arctic wildlife (Parmesan, 2006; Post et al., 2009). In addition, as demonstrated in other contexts where Indigenous minorities have been moved into permanent settlements, life in centralized communities can contribute to the increased localization of harvesting pressure on wildlife populations and consequently to the depletion of local resources (Hitchcock, 1995; Leeuwenberg and Robinson, 2000). This pressure, when combined with modernized hunting practices and technologies and decreased diversity in country food consumption, may threaten the viability of local populations of free-ranging wildlife. Finally, sustainability of wildlife and safety of wildlife for human consumption are becoming increasing concerns in the Arctic because of the emergence of new pathogens, including zoonoses. For example, Kutz et al. (2015) documented unusual muskox mortalities associated with the emergence of the zoonotic bacterium *Erysipelothrix rhusiopathiae*, which has been newly isolated in muskoxen and apparently is new in the Arctic. All these phenomena warrant special attention because they can modify the resilience of Arctic socio-ecological systems.

In these rapidly evolving contexts, wildlife health surveillance is crucial to allow the timely implementation of strategies for wildlife conservation, sustainability and population viability, as well as for the protection of human health (Kutz et al., 2013b; Stephen and Duncan, 2017). The critical first step towards delivering improved outcomes for both people and wildlife is understanding the local human-wildlife relationships, including how wildlife is culturally and economically valued, what type of interactions exist between people and wildlife populations, and what outcomes (both positive and negative) result from these interactions (Decker et al., 2012). In addition, in communities that largely depend on the harvesting of wild game for subsistence, it is valuable to understand the local practices for harvesting, preparation, and consumption of wildlife meat, as well as, people's perceptions of its safety for humans, when delivering information on wildlife diseases. Communicators can thus better frame messaging on wildlife health and diseases so that resource users do not exaggerate or underestimate the threats to their health (Decker et al., 2010; Stephen and Duncan, 2017).

In this study, we explored the multifaceted interactions between people and wildlife, with specific reference to the residents of Iqaluktutiaq (Nunavut, Canada) and muskoxen (*Ovibos moschatus*). This research is part of a broader project focused on gathering traditional and local knowledge to inform a community-based participatory muskox health surveillance system in Iqaluktutiaq. Our present work, including methods and findings, serves as a model to better explore the complex human-wildlife interface in other settings characterized by traditional food systems and contributes to efforts to promote improved socio-ecological resilience of rural northern communities.

2.2. Methods

2.2.1. Study area

We conducted our study in the community of Iqaluktutiaq (Cambridge Bay), located in the southeastern part of Victoria Island in the Kitikmeot Region of Nunavut (Fig. 2.1). The community grew around a trading post that was settled in 1921 by the Hudson's Bay Company. Starting in the 1950s, more and more Inuit started to live year-round in the community, which grew rapidly with the increase in municipal services (Municipality of Cambridge Bay, 2017). Currently, the population of Iqaluktutiaq is approximately 1600 people, the majority of whom are Inuit (Statistics Canada, 2016). Although life in the community is rapidly changing with influences from southern Canada, unemployment remains high and harvesting free-ranging wildlife is essential to the subsistence economy. In Iqaluktutiaq, as in most Arctic communities, gardening and agriculture are limited, so any fresh food other than country food has to be flown in (Myers et al., 2005; Loring and Gerlach, 2009; Meakin and Kurvits, 2009).

Another important year-round resident of the Iqaluktutiaq area is the muskox (*Ovibos moschatus*). An Ice-age survivor that was considered almost extinct on the Arctic mainland at the beginning of the 20th century, the muskox was finally protected in Canada in 1917 (Lent, 1999). With the implementation of active management (hunting bans), muskox numbers increased, especially on Banks and Victoria Islands in the Canadian Arctic archipelago, and since the 1960s, muskoxen have recolonized their historic range (Dumond, 2006; Gunn and Patterson, 2012) (Fig. 2.1).

Recently, however, local and scientific knowledge show a decline in muskox numbers in the Iqaluktutiaq area (Leclerc, 2015; Tomaselli et al., 2018b) and increasing evidence, including disease emergence and mortality outbreaks, that the health status of muskoxen has deteriorated (Kutz et al., 2013a, 2015, 2017; Tomaselli et al., 2016, 2018b). These combined events raise concern regarding current and future sustainability and resilience of muskoxen in the study area.

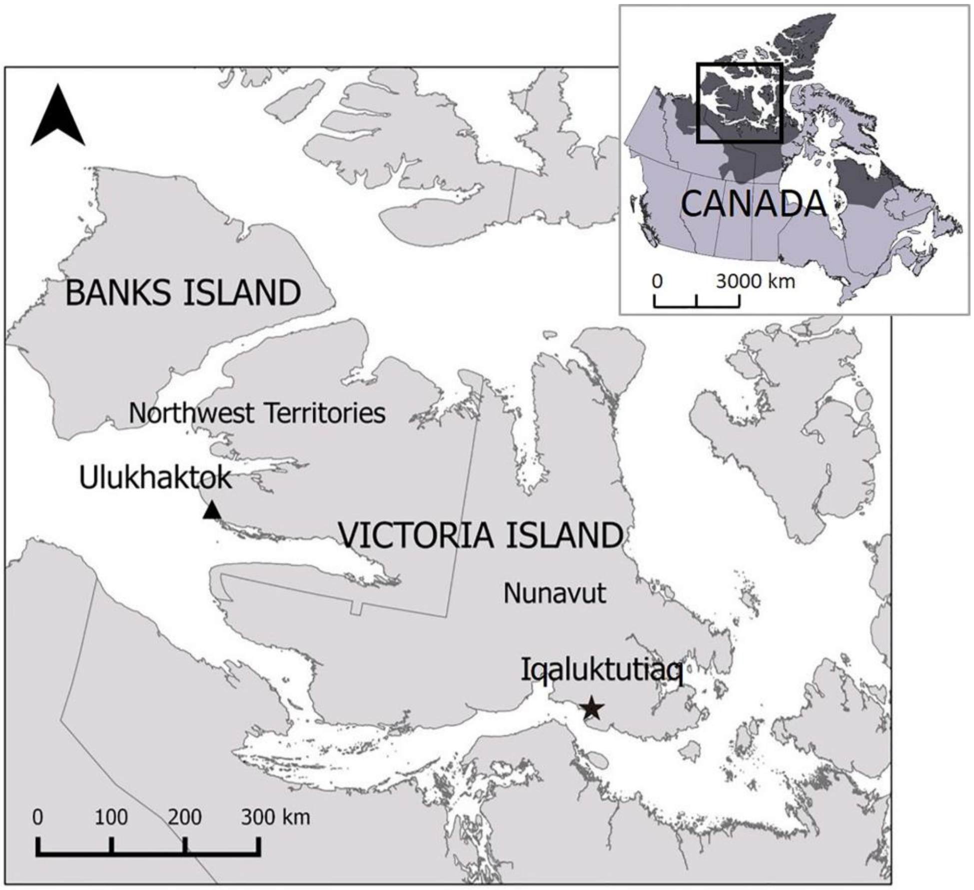

Figure 2.1. Map of Victoria Island showing the communities of Iqaluktutiaq, Nunavut (area of study) and Ulukhaktok, Northwest Territories. The current known distribution of muskoxen in Canada is shown in dark grey on the smaller map at top right, using information from Kutz et al., 2017. Map generated in QGIS 2.8.9.

2.2.2. Interview process and data analyses

From July to September 2014, we performed 30 individual semi-structured interviews in the community of Iqaluktutiaq. We recruited participants that were identified as 'muskox experts' by the Kitikmeot Inuit Association (KIA) and the local Ekaluktutiak Hunters and Trappers Organization (EHTO) (purposive sampling; Davis and Wagner, 2003). We also asked participants to identify additional community experts to include in our study (snowball technique; Green and Thorogood, 2014b). We adopted the principles of grounded theory and defined the sample size by the thematic saturation approach: that is, we stopped recruiting participants when no new information or themes emerged from the narratives of new interviewees (Watling and Lingard, 2012; Green and Thorogood, 2014b). Participation was voluntary, with written informed consent, and interviewees could withdraw at any time during the study. Anonymity was assured by assigning each participant a pseudonym and following a standard protocol for data and identity management. A monetary compensation, the amount set by the KIA, was issued after the interviews. The length of the interviews varied among participants, with an average of approximately two hours.

The questions explored participants' perspectives on the importance of muskoxen, the relative importance of muskoxen as country food, muskox harvesting and butchering practices, including meat storage, and preparation and consumption methods (see Appendix A). Finally, we explored participants' concerns regarding the local muskox population. Open-ended questions were used in the interview process to avoid constraining interviewee responses to predetermined categories and to allow for more open dialogue and emergence of themes (Huntington, 2000). Participatory proportional piling techniques (Chambers, 1994c; Mariner and Paskin, 2000) were implemented to further explore the relative importance of different country foods in the diet of participants. Proportional piling exercises use a fixed quantity of counters as a unit of measure to help participants identify proportions (Mariner and Paskin, 2000). Here we used a fixed mass (0.5 kg) of beans that were measured with a measuring cup with a percentage scale to allow rapid identification of proportions (Tomaselli et al., 2018b: Appendix B, in this thesis Appendix G). We began by asking questions about the relative annual proportion of country food and store-bought food consumed and how these proportions have changed over time. Then, we explored the relative importance of muskoxen as food, measured against the total amount and variety of country foods consumed, and inquired whether and how proportions have changed over time. Descriptive statistics were used to analyze and report quantitative data originating from the proportional piling exercises.

During the interviews, field notes were taken and the entire interview was audio-recorded to allow for thorough thematic content analysis (Green and Thorogood, 2009c; Braun and Clarke, 2006). Audio records were analyzed by coding the data in themes using both deductive and inductive approaches. Key information for each theme was transcribed to allow for comparison among interviewees and emergence of patterns within the data (Green and Thorogood, 2009c). Once the information was interpreted and summarized, we verified the findings by presenting the results to participants through individual or group community feedback sessions held in May 2016 (Johnson, 1997; Green and Thorogood, 2009c). Participants had the opportunity to comment on the aggregate data presented in order to corroborate, further refine, and expand on or clarify results. A local interpreter and translator suggested by the KIA was present during interviews and feedback sessions with two Elders whose first language was Inuinnaqtun and who were not fluent in English. The remaining participants did not require and request the presence of the interpreter.

2.3. Results and discussion

The participants included 28 year-round community residents, of whom 23 were Inuit (nine Elders, and 14 adults) and five non-Inuit, and two summer residents (commercial float plane pilots). For the community of Iqaluktutiaq, 'Elder' refers to an Inuk of 60 age or older who has earned respect as an Elder from this community. Participants ranged from 30 to 84 years of age, with an average age of 53 years. Interviewees were predominately male, with only five females among the 30 participants. Finally, 26 of the 30 interviewees participated in feedback sessions and all agreed with the results we present here.

2.3.1. Importance of muskoxen

All 30 participants considered muskoxen to be important at both the individual and community levels. Four major themes emerged from participant narratives: nutritional, sociocultural, economic, and environmental importance. Subthemes identified in each of these domains provide a deeper understanding of participants' values and attitudes toward muskoxen.

2.3.1.1. Nutritional importance

Muskoxen are considered to have been particularly important historically as a source of food, and they remain so today. Sharing meat with the immediate and extended family network and community members is a practice deeply connected to Inuit culture and tradition: *"my family loves the muskox meat, it is good for people to eat muskox meat and share it with others, especially with Elders … My parents ate lots of muskoxen ... Elders like that a lot, muskox was important to them"* (Elder, Interviewee 9). Muskoxen were historically considered a reliable food resource to harvest, possibly owing in part to their sedentary nature, especially when other country foods were scarce. As one Elder (Interviewee 5) explained, *"muskoxen have always been our meat, an important source of food that we used to share with families. Muskoxen were always there also when other foods were scarce, but now muskoxen are scarce."* Even though, at the time of our study, muskoxen were less abundant in the Iqaluktutiaq area then they used to be (see Tomaselli et al., 2018), the harvesters we interviewed continued to consider them a reliable source of country foods. Muskoxen are particularly important to offset the local scarcity of caribou, a situation occurring during our study. As an Inuk harvester eloquently explained, *"the importance of muskox* [as a source of food] *fluctuates along with the abundance of caribou. When caribou are plenty we don't get as many muskox, and we do not rely on muskox at that time* [but] *we tend to get more muskox when the caribou are not plentiful…this* [transition from caribou to muskoxen in Iqaluktutiaq] *started in the last couple of years … Even this summer we are having* [a] *hard time getting caribou, so I know a lot of people would be harvesting muskox this fall, just to have the meat"* (Interviewee 13).

Finally, participants highlighted that muskoxen are bigger and heavier than caribou and provide more meat per hunt effort: this further emphasizes the critical value of muskoxen for local food security. "*There is a lot of meat in them* [muskoxen]…*They are bigger than caribou,* [you can get] *a lot of meat out of them…and you can give them out to old people too…or when somebody has no skidoos we share it* [muskox meat]*"* (Elder, Interviewee 26) and then, *"the meat you buy at the store here is pretty expensive. So, there is value in getting a muskox because the meat will last longer than a caribou…you know when people don't have an income, they might be able to buy bullets and gas to go and harvest a muskox and when they come back it will last a long time"* (Inuk harvester, Interviewee 11).

2.3.1.2. Sociocultural importance

The sociocultural importance theme emerged from participants' narratives and had three subthemes: traditional use, community identity, and psychophysical wellbeing.

The muskox is an important part of Inuit culture, contributing to the traditional subsistence economy by providing food, tools, clothing, and shelter, as well as to social life, by inspiring art and games. For example, historically, horns were useful for making hunting tools like the *kakivak* (fishing spear); bones were used to make scraping tools to soften caribou hides before sewing them; ribs were useful as drilling tools, to make sleds runners, and even bone arrows. Bones were also used to make games for children, and horns were carved to create art. The durable and highly insulating muskox hides were useful for bedding, and both skins and hides were used to make *kamiit* (boots) and parkas, while the *qiviut* (muskox inner wool) was used inside *kamiit* and mitts because of its insulating properties. Additionally, bones were also used to make games for kids and horns were carved to create art. One Elder (Interviewee 3) explained, "*I still use the skin for my bedding, like a foam. If you live in an igloo or in a tent you like to put it* [the muskox hide] *on the ground: you put the skin down and the fur up. Other people like to use it for the kamik … and there are some bones of the muskox that my grandfather I have seen to make scraping tools* [with], *so we could soften the skin of caribou before mom sewed some* [skins] *together."* According to participants, muskox hides are still commonly used for bedding, especially in campsites, but other traditional uses are less common now.

The muskox is considered to be a unique, iconic animal; an integral part of the landscape; and connected to Inuit culture and identity: *"muskox means identity, where we come from!"* (Inuk woman, Interviewee 13). Reflecting on Iqaluktutiaq identity, some participants recalled that the traditional community games held every spring in Iqaluktutiaq are called *umingmak frolics* (muskox games). Additionally, the annual muskox commercial harvest, although suspended in 2012, was also considered to have helped shape community identity: "*muskox is part of our community identity! We used to do our annual muskox harvest here on the island … I think that the community identity kind of grew with the commercial harvest."* (Inuk hunter, Interviewee 11).

Muskoxen are also valued for their aesthetic value: *"personally I will never get tired to see muskoxen. They look so nice and they have a so nice temperament"* (non-Inuk resident, Interviewee 12). For the Inuit that we worked with, the connection with muskoxen also has a deep spiritual meaning, a meaning so strong that it could influence the wellbeing of a person. In summer 2014, when we conducted the interviews, it was evident to community members that the local muskox population was in decline (Tomaselli et al., 2018b). In this context, an Elder (Interviewee 3) said, *"I miss their presence out there* *because I love watching them…I hope to see them before winter comes again. When you don't see muskoxen it is kind of lonely. It is lonely when you don't see part of your animals that roam close by your community."*

2.3.1.3. Economic importance

Many economic opportunities are associated with muskoxen. Community revenue and business development are two sub-themes that emerged in participant narratives about the economic importance of muskoxen.

Muskox commercial harvesting and outfitted hunting activities were consistently highlighted as creating important employment opportunities for the community. Interviewees explained that the annual harvest provided a number of jobs for local hunters, Elders, and women who were employed in either harvesting or processing activities: *"for the community, muskox is important because, when they had the muskox harvest, hunters, haulers, and abattoir workers were employed, and I say 'had' because they haven't had the muskox harvest for about two or three years now"* (Inuk hunter, Interviewee 11). The muskox commercial harvest was suspended in 2012 because of local declines of muskoxen. Participants also highlighted the economic importance of the outfitted muskox sport hunts as these are still organized and provide a regular source of revenue to local Inuit harvesters employed as guides. One Elder (Interviewee 16) said, *"it* [the muskox] *is important for the community, especially for the sport hunters. It makes a little bit of income for people in town, so it keeps up the* [local] *hunters to be able to get gas and the other stuff they need to go out on the land."* The selling of carved muskox horns is another economic activity contributing to the local cash economy. As another Elder (Interviewee 3) explained, *"an artist can make art out of the* [muskox] *horns, and it is good for them to make their own money if they need to buy things for their tables, to pay for their power, telephone* [and bills]*"*. Finally, the *qiviut*, harvested from the muskox hides to be sold commercially and used for knitting fine garments, is a source of revenue for the local Hunters and Trappers Organization.

Participants indicated that all of the above economic activities increase the revenue of community members and provide opportunities for entrepreneurship. One interviewee even emphasized that the economic potential of muskoxen has not been fully realized. He suggested that muskoxen could be a key for the future economic development of the community through ecotourism activities and local processing of *qiviut*: *"they* [muskoxen] *could be even more valuable. I think people should be looking at tourism for muskox…There is not really anything* [for economic development] *except for sport hunters, but nothing for people who would like just to see them; and the wool could be used more than what has been used now."* (Inuk hunter, Interviewee 14). This last concept, although expressed at the time of the interviews by only one participant, was embraced by the other interviewees during the feedback sessions.

2.3.1.4. Environmental importance

Although less represented in participant narratives, perhaps because it is considered an obvious value, the environmental importance of muskoxen nonetheless emerged as a separate theme in the narratives of three Inuit participants. The long-lasting ecological role of the muskox was discussed by one participant who recognized the historical importance of this Ice-Age survivor in the northern ecosystem. Finally, another interviewee identified the contribution of muskoxen to local biodiversity and pointed out the difference between the mainland and island subspecies. The uniqueness of the island muskoxen is also believed to contribute to the identity of the island community of Iqaluktutiaq: *"I have heard* [of]*, and I have seen myself, muskox from further south, from the Bathurst Inlet area* [on the mainland]*, that have longer legs than the muskox out on the island. So, when I talk about identity, that's what I mean: the different species!"* (Inuk hunter, Interviewee 13).

At the time of the interviews, participants reported a substantial decline of muskoxen in the Iqaluktutiaq area (Leclerc, 2015; ECCC, 2017; Tomaselli et al., 2018b). Participants provided valuable insights into the impact of the local muskox decline on both the community and individuals and this is clearly expressed in many of the quotes (Appendix B). Community residents consider reduced number of muskoxen to have negative economic consequences, significant implications for food security, and negative effects on the social and cultural system. Furthermore, the absence of muskoxen is considered a barrier to the connection and flow of knowledge among generations, especially between Elders and youth. An Inuk hunter (Interviewee 15) emphasized this concept by saying, *"I have learned from Elders that muskox are* *important and I am the next* [generation] *after the Elders…It is important that younger generations try to keep the tradition, but muskox herds are dwindling."*

2.3.2. Muskoxen in the traditional and contemporary food system

We explored the relative importance of muskoxen in the context of the traditional food system with the 28 year-round residents (23 Inuit and five non-Inuit), but we excluded the two summer residents. Results for Inuit and non-Inuit community residents are reported separately. Appendix C summarizes the average consumption of country foods and store-bought foods in the annual diet of participants. Because participants included in this study were mainly active hunters, we don't think that the data on county food consumption reflect the community as a whole. However, we do believe that these data are an approximation for the dietary behavior of hunters within the community.

2.3.2.1. Inuit

No differences between age groups (Elders vs. adult Inuit) were found with respect to the relative proportions of country foods, so these data are reported combined.

Inuit participants ate three to 10 types of wild game, of which eight were the most common, and Elders reported never eating fewer than six types of country foods. The three most consistently consumed country foods were fish, caribou, and muskoxen. The annual median relative proportions of the different types of country foods are reported in Figure 2.2.

Caribou represented 30% and fish 25% of the annual country food intake, while muskoxen accounted for only 10%. However, the amount of muskox consumed for subsistence depended on the local availability and accessibility of caribou. Caribou are generally preferred over muskoxen for several reasons, including personal preference, but also because they are easier to butcher, transport, and process than muskoxen: *"the muskox is different than the caribou. It is more tougher, more heavier…it is more needy* [more effort is required to butcher the carcass and transport meat packages] *than caribou"* (Interviewee 15). However, if caribou are not locally available or accessible, the amount of caribou that hunters would harvest is replaced by muskox (Appendix D). This form of prey switching helps stabilize the country food supply system and contributes positively to food security when muskoxen are available. This situation was described historically in the Iqaluktutiaq area when caribou were further away from the community: *"in the past, we were eating more muskox* [instead of] *caribou. Maybe half* [of what is caribou now was replaced by muskox] *in the 60s and 70s"* (Interviewee 25). The diet switch from caribou to muskox was described as happening again at the time of our study, *"we are at a point that in the last three years, two years we are not getting as much caribou, so we know that we need to get one or two muskox* [instead]*...Just today one of my friends told me that he got a muskox and he never got a muskox before, just because they are not getting the caribou"* (interviewee 13).

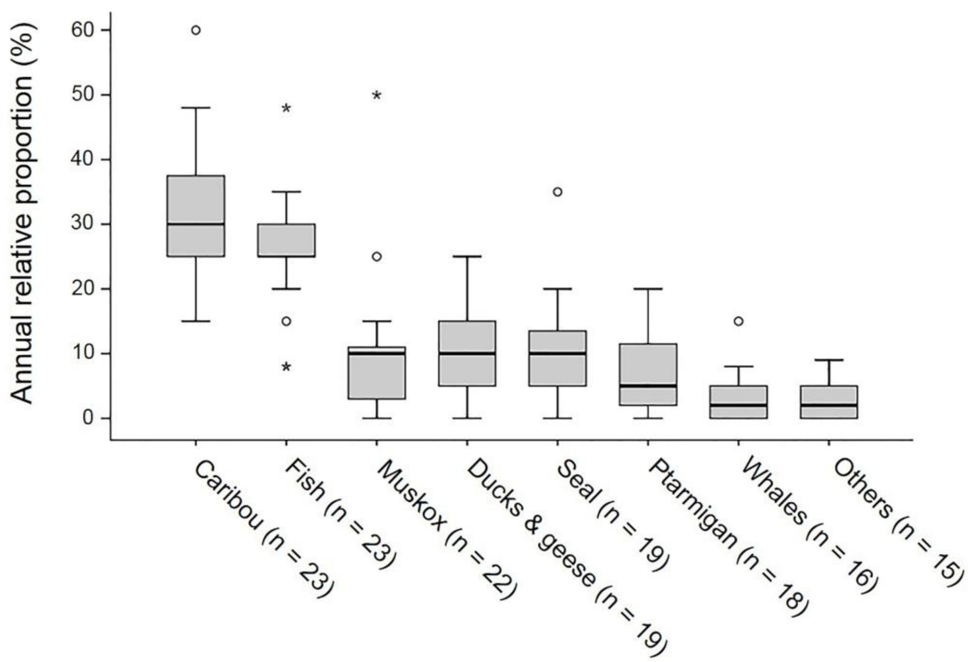

Figure 2.2. Box plots show the relative proportion of country foods consumed annually by 23 Inuit interviewed in Iqaluktutiaq in summer 2014, with median values (heavy horizontal lines), first and third quartiles (lower and upper limits of box), and ranges of data (vertical lines), as well as points outside the ranges: outliers (empty circles) and extreme values (asterisks). On the horizontal axis, the parenthesis after each species shows the number of participants who reported consuming it. "Others" include hares, polar and grizzly bears, Arctic foxes, and moose.

This concept was well illustrated by Interviewee 23, who has been switching his diet from muskoxen to caribou when the last one became available close to Iqaluktutiaq (from 2000 to 2010); progressively, since 2010, he had transitioned back to muskoxen because caribou became scarce again (Fig.

2.3; Appendix D). However, in contrast to the past, when muskoxen were increasing in number in the Iqaluktutiaq area, at the time of our study both caribou and muskoxen were declining (Leclerc, 2015; ECCC, 2017; Tomaselli et al., 2018). In this particular situation, the described caribou-muskox diet switch is likely to be ineffective to stabilize the traditional subsistence food system since neither species is predictably available (Fig. 2.3). In addition, the possible increased hunting pressure on declining muskoxen, as a consequence of the absence of caribou, might also negatively influence muskox future sustainability and resilience, further exacerbating food insecurity.

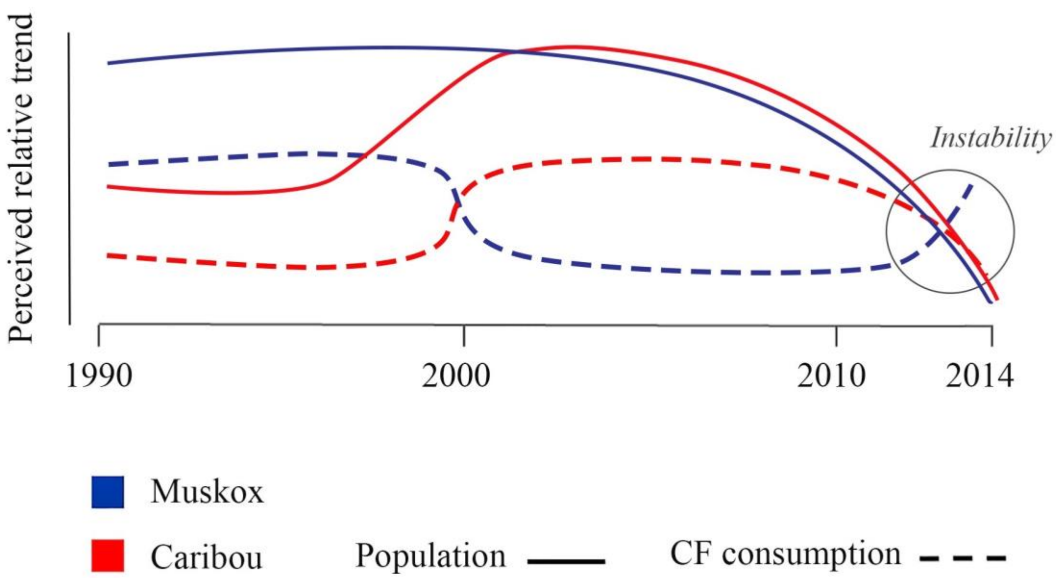

Figure 2.3. Country food (CF) choices of Interviewee 23 from 1990 to 2014 (dotted lines) in relation to the perceived population trend of muskoxen and caribou (solid lines). This graphic representation of the narrative and proportional piling exercise of Interviewee 23 exemplifies the muskox-caribou prey switch mechanism.

Both availability and accessibility of caribou and muskoxen were factors negatively impacting the traditional food system and harvesting practices. Interviewees explained that when animals were less accessible because they were further away from the community, hunters might be discouraged from practicing subsistence harvesting because the costs associated with those activities would increase, meaning that more gas and time are required for a successful hunt and harvest: *"I really cut down the number of* *muskox I hunt per year now, because we have to go really far away to hunt muskox and I just lost the interest in hunting them: hauling them back for 45 or 50 miles can be pretty tough…I just have a quad; I don't have a skidoo"* (Interviewee 15).

Finally, interviewees explained that the country food compensatory mechanism of muskoxen when caribou are fewer in number or not available is common in other communities. For instance, *"in Ulukhaktok,* [people's diet] *already shifted* [from caribou to muskoxen] *in the last 20 years...because the caribou were gone from the area…We were sending a lot of caribou meat to Ulukhaktok in the last 15 years"* (Interviewee 13). From this quote it is clear that there are several intra- and inter-community strategies (e.g., caribou-muskox diet switch and social sharing network of country foods among communities, respectively) that can contribute to the stability of the traditional food supply system. Any barrier to the sustainable implementation of these adaptive solutions can consequently have a negative effect on northern food security.

2.3.2.2. Non-Inuit

Four of the five non-Inuit year-round residents interviewed were originally from southern Canada but had moved to live long-term or permanently in Iqaluktutiaq; the fifth had always been a Nunavut resident. Three of the non-Inuit participants were also active hunters.

Responses from non-Inuit residents were similar to what we found for Inuit. Among non-Inuit residents, the number of country food types consumed varied from two to 10 different types. Fish, caribou, and muskox were the three most important country foods, and the annual country food intake of non-Inuit interviewees was represented by 50% (interquartile range, IQR: 1-25) fish, 25% (IQR: 30-70) caribou, and 15% (IQR: 15-30) muskox.

Local availability of wildlife clearly influenced the dietary behavior of our non-Inuit participants. Voluntary reduction of harvest was done because of declining caribou and muskox populations, and this reduction influenced both the overall amount of country foods consumed and the relative proportion of the different types of wild game harvested.

2.3.3. Harvesting practices

All participants interviewed had been harvesting muskoxen through the subsistence harvest, outfitted sport hunts, and/or the commercial harvest (Table 2.1). At the time of the interviews, 24 participants were still actively involved in subsistence muskox harvesting, sport hunts, or both, but not in the muskox commercial harvest (suspended since 2012). A brief description of the different types of harvest and associated practices based on participants' narratives is provided below.

Table 2.1. Number of Inuit and non-Inuit muskox hunters from Iqualuktutiaq (Victoria Island, Nunavut) interviewed in summer 2014 who participated in each type of muskox harvesting activity.

	Study participants involved (n)		
Types of muskox harvest	***Inuit***	***Non-Inuit***	***Total***
Only Subsistence	8	1	9
Only Sport	0	2	2
Only Commercial	1	2	3
Subsistence + sport	4	0	4
Subsistence + commercial	4	2	6
Subsistence + sport + commercial	6	0	6
Total	23	7	30

2.3.3.1. Subsistence harvest

Muskox subsistence harvesting had been practiced by 25 of the participants interviewed (22 Inuit and three year-round residents). Among these, 21 were still involved in subsistence harvesting at the time of our interviews. About 90% hunted one to two muskoxen per year, 5% hunted more than 2 muskoxen per year, and the remaining 5% harvest only one muskox every two years. Additionally, 90% of the hunters preferred to harvest sub-adult animals (2-3 years old) for subsistence purposes, with no strong preference between females and males. The remaining 10% was equally divided in preferring to harvest adult cows or juveniles (yearlings or calves), with calves especially preferred by Elders (Appendix E: Interviewee 26). We found that the favorite hunting season varied with respect to the hunters' personal preferences and was influenced by environmental conditions (e.g., cold in the winter vs. mosquitos in the summer); the vehicle preferred or available for travelling on the land (e.g., four-wheeler vs. snowmobile); preference for harvesting a muskox in excellent body condition (fall) or with a thick hide with lots of *qiviut* (end of winter - beginning of spring) (Appendix D: Interviewee 12).

One Elder shared his knowledge about traditional hunting management practices that he learned from his father, *"every time I see five animals in one herd I don't shoot it, when they are really lots, maybe 10 or 15, then I get one…when I was young my dad told me: ‹‹you can't shoot a muskox when there are only just* [a] *few* [animals] *in one* [herd]*››. You never know what might be happening …and when the young ones* (calves) *are coming out, March, April, May, you can't shoot them, never do that. They are important! To keep the little ones is important!"* Three other Elders shared another traditional hunting management practice: when they were young, their families used to hunt no more than one muskox per season and shared the harvested meat with the families living close by (Appendix D: Interviewee 3). In the feedback sessions, those four Elders added that they were also taught not to hunt pregnant cows.

Muskoxen hunted for subsistence were butchered in the field, regardless of the hunting season, and transported back to the community in segments identified as more easily transported 'meat packages' (see Binford, 1978). One Inuk participant described sometimes hauling the full carcass back to town, especially in extremely cold weather conditions, so that the butchering could be performed closer to home (Appendix D: Interviewee 27). However, during the feedback sessions, the practice of transporting whole animals was considered to be poor carcass handling, both from a food safety perspective and with respect to culturally appropriate Inuit harvest practices.

The field butchering activities for subsistence hunted muskoxen were described as consisting of first removing the head and the lower legs from the carcass, then skinning, next removing gut and internal organs, and finally quartering the animal. The quartered carcass and the rib cage was always brought back to town, and often the head and hide as well. However, participants described sometimes leaving the hide, the head, or both in the field to minimize the weight to haul back, especially in the summer using four-wheelers (quads) for travel (Appendix D: Interviewee 23 and 15). Similarly, feet and hooves were generally left behind, and the gastrointestinal tract was never brought back except on very rare occasions when selected parts (i.e., reticulum, stomach, and intestine) were to be consumed, a practice reported by only three participants. Most (80%) of the subsistence harvesters interviewed reported leaving the lungs at the kill site but saving the heart for consumption. Finally, half of the interviewed hunters reported also keeping the liver and kidneys; the latter were especially valued when surrounded by fat (Appendix D: Interviewee 14). A few participants reported saving the abdominal fat found on the greater omentum or surrounding the abdominal organs when the muskox was particularly fat (Appendix D: Interviewee 25 and 26). When the internal organs were kept, their use differed depending on the type of organ and the hunter's preferences and needs. Although organs were important both for personal consumption and for dog food, muskox hearts and livers were more often used for human consumption, while lungs and kidneys were typically fed to dogs (Appendix D). Similarly, muskox feet and hooves, when kept, were used either for personal consumption (considered delicacies by Elders) or as dog food (Appendix D: Interviewee 3 and 23). Additional information regarding the use and consumption of muskox organs is provided below.

Throughout our study, we documented traditional butchering practices in as much detail as possible. This information increased our knowledge and understanding about the interactions between study participants and muskoxen and is also useful for public health (i.e., risk of pathogen exposure) and management considerations, as discussed below.

One young Inuk hunter (Interviewee 8) explained a traditional butchering practice as follows: *"I have been always told ‹‹If you catch an animal that has a calf in it, either caribou or muskox*, [you] *cut* [the womb and take] *the calf out of the animal and leave it* [the calf] *on the land››. It didn't happen to me with muskox but* [with] *caribou yes it has* [happened]*".* The practice of extracting fetuses from the womb of harvested pregnant cows (muskoxen or caribou) was further confirmed during the feedback sessions by other participants, including Elders, and was explained to be associated with spiritual values. However, when we presented these findings during the feedback sessions to four of the oldest Elders interviewed, they unanimously commented that hunters should not harvest a pregnant cow in the first place: *"if a cow is expecting a calf you don't shoot it. But if younger hunters do that, they should learn not to do it!"*

(Interviewee 9). This comment stimulated further discussion about the importance of teaching traditional hunting practices to younger Inuit hunters, including how to recognize which animals to harvest and not to harvest, how to butcher them correctly, and the proper use of different parts of the carcass.

Finally, two Elders who grew up in the Bathurst Inlet area on the mainland shared knowledge that revealed cultural taboos in practice when they were young. These taboos prevented children from participating in the butchering activities and from seeing any internal organs with identified lesions or abnormalities. Such abnormalities were typically fed to dogs or, if the carcass was too badly affected, it was buried on the land. One Elder (Interviewee 4) explained: *"when I was growing up, I heard about disease in the heart…but* [as] *children we were not allowed to see the interior parts of an animal, and if the animals had a disease, we were not allowed to see the body and the lesions."* Although this practice might not be generalized to other areas or even to certain families, it is important to document it as this helps us to further understand the local context.

2.3.3.2. Outfitted sport hunts

Twelve interviewees were involved in the outfitted sport hunts: 10 were Inuit hunters employed as guides, and two were summer residents involved in the logistics of the muskox outfitting activities conducted in the summer. Participants explained that sport hunts in Iqaluktutiaq happened at fixed times of the year during spring (March-April), summer (August), and fall (October-November), though these times were subject to change depending on regulations. Animals typically selected by sport hunters were mature bulls with desirable coat and trophy characteristics (big horns and boss).

Butchering activities for sport-hunted muskoxen were described as being similar to butchering practices for muskoxen harvested for subsistence. The main exception consisted of maintaining the hide mostly intact. Depending on the type of taxidermy display preferred by the sport hunter, the muskox hide could be fully intact including the hooves (full body mount) or discontinued at the shoulder level (shoulder mount). It was explained that the horns were cut from the skull and the skull was generally left in the field unless the hunter requested a European skull mount. In this case, the full skull including the jaw was collected; however, this was reported to be a very rare occurrence. The internal organs were left in the field, often together with the rib cage, but the legs and selected meat cuts (i.e., backstraps and tenderloins) were brought back to camp or town. It was further explained that the sport hunters would typically save a few meat cuts, while the rest was shared with community members. However, participants also reported that muskox adult bulls were not particularly desirable as country food because their meat had a strong flavor and harder texture than the meat of the sub-adult animals normally harvested for subsistence purposes. An eloquent description of the butchering activities for sport hunts is provided by Interviewee 19 (Appendix D).

One discussion theme that emerged during the feedback sessions, triggered by the fact that the rib cages of sport-hunted animals are often left in the field, relates to the importance of ensuring that the meat of sport-hunted muskoxen is not wasted but is fully harvested and shared with community members. Other themes that emerged from the analyses of participants' narratives were the importance of Elders' delivering specific training on proper harvesting practices to Inuit guides and subsistence harvesters (especially younger hunters) to ensure that the carcasses are fully and properly harvested and used and that the meat (even the less desirable meat from muskox bulls) is fully consumed.

2.3.3.3. Commercial harvest

Of the 15 interviewees (year-round residents) who had been involved in the commercial harvest, 12 were employed in the harvesting, processing the carcass, or both, and the remaining three, in the logistics associated with the harvesting and processing activities (Table 2.1).

Participants explained that the community of Iqaluktutiaq has been harvesting muskoxen for commercial purposes since the 1980s. Initially, the activity was organized as a territorial harvest with a portable abattoir, and the meat was marketed in the territory. Subsequently, to meet the Canadian Food Inspection Agency (CFIA) requirements and standards for export outside the territory and even outside Canada, the abattoir was moved to town and muskoxen were harvested in an area around the community so that the carcasses could be butchered inside the inspected facilities. The federally inspected harvest was conducted once per year in winter, between February and March, and all muskoxen present in the herds were harvested as long as they were inside the allowed hunting area to comply with CFIA regulations.

Participants explained that the hunting area was within the radius of a maximum one-hour snowmobile ride from town so that the carcasses could be inspected at the abattoir prior to freezing. During the feedback sessions, three of the oldest Elders were concerned that female and male muskoxen of all age classes were harvested for commercial reasons; they considered this an inappropriate harvesting practice that was not aligned with Inuit tradition and "way of doing things". The last muskox commercial harvest took place in February-March 2012. After that, commercial harvesting was suspended because of the decline in muskox numbers in the permitted hunting area.

2.3.4. Food practices related to muskoxen

Questions about food practices were asked only to the 27 year-round residents who consumed muskoxen.

2.3.4.1. Storage techniques and practices

Interviewees stated that meat storage mostly depends on the season in which muskoxen are harvested. When the harvest occurs during the cold months of the year (late October to April), the meat, either quartered or cut in smaller portions, is stored in personal freezers or left outside, protected in shacks adjacent to the house, in meat boxes, or even cardboard boxes. By May, when the ambient air temperatures start to increase, the meat stored outside is then transferred into personal commercial freezers. When harvesting activities occur in summer, the meat is processed in smaller portions and mostly stored in freezers, but it can also be preserved dried as umingmak *mipku* (muskox dry meat).

Elders shared their knowledge regarding traditional ways to store muskox meat, which was typically preserved as umingmak *mipku* in the summer and frozen in the winter months. In early fall, when the ground was not yet covered in snow, the meat was often left on the land and protected in a food cache built with rocks. Later the next spring or early in the summer, when the snow and ice started to melt, the meat was recovered. This system allowed the meat to be preserved for longer periods of time and minimized the transport costs of food resources (Appendix D: Interviewee 3).

Although mostly preserved frozen during the winter months, the cached meat underwent the process of aging and fermentation. Caching, therefore, required refined technical expertise to avoid meat spoilage. During the feedback sessions, participants explained that, although less common today than in the past, caching is still practiced. Interviewees described different techniques (e.g., in the permafrost, on the ground, spreading the stomach content on the meat) and different names for caching meat, which further highlights the complexity of this highly specialized traditional preservation technology developed in a subsistence society based on hunting.

2.3.4.2. Muskox consumption and preparation

A list of the different muskox cuts and organs consumed by the study participants and the ways that they are eaten is provided in Table 2.2.

A major finding was that, in contrast to caribou consumption, not all muskox parts were regularly consumed because of personal preferences and also because of lack of familiarity with eating certain parts. For example, a young Inuk hunter (Interviewee 8) said, *"I have never tried the muskox head before…I have never tried the tongue. Curious though, caribou tongue is always really good. I eat the caribou head, the brain, the tongue, the meat of the jaw, but I have never tried muskox head before. I have never been taught how to eat it so I have never taught myself to cook it before because I have never seen it done".* This theme emerged among adult Inuit harvesters, but was reiterated also by one Elder (Interviewee 24) who said, *"caribou you eat it all, but no the muskox…the head I eat only in caribou, the eyes only in caribou, and the brain in caribou and the seal, the bone marrow only in caribou, I have never tried it in muskox…I don't know why. Nobody told me I guess".*

Traditional cultural taboos related to muskox butchering and consumption also emerged from participant narratives. Two Elders interviewed explained that they were not allowed as females to eat muskox internal organs: *"we were taught to eat the outside part of the muskox* [the meat] *but not the internal organs; those were fed to the dogs...especially the girls were not allowed to eat the inside part of the muskox; but we know in other part of the nuna* [land] *other people were used to eat the internal parts,* [like] *in Gjoa Haven"* (Elder, Interviewee 5). A similar cultural taboo was described by an Inuk hunter

(Interviewee 14) originally from Resolute Bay, who explained that for his family still living in Resolute Bay, muskox is a food *"that men eat and not a food that women eat"*. He associated this behavior with the traditional consumption of fermented muskox meat. Traditional and cultural taboos associated with muskox consumption and butchering might have local significance but need not be practiced in the same way in other regions, communities, or even families.

Table 2.2. Muskox parts consumed by year-round residents from the community of Iqaluktutiaq (Victoria Island, Nunavut, Canada) (n = 27). For each part, the number of interviewees who consumed it, and how they consumed it, is indicated.

Muskox part	***No. of interviewees***	***Food preparation***
Meat	n = 27	Cooked, frozen, dried, aged
Heart	n = 19	Cooked, frozen, raw
Tongue	n = 17	Cooked, raw
Liver	n = 11	Cooked, frozen, raw, aged
Kidney	n = 10	Cooked, raw
Bone marrow	n = 10	Cooked, frozen, raw
Eye balls	n = 7	Cooked, raw
Feet (ligament and tendons)	n = 7	Cooked
Ears	n = 5	Cooked
Hooves	n = 5	Cooked, aged
Abdominal fat	n = 4	Frozen, raw, dried
Nose and lips	n = 4	Cooked
Brain	n = 3	Cooked, raw
Lung	n = 2	Cooked, frozen, raw
Stomach	n = 1	Raw, aged
Selected part intestine	n = 1	Cooked, raw, aged
Reticulum	n = 1	Cooked

2.3.5. Participants concerns about muskoxen

Finally, all participants were asked if they had any concerns regarding muskoxen in the Iqaluktutiaq area, and the 28 participants who hunted or consumed muskoxen were also asked if they had specific concerns in butchering, handling, or eating muskoxen. General concerns emerging from participants' narratives pertain to local observations of muskox and the caribou decline, as well as to deterioration of both muskox and caribou health (summarized in Tomaselli et al., 2018). However, the majority of the interviewees didn't express any concern regarding butchering, handling or eating muskoxen, with the exception of two Elders and two Inuit hunters. The Elders explained that they were afraid to eat muskox meat because they were aware of recent observations of dead muskoxen on the land. They also explained that they felt the responsibility as Elders to be prepared to teach the next generation of Inuit about how to cope with changes in the health of muskoxen. One Elder (Interviewee 4) explained, *"now muskox is still food but we need to watch the meat. We need to prepare the meat because we hear stories about muskox dying and it is very scary to use the part of the muskox…we are concerned for the animals, we are concerned for our next generation. We need to prepare* [ourselves] *on how to prepare the next generation* [for] *these changes".*

One of the two Inuit harvesters (Interviewee 7) expressed a general concern about the safety of muskox meat, stating that *"we preferred the meat* [of muskoxen], *but now we heard that some muskox are having some kind of worms like …they are not too healthy now for eating".* This interviewee was clearly referring to the muskox lungworm, *Umingmakstrongylus pallikuukens*, which was described in recent years in the Iqaluktutiaq area (Kutz et al., 2013a). Although this lungworm is not a human health concern, this quote represents how the lack or misinterpretation of information can influence the perception of risk, consequently modifying or conditioning dietary behaviors. Finally, the other Inuk harvester (Interviewee 19) expressed concerns about handling muskoxen with signs of disease, stressing the importance of personal protection to avoid or minimize the risk of infection.

2.4. Summary and conclusion

Muskoxen have a multidimensional importance for Iqaluktutiaq residents. They contribute significantly to local food security in different ways. For example, muskoxen provide more meat per hunt effort in comparison to caribou, and they serve as an important 'replacement food resource' to mitigate the food insecurity arising from the unavailability or inaccessibility of caribou. Through our work, we found that the county food security system of Iqaluktutiaq may currently be under stress because of the concurrent decline of both caribou and muskoxen and the consequent unavailability of both species for successful harvesting. This situation may not only exacerbate food insecurity and lead to unhealthy food choices (i.e., increased consumption of lower quality market food), but also have a negative impact on the local economy and the social and cultural aspects of Arctic community life and well-being. It becomes urgent, therefore, to understand muskox population health and the drivers of muskox decline. This understanding will enable sound management aimed at the future sustainability of muskoxen, directly improving community food security and helping to maintain sociocultural identity, as well as sustaining opportunities for the local economy.

Through this work, we gained a better understanding of opportunities to develop a participatory surveillance program and the logistical challenges involved. Knowing which types of animals are harvested, when they are harvested, and what organs are valuable for consumption is relevant for developing and implementing a successful hunter-based surveillance program and the a priori evaluation of possible sampling heterogeneity and biases. In addition, understanding hunters' behavior and interactions with muskox carcasses (e.g., butchering practices, meat consumption) is essential for the correct interpretation of local knowledge on muskox health and diseases gathered through participatory methods as part of an active surveillance program (see Tomaselli et al., 2018b). For example, this research highlighted that lungs are minimally inspected, since they are generally discarded and not consumed; therefore, we can expect to have minimal observations of lesions localized in the lungs. Ultimately the aim of a muskox health surveillance program will be to enable informed management actions that promote both muskox conservation and public health protection. The information about the local context that is summarized here can serve to improve co-management strategies for muskoxen and disease prevention for humans.

We see our work as a first step toward understanding community concerns and collaboratively identifying solution strategies that align with Inuit culture, practices, and beliefs. This process has a direct value for improving co-management efforts and outcomes. For instance, we documented current practices that are in conflict with the Inuit traditional "way of doing things' that was meant to preserve wildlife resources. Elders identified the need to create formal teaching opportunities to pass on traditional harvesting practices to younger generations and less experienced hunters, so as to avoid harvesting the wrong animals (e.g., pregnant cows or leaders of the herds, both caribou and muskoxen), poor butchering (e.g., full carcass butchered in the community), or inappropriate use of carcasses (e.g., selection of certain meat cuts and wastage of others). They also reinforced the importance of teaching traditional and contemporary methods of preparing and consuming muskox meat so as to promote the consumption of country foods. We documented that the traditional knowledge of muskoxen is rapidly evolving in Iqaluktutiaq and its maintenance is threatened by the absence of the animals in the area, among other factors. In this context, it is a priority to preserve traditional knowledge on muskoxen and facilitate the knowledge exchange among generations, particularly between Elders and youth. To achieve this goal, we recommend continued participatory engagement of Iqaluktutiaq residents so as to promote a platform for knowledge exchange among generations. This exchange will also help a large variety of stakeholders (e.g., community and governmental organizations, health and wildlife professionals, researchers, and NGOs) to better adapt current programs to the local reality and needs and to identify new priorities.

With respect to public health, this study highlights the importance of both understanding the local harvesting context to better assess the risks of human exposure to hazards (zoonotic agents or contaminants) and adequately communicating such risks. For instance, we documented the practice of extracting the fetus out of the womb of hunted pregnant caribou or muskox cows. Considering the endemicity of brucellosis in caribou (Forbes, 1991), this practice could increase the risk of exposure to *Brucella* spp. for hunters.

Knowledge about such practices will aid in implementing mitigation strategies that are specifically tailored to the local context and thus more likely to be effective.

Risk communication applied to wildlife diseases and food safety is also crucial in the Arctic, where country foods play a critical role in food security and people regularly act as their own food inspectors (Myers et al., 2005). If risk communication is not appropriately implemented, perceived risks could modify people's dietary choices and contribute to the decline of traditional harvesting and country food consumption, which are already a concerning trend in the Arctic (Furgal et al., 2005; Myers et al., 2005; Myers and Furgal, 2006; Stephen and Duncan, 2017). However, even if appropriate messaging is used to communicate risks regarding the safety of wildlife for human consumption, it is still possible to produce undesired adverse effects. For example, some interviwees described muskoxen that became *"scary"* or *"not too healthy"* to eat. Participatory risk analysis can assist in the evaluation of risks, as well as the implementation of strategies that avoid or minimize unwanted effects when communicating risks (Grace et al., 2008). Wildlife and public health professional should work collaboratively with local communities and organizations to develop and implement appropriate risk communication strategies. Most importantly, the effects of the resulting messaging should be carefully evaluated so to avoid generating the undesired adverse effect of discouraging the consumption of country foods (Furgal et al., 2005), which remain the most nutritious and culturally appropriate foods in the Arctic (Myers et al., 2005; ICC, 2012). As one Inuk subsistence harvester we interviewed well explained, *"you stay full longer with country foods, and you stay energized"* (Interviewee 15).

Finally, this study reinforces the importance of community-based participatory research in the Arctic that empowers local people (in our case resource users) in the process of knowledge generation and identification of concerns, priorities, and solution strategies customized to the local reality and needs (Berkes and Jolly, 2002; ITK and NRI, 2006; Huntington, 2011; Brunet et al., 2014). Collaboration, better communication, and knowledge exchange among stakeholders are additional positive outcomes derived from this research. We recommend that local stakeholders build on our findings and further share knowledge and engage with residents of Iqaluktutiaq to fully understand specific aspects of the local context (e.g., community concerns and solutions, traditional butchering and management practices). On the basis of our experience, we encourage wildlife researchers and professionals working in subsistence-oriented systems to engage with local resource users with the aim to understanding the local human-wildlife context. Such engagement can contribute to generating better outcomes for both people and wildlife, and ultimately, to the future resilience of subsistence social-ecological systems.

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Chapter 3. Local knowledge to enhance wildlife population health surveillance: conserving muskoxen and caribou in the Canadian Arctic

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Abstract

Monitoring and surveillance of wildlife populations, including demographics and health, is often challenging, particularly in resource-constrained and remote settings. However, in areas characterized by subsistence oriented societies, the users of renewable resources hold a vast and holistic ecological knowledge about the natural environment. This knowledge can be instrumental for understanding and early detection of changes in wildlife populations. Using qualitative research methods and participatory epidemiology techniques we documented the local knowledge from resource users of the community of Iqaluktutiaq (Nunavut, Canada) to assess the health and population status and trends for muskoxen and caribou in the area. Semi-structured individual interviews, followed by group interviews, were implemented with 38 participants, and research findings were summarized and then verified with 31 interviewees. Local knowledge identified major declines in the number of muskoxen and caribou in the study area that were corroborated by subsequent aerial population estimates for both species. Observations made by participants allowed inference of possible mechanisms for the recent population declines, including poor recruitment, poor body condition, and increased morbidity and mortality (including endemic and emerging diseases). Engaging resource users in the process of knowledge generation was useful to identify further research priorities and fostered trust among parties that facilitated the subsequent collaborative development of management plans for these species. We use our experience to illustrate that local knowledge contributes to a holistic understanding of wildlife health and can serve as an early warning system to detect changes in wildlife populations. These participatory approaches are portable to other species and settings and can enhance conservation and co-management efforts for wildlife species worldwide.

3.1. Introduction

The importance of understanding wildlife health for sound management and conservation efforts (Deem et al., 2001; Peterson and Ferro, 2012; OIE, 2014; Stephen, 2014; Decker et al., 2016), and the importance of including resource users in both knowledge generation and decision making processes (e.g., co-management) (Berkes et al., 2000; Decker et al., 2012; Jordan et al., 2016; Predavec et al., 2016) have emerged as conservation priorities in recent years. However, measuring wildlife population health, including demographics and the diversity and status of infectious and non-infectious diseases (Hanisch et al., 2012; Stephen, 2014), faces major technical, logistical, economic, and even political constraints (Wobeser, 2007; Ryeser-Degiorgis, 2013) that make establishing wildlife health status difficult. Additionally, although the use of indigenous and resource users' knowledge is not new to conservation biology (Gadgil et al., 1993; Berkes, 2004; Brook and McLachlan, 2008), its specific application to enhance wildlife health assessment is in its infancy. Despite many challenges, effective wildlife management in an increasingly complex world requires a shift to a conservation paradigm that simultaneously incorporates wildlife population health assessment and meaningful participation of local resource users, recognizing the breadth and depth of their knowledge and their 'holistic way of knowing'.

Users of natural resources, especially those who live in subsistence-oriented communities, have firsthand experiential knowledge, as well as a long oral tradition of sharing knowledge about the status of, and ecological processes occurring in, their local environment, with this providing a holistic perspective for interpretation of their and other's observations (Gadgil et al., 1993; Berkes et al., 2000; Huntington et al., 2000; Rist and Dahdouh-Guebas, 2006; Berkes and Berkes, 2009; Huntington, 2011). Capturing this rich body of knowledge in a systematic manner may provide new and valuable information that cannot be obtained through scientific investigations alone and can greatly improve wildlife management.

In the past decades, there have been increasing efforts to include knowledge of indigenous and local people in natural resource co-management (Berkes et al., 2000), conservation of biodiversity (Johannes, 1989; Gadgil et al., 1993; Drew, 2004), and wildlife biology and ecology research (Ferguson et al., 1998; Huntington et al., 1999; Mallory et al., 2003; Steinmetz et al., 2006; Butler et al., 2012). In wildlife health and disease research, although collaboration with hunters is a common practice to enhance capacity for sample and data collection (OIE, 2014; Carlsson et al., 2016), only a few published studies use observations of resource users as a source of epidemiological data for disease detection (Madslien et al., 2011; Chen et al., 2012), or to record interspecific interactions at the wildlife-domestic livestock interface that may increase pathogen transmission (Brook and McLachlan, 2009; Brook, 2010). While there have been some efforts to use local knowledge to identify wildlife health issues and to inform better research questions (Brook et al., 2009; Carlsson et al., 2016), the formal and direct use of local knowledge to assess the health of wildlife populations, including status and trends, is currently missing.

One barrier to the use of resource users' knowledge in wildlife management may be the perception that it is not gathered in a rigorous scientific manner; consequently, it may be dismissed as little more than anecdotal (Gilchrist et al., 2005; Brook and McLachlan, 2005; Drew, 2005). The use of standardized and repeatable methods for documenting local knowledge is thus essential if results are to be trusted by wildlife professionals and are to be used in making critical wildlife management and conservation decisions. Participatory epidemiology (PE) and participatory disease surveillance (PDS) provide the framework for incorporation of local knowledge into wildlife management. These methods, developed in the 1990s from participatory rural appraisal (Chambers, 1994c) and implemented extensively in pastoral communities in developing countries, have been invaluable for enhancing veterinary surveillance capacity (Mariner and Paskin, 2000; Jost et al., 2007; Catley et al., 2012). Reliance on indigenous knowledge networks, particularly ethnoveterinary knowledge of participants, is a key concept in PE and PDS. Resource users are empowered in these systems, being the keepers of epidemiological data that is useful in multiple contexts, including detection of disease emergence (Jost et al., 2010), collection of historical and baseline morbidity/mortality data (Thrusfield, 2005), understanding disease impacts (Catley and Admassu, 2003), and contributing to disease eradication (Mariner and Roeder, 2003).

The Canadian Arctic serves as an ideal location for implementation and evaluation of participatory wildlife health surveillance programs using PE and PDS methods for several reasons. First, communities are physically remote and isolated and traditional scientific investigations are logistically difficult and extremely expensive. These communities have maintained a close connection with the natural ecosystem, including a historic continuity of subsistence use of natural resources, and have maintained traditional and local ecological knowledge systems (Usher, 2000). In these regions, climate change is rapidly altering ecosystem processes, including host-parasite interactions, (McCarty, 2001; Altizer et al., 2013; Kutz et al., 2014) the effects of which are unlikely captured by 'scientific' monitoring alone (Dowsley, 2009). Finally, wildlife co-management is a legislated requirement through aboriginal land claims agreements. For example, the Nunavut Wildlife Act (2003) mandates the integration of *Inuit Qaujimajatuqangit* or Inuit knowledge into wildlife management (Armitage et al., 2011).

As part of a broad project focused on the development of a participatory health surveillance system for wild muskoxen (*Ovibos moschatus*) in the Canadian Arctic, we investigated how indigenous and local knowledge can contribute to understanding wildlife population health status and trends. The objective of this paper is to illustrate a systematic approach for gathering important and often missing historic and contemporary epidemiological data about free-ranging wildlife. We do this by presenting a participatory study that documents local knowledge on muskox and caribou (*Rangifer tarandus*) populations in the Canadian Arctic. This work has the potential to be transferable to other wildlife species and settings, with this increasing the ability to include wildlife population health assessment into conservation programs while ensuring participation and empowerment of local resource users in co-management systems.

3.2. Methods

3.2.1. Terminology

Various terms have been proposed and used in the literature to refer to experience-based knowledge, including traditional and local knowledge, traditional and local ecological knowledge, indigenous knowledge, folk knowledge, and wisdom (Berkes et al., 2000; Usher, 2000; Huntington et al., 2002; Rist and Dahdouh-Guebas, 2006; Brook and McLachlan, 2008). In this paper, we use the term local knowledge (LK) to refer to a local body of knowledge, not associated with aboriginal ethnicity, but characterized by both historical and contemporary knowledge acquired through extensive observation of the environment and its species. Therefore, here LK includes, but it is not limited to, Inuit knowledge. In addition, we use the term ethnoveterinary knowledge (Mariner and Paskin, 2000) with specific reference to LK on wildlife health and diseases.

In this paper, we use the term wildlife health in the broadest sense, referring not only to the occurrence and/or exposure to infectious and non-infectious disease, but also including body condition, and population demographics and trends (Hanisch et al., 2012; Stephen, 2014).

3.2.2. Study area

Our study occurred in the community of Iqaluktutiaq (also known as Cambridge Bay) in the Kitikmeot Region, Nunavut, Canada. Iqaluktutiaq, with a population of approximately 1600 people, 79% Inuit (Statistics Canada, 2011), is situated on south-east Victoria Island in the Arctic Archipelago. The two ungulate species harvested by residents of this community are muskoxen, mainly island muskoxen (*Ovibos moschatus wardi*), and caribou, mainly of the Dolphin and Union herd (*Rangifer tarandus groenlandicus*). Muskoxen are resident on the island (Gunn and Adamczewski, 2003), while caribou migrate seasonally between the island (summer) and the mainland (winter) (Dumond et al., 2013). Hunting of both species, for subsistence by residents and for sport by guided hunters, contributes largely to local food security and community revenue (Kutz et al., 2017; Tomaselli et al., 2018a). This research program was initiated in response to community concerns about invasion and spread of two species of lungworms (Kutz et al., 2013), widespread mortalities of muskoxen (associated with the bacteria *Erysipelothrix rhusiopathiae*) (Kutz et al., 2015), and the local decline of muskoxen resulting in the suspension of the commercial muskox harvest in 2012 (Tomaselli et al., 2018a).

3.2.3. Study design

Data collection occurred in three phases: individual semi-structured interviews, small group interviews, and feedback sessions. Color topographic maps of the area (scale 1:500,000) were used to assist participants in their narratives. A translator was present through all stages. Participation in the study was voluntary and with written informed consent, confidentiality was protected, and participants could withdraw at any time. Monetary compensation, the amount set by the Kitikmeot Inuit Association (KIA), was given to participants after interviews (hourly rate of $100 for Elders and $50 for other participants). The study obtained community approval through the KIA and Ekaluktutiak Hunters and Trappers Organization (EHTO); the research was approved by the Conjoint Faculties Research Ethics Board at the University of Calgary (REB14-0646) and the Nunavut Research Institute (license 04017 14N-M and renewals).

3.2.3.1. Individual semi-structured interviews

Semi-structured individual interviews (Huntington, 2000) were designed to gather LK about muskoxen in the Iqaluktutiaq area using a check-list of open-ended questions on participants' observations for hunted and non-hunted animals. Topics included hunting experience, and muskox distribution, abundance, health, and diseases (see Appendix F for interview guide). Participant recruitment followed the methods recommended for both LK (Davis and Wagner, 2003) and PE studies (Mariner and Paskin, 2000), directed to identify key informants that fit with study objectives. 'Muskox experts' were selected by purposive sampling through the KIA and the EHTO, and by snowball technique by asking participants to identify other key informants to include in the study (Green and Thorogood, 2014b). The sample size was defined using the thematic saturation approach (Green and Thorogood, 2014b). Interviews were audio-recorded, field notes were taken, and key information was later systematically transcribed to provide the basis for thorough thematic content analysis (Mariner and Paskin, 2000; Green and Thorogood, 2014c). During the individual interviews, participants also described changes in abundance and health of the Dolphin and Union caribou herd (hereafter referred to as caribou) in the study area. As this added an important observational component, possibly linked with changes in muskox population health, we further probed participant observations on caribou in the small group interviews. Study participants, although purposefully selected as muskox experts, also had deep knowledge about caribou and often were primary caribou harvesters (Tomaselli et al., 2018a).

Individual interviews were useful to understand the study system with reference to the interactions between interviewees and muskoxen/caribou (see Tomaselli et al., 2018a), as well as gather baseline information on muskox and caribou health, including diversity of observed abnormalities. Themes that emerged from the individual interviews were used to design and were further explored in small-group interviews.

3.2.3.2. Small group interviews

Semi-structured interviews were used to collect primarily quantitative data on participants' observations and perceptions on muskox and caribou health, including information on demography, body condition, morbidity and mortality over time. To do so, we used a checklist of participatory analytical activities, adapting PE methods described by Mariner and Paskin (2000) to our research needs and context (Fig. 3.1; for detailed methods see Appendix G). Participatory activities helped through visual techniques (e.g., drawing, proportional piling, mapping, etc.) to reach consensus among participants and generate quantitative data as the outcome of the discussion process (Mariner and Paskin, 2000). In this phase, we also applied the triangulation technique recommended in social science studies as a way to improve data quality and reliability (Mathison, 1988; Green and Thorogood, 2014d). This involved recruitment of new participants through the purposeful sampling and the snowball technique described above. Each group was composed of key informants who participated in the individual interviews, along with at least one new interviewee. Participants were grouped according to age, hunting experience, and hunting areas of preference.

Group interview checklist:

1. Participants' area of observation - *mapping exercise*
2. Muskox and Caribou demography
    - a. Relative abundance - *drawing exercise*
    - b. Relative decline - *proportional piling exercise*
    - c. Group size and distribution - *categorization exercise*
    - d. Group sex and age structure - *proportional piling exercise*
3. Muskox and Caribou body condition - *proportional piling exercise*
4. Muskox and Caribou morbidity and mortality
    - a. Relative morbidity and mortality - *proportional piling exercise*
    - b. Relative prevalence of diseases - *proportional piling exercise*
    - c. Causes of mortality - *proportional piling exercise*
5. Patterns of Muskox disease outbreak
    - a. Spatio-temporal distribution - *mapping exercise*
    - b. Seasonality - *seasonal calendar and proportional piling exercise*
    - c. Sex and age characteristics - *proportional piling exercise*

Figure 3.1. Checklist of participatory exercises performed in the small group interview setting.

3.2.3.3. Feedback sessions

As a final step of data analysis, findings were corroborated and refined with study participants (Burke, 1997; Green and Thorogood, 2009c). All interviewees were invited to view and comment on a PowerPoint presentation that summarized the interview data analyses and interpretation. If participants disagreed with the information presented, we were ready to further probe on the specific theme/s, understand the motivations behind such disagreement, and, if needed, repeat the interview process. To facilitate participation in the validation phase, multiple feedback sessions were organized as individual or group meetings.

3.2.4. Data analysis and visualization

Descriptive statistics were used to summarize quantitative data and a cubic regression model was used to summarize data on relative population abundance over time. Analyses were performed using IBM SPSS Statistics 22.0 software. The software ArcGis 10.2 was used to visualize georeferenced data.

3.3. Results

Thirty key informants were interviewed individually from July to September 2014. Participants included year-round residents (Inuit, n=23; non-Inuit, n=5) and summer residents (commercial pilots, n=2). Themes that emerged included changes in muskox and caribou demography, body condition status, morbidity and mortality, and observations of muskox 'acute mortality' cases consistent with disease outbreaks. From November to December 2014, 19 community members, 11 previously interviewed and 8 new interviewees (triangulation), participated in 7 small-group interviews with 2 to 3 participants/group. From June to July 2015, 31 of the 38 interviewees participated in the feedback sessions and agreed with the results presented.

Observations covered a vast area of land from the Arctic mainland to as far northeast as Ellesmere Island in the High Arctic. However, the area consistently observed by the majority of the participants, and consequently used as the 'area of observation' for the context of this paper, was approximately 150 km, or 93 miles, radius of land around Iqaluktutiaq (Appendix H).

3.3.1. Muskox and caribou demography

3.3.1.1. Abundance

Participants in individual and group interviews all reported recent declines in muskox and caribou numbers. In individual interviews, an Elder (Interviewee 6) said: *"not only muskox have declined, caribou too …* [Caribou declined] *the same way and the same time* [as muskoxen]" (for other representative quotes see Appendix I and J). In group interviews, participants did a drawing exercise to characterize the relative abundance of muskoxen and caribou over time. A cubic regression line fit to these abundance curves provided the best model for muskox (R^2=0.651) and caribou (R^2=0.607) population trends. For both species, populations peaked and then began to decline around the mid-2000s, with a major decline after 2010 (Fig. 3.2).

Descriptive narratives from both the individual and group interviews provided a richer understanding of the trends. Participants reported that in the 1960s and 1970s it was rare to see muskoxen, but from the 1980s to early 2000s, muskox numbers increased and it was common to see herds in the vicinity of the community, and in numbers large enough to make it unnecessary to go further away to hunt muskoxen for personal consumption (Appendix I). Regarding caribou abundance, participants observed low numbers of animals in the 1960s and 1970s and further noted that they were not close to the community. In the mid-1980s, caribou started migrating within a few miles of the community and in the autumn it was typical to observe big herds gathered on the shoreline both to the east and west side of the community, waiting for the sea ice to freeze (Appendix J).

The abundance curves generated during group interviews identified ‘pre-decline’ (from the 1990s to mid-2000s) and ‘decline’ (from mid-2000s to the end of 2014) periods. These periods were then used for context in subsequent participatory exercises to assess changes in abundance, groups (size, composition, distribution), body condition, morbidity and mortality (Fig. 3.1; Appendix G).

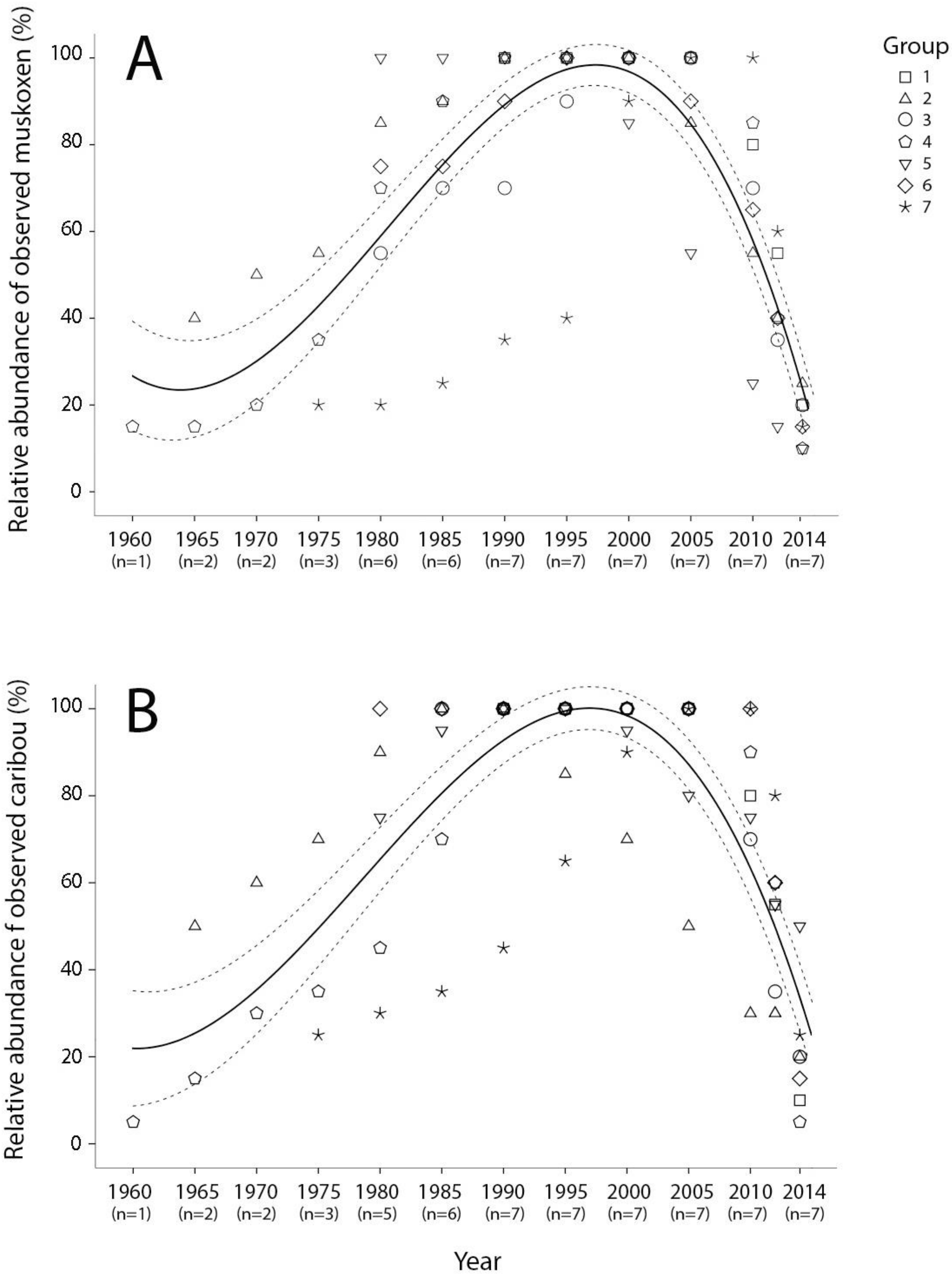

Figure 3.2. Participants' observations on relative abundance (%) over time of muskoxen (A) and caribou (B) in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada). The number of groups providing the information is specified in parenthesis under each year.

3.3.1.2. Decline in abundance

Using a proportional piling exercise, participants reported an 85% (IQR and range: 75-90; n=7) decrease of muskoxen and 80% (IQR: 75-90; range: 50-95; n=7) decrease of caribou, from the pre-decline period to the end of 2014. Increase in predators, changes in migratory routes (caribou) or emigration events (muskoxen), as well as, human disturbance, environmental changes, and changes in the health status of the animals were among the factors that participants associated with the decline of both ungulate species. During the feedback sessions (summer 2015), participants emphasized that they were still observing a declining trend for both species.

3.3.1.3. Group size and distribution

According to individual narratives (Appendix I) and group interviews the size of muskox groups and the distance between groups changed over time: *"within the last ten years is when it started to be more difficult to see herds* [of muskoxen] a*nd then more recently within the last 3 to 5 years I would say that it is extremely difficult to find certainly any larger, and if you do find muskox they are usually loners or very small herds"* (Interviewee 17).

Using a categorization exercise, six of seven groups indicated that in the pre-decline period, the average size of a muskox herd was more than 30 animals with an average of 5 to 10 miles (8 to 16 km) between herds. Progressively, smaller and more scattered groups were observed and, by the end of 2014, interviewees observed fewer than 10 muskoxen per herd, with more than 20 miles (32 km; n=4 groups), and often more than 50 miles (80 km; n=3 groups), between herds.

Regarding caribou herd size, all groups reported that prior to the decline, during the fall migration from late October to mid-November, they used to see *"hundreds of caribou gathered in a single herd"* near the shoreline, waiting for the sea ice to freeze before migrating to the mainland. Progressively, fewer caribou were noticed in the usual areas, and, by the end of 2014, participants observed *"very small, very few, and very scattered herds"* of caribou, ranging from 3 to 30-40 individuals, but more frequently less than 10 caribou. The observations regarding caribou herd size emerged also from the analysis of the individual narratives (Appendix J).

3.3.1.4. Sex and age structure

Although participants were not directly asked, the observation of fewer calves in declining muskox herds emerged as a theme from individual interviews. This was followed up in group interviews using a proportional piling exercise to determine sex and age structure of muskox and caribou herds. For calves, the aggregate observation throughout the year was reported (as opposed to attempting to estimate calving, survival, or recruitment rates). Because of this, possible misclassification between calves and yearling might have arisen (e.g., late winter calf mistakenly referred to as yearling), especially for muskoxen; therefore, we report 'juveniles' as the sum of observations for calves plus yearlings. Observations for calves and yearlings separately are presented in Appendix K.

The proportion of adult muskoxen increased from 75% in the pre-decline to 90% in the decline period (n=7). All interviewed groups reported a decrease in the observed proportion of juveniles from 25 to 10% (n=7) over this period (Fig. 3.3A). Four of 7 groups reported a relative increase in adult females from 47.5% (IQR: 42.5-50; range: 40-50) to 65% (IQR: 57-75; range: 54-80), whereas the proportion of males remained similar across periods (Appendix K). Three groups did not feel confident in providing the relative proportion of adult muskoxen divided by gender.

Similarly, for caribou, groups reported an increase in the proportion of adults, from 65% in the pre-decline to 80% in the decline period (n=7). Concurrently, there was a decrease in the proportion of juveniles from 35% to 20% (n=7) (Fig. 3.3B). Not all the groups felt confident in providing the proportions of adults by sex, but for those that did, the proportion of adult female caribou increased from 42% (IQR: 34.5-45; range: 30-45; n=4) in the pre-decline to 50% (IQR and range: 50-55; n=3) in the decline, while the proportion of adult males did not vary between the two periods (Appendix K).

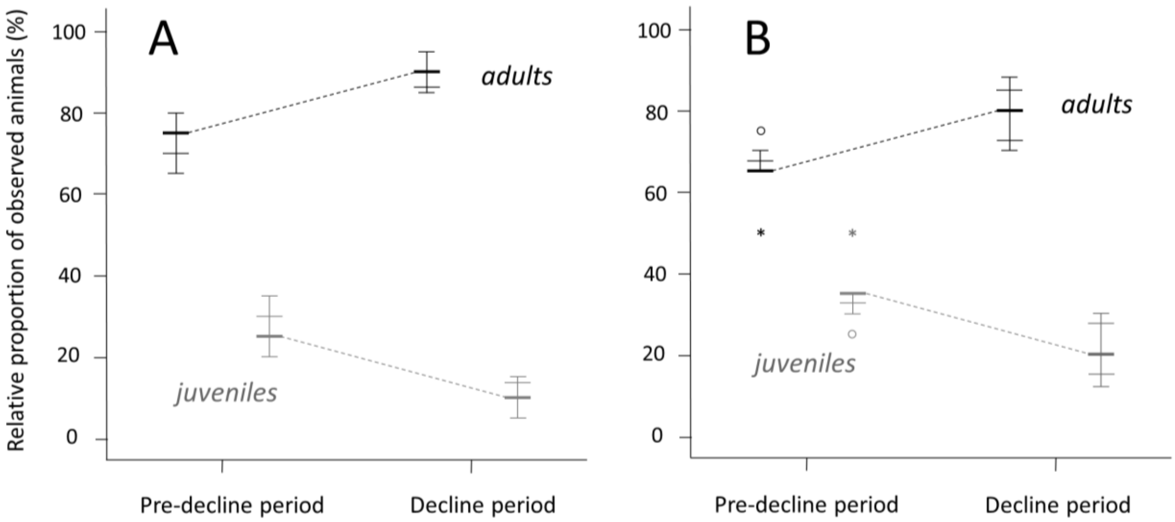

Figure 3.3. Participants' observations on relative proportion (%) of adults and juveniles muskoxen (A) and caribou (B) in the pre- and decline periods in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada). The thick horizontal lines correspond to the medians; the distance between the thin longer horizontal lines to the interquartile range; the whiskers to the range of the data except for outliers. Circles and asterisks represent outliers (i.e., extend for more than 1.5 times the interquartile distance) and extreme outliers (i.e., extend more than 3 times the interquartile distance), respectively.

3.3.2. Muskox and caribou body condition

Changes in the body condition of muskoxen emerged voluntarily as a theme in the individual interviews. This was explored further in group interviews where participants did a proportional piling exercise to indicate the proportion of animals that they observed in different body condition classes: excellent, good, fairly good and poor. Overall, from the pre-decline to decline period, fewer animals were classified in excellent condition and more in fairly good and poor condition (Fig. 3.4a). Narratives supported these findings, with many participants in group interviews reporting that it was common to hunt both muskoxen and caribou with 5 to 8 cm of back fat during the pre-decline; whereas, at the time of the interview, *"you would be very lucky to get an animal with 3 cm of back fat, but usually they have 1 cm or nothing"*.

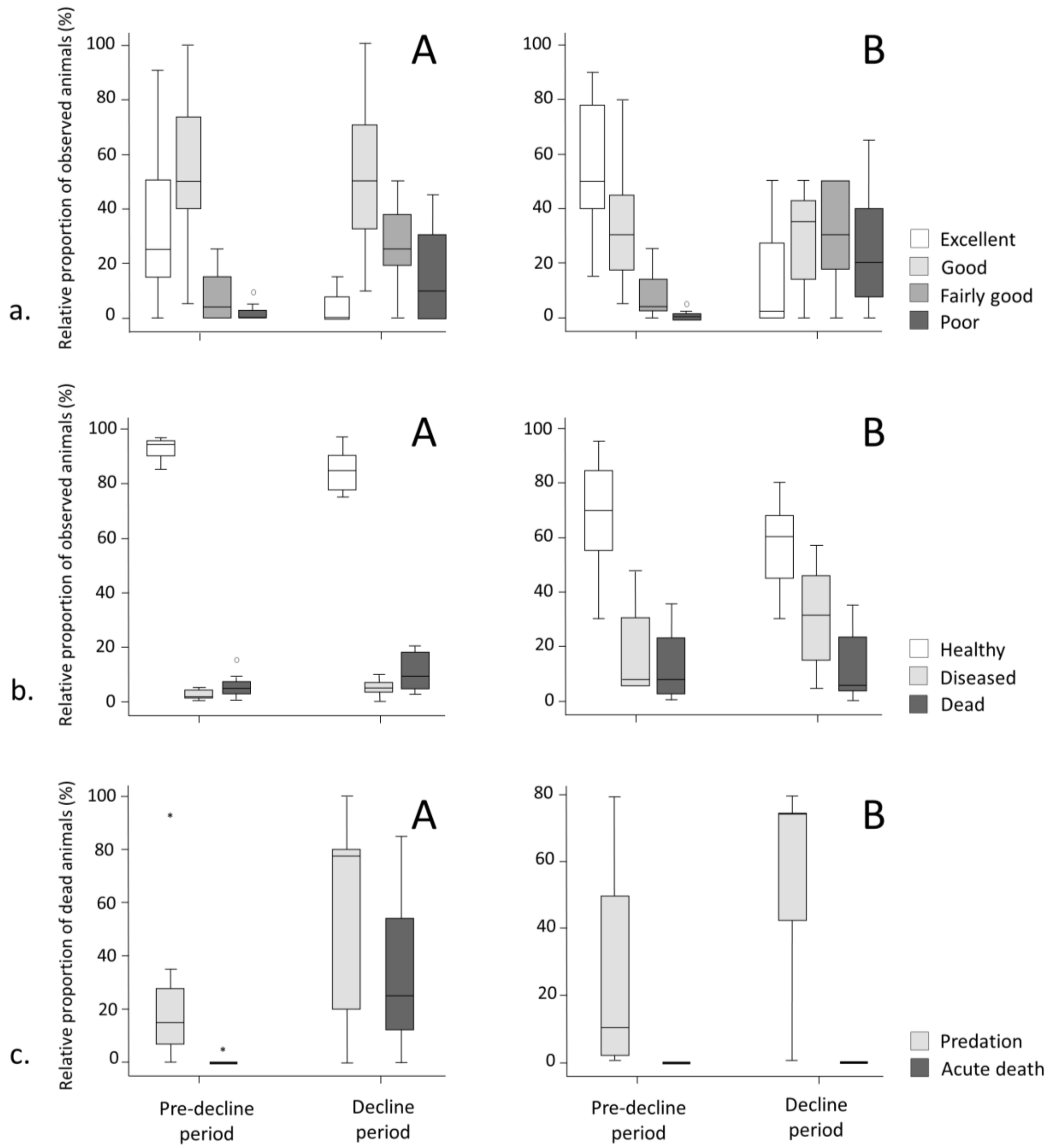

Figure 3.4. Participants' observations on muskoxen (A) and caribou (B) in the pre- and decline periods in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada): (a) body condition status expressed as relative proportion (%) of excellent, good, fairly good and poor animals; (b) relative proportion (%) of health, diseased and dead animals; (c) relative proportion (%) of mortality attributed to predation and acute death. The thick horizontal lines correspond to the medians; the lower and upper lines of the boxes to the first and third quartiles, respectively (interquartile distance); the whiskers to the range of the data except for outliers. Circles and asterisks represent outliers (i.e., extend for more than 1.5 times the interquartile distance) and extreme outliers (i.e., extend more than 3 times the interquartile distance), respectively.

3.3.3. Muskox and caribou morbidity and mortality

Increased observation of abnormalities in hunted and observed muskoxen and caribou, recent observations of muskox carcasses with attributes that we infer to be suggestive of a disease outbreak, and increased observations of muskox and caribou mortality due to predators were among the themes that consistently arose from the individual narratives.

Using a proportional piling exercise, group interview participants were asked what proportion of animals observed were healthy, sick or dead. For both muskoxen and caribou, from the pre-decline to the decline period, the proportion of animals observed healthy had decreased and the proportion of diseased had increased. For muskoxen, there was also an increase in the proportion of animals observed dead, but no change was observed in the proportion of dead caribou (Fig. 3.4b).

3.3.3.1. Relative prevalence of diseases

Participants in the individual interviews reported a variety of lesions or more generic syndromes in hunted and observed muskoxen and caribou (Table 3.1). The relative prevalence and trend over time were assessed through proportional piling in group interviews (Table 3.2 and 3.3). Rarer, but more recent observations reported by individual participants and not captured by the proportional piling, included lesions described as *"white eyes"* consistent with corneal opacity in adult male muskoxen (attributed by participants to injuries incurred during the rut, however noticed only since 2010). In caribou the lesions described included *"scabs on the nose and mouth"* (an adult female hunted between 2005 and 2007 and an adult female and her calf observed in 2010), hard and swollen testicles consistent with orchitis (noticed since the 1990s but with increased reports in 2014), *"different color patches"* in the lung *"that was stuck in the rib cage"* consistent with pneumonia (described in one caribou hunted in 2013), and liquid cysts in the lung parenchyma (one caribou hunted in 2008). In addition, observations of yellow coloration of subcutaneous tissue associated with pale skeletal muscle were described in both muskoxen and caribou, and in particular in individuals with poor body condition since 2008.

Table 3.1. List of lesions and syndromes observed by participants in the hunted and observed muskox and caribou populations in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada) and their most likely differential etiologies in this context.

Observed lesions	**Differential etiology**
Warble flies larvae	*Hypoderma* spp.
Nasal worms	*Cephenemyia* spp.
Swollen jaw	*Actinomyces* spp.
	Actinobacillus spp.
	Non-specific tooth root infection
White muscle cysts	*Taenia* spp.
Liver cysts	*Taenia* spp.
	Echinococcus canadensis
Lung cysts	
solid cysts	*Umingmakstrongylus pallikuukensis* (only muskox)
liquid cysts	*Echinococcus canadensis*
Swollen joints – limping	*Brucella* spp.
	Erysipelothrix rhusiopathiae
	Chlamydia spp.
	Mycoplasma spp.
	Injuries
Swollen and hard testicles	*Brucella* spp.
	Besnoitia spp.
Sand paper	*Besnoitia* spp.
Scabby lesions (nose and mouth)	Orf virus (*Parapoxvirus*)
	Mechanical damage
Hoof anomalies/infections	Mycotic infections (e.g., *Spherophorous* spp.)
	Bacterial infections (e.g., *Actinomyces* spp.)
	Parasitic infections (e.g., *Besnoitia* spp.)
	Nutritional deficiencies/imbalances
White eye	Herpesvirus
	Bacterial infections (e.g., *Chlamydia* spp.)
	Injuries
Yellow color of subcutaneous tissue	Nutritional deficiencies
	Resolution of hematoma
	Bacterial/parasitic infections
Traumatic lesions/abscesses	Injuries
	Bacterial infections

Table 3.2. Group interviews: participants' perceptions on diseases (lesions/syndromes), expressed as relative prevalence (%), and observations of disease occurrence (provided by the groups that reported the specific disease), in the hunted and observed muskoxen in the Iqaluktutiaq area (Victoria island, Nunavut, Canada) during the decline period.

Observed lesions	**Relative prevalence**				**Disease occurrence**	
	N	**Median**	**IQR**	**Range**	**N**	**Observations**
Warble flies	7	3	0-5	0-30	5	Noticed since 1985 as an occasional finding (1/5). The majority of the groups started to notice it after 2000-2005 (4/5).
White muscle cysts	7	15	0-30	0-35	5	Noticed since 1985 as an occasional finding (1/5). The majority of the groups started to notice it with an increasing trend after 2000-2005 (4/5).
Liver cysts	7	5	0-15	0-50	4	Noticed since the 1980s – 1990s as an occasional finding (3/4). One group believe that it is increasing since 2005 (1/4).
Lung cysts	7	1	0-5	0-10	4	Noticed since the 1980s - 1990s as an occasional finding (2/4; description of the cysts is consistent with *Echinococcus canadensis*). Two groups noticed it since late 2000s with an increasing trend (2/4; description of the cysts consistent with muskox lungworm *Umingmakstrongylus pallikuukensis*).
Swollen joints - limping	7	5	3-25	0-30	6	Noticed since the 1980s as an occasional finding (3/6). The majority of the groups noticed and increasing trend of the finding since 2005 (4/6).
Sand paper	7	5	0-5	0-5	5	Noticed since the 1980s-1990s as an occasional finding (2/5). The majority of the groups started to notice it after 2000 (3/5).
Scabby lesions (nose and mouth)	7	1	0-10	0-10	4	First noticed in one adult male in 2004 (1/4). Then in two bulls that were sport hunted in 2008 (1/4), and in one adult male sport hunted in 2014 (2/4). Also a dead calf was observed with these lesions in 2012.
Hoof anomalies/infections	7	1	0-3	0-10	4	Noticed since the 1990s as an occasional finding (2/4). Two groups started to notice it with an increasing trend since the declining period (2/4).
Traumatic lesions/ abscesses	7	20	5-30	0-50	6	Always noticed (6/6) with a stable (5/6) or slightly increasing trend (1/6). Due to inter- (predators including hunters) or intra-specific interactions (other muskoxen, especially during the rutting season), and other natural causes.

Table 3.3. Group interviews: participants' perceptions on diseases (lesions/syndromes), expressed as relative prevalence (%), and observations of disease occurrence (provided by the groups that reported the specific disease), in the hunted and observed caribou in the Iqaluktutiaq area (Victoria island, Nunavut, Canada) during the decline period.

Observed lesions	**Relative prevalence**				**Disease occurrence**	
	N	**Median**	**IQR**	**Range**	**N**	**Observations**
Warble flies	7	40	30-50	20-70	7	Always noticed in almost all the animals during spring and summer time (7/7). It was even a source of food when Inuit lived in outpost camps and prior to life in the community.
Nasal worms	7	2	0-10	0-30	4	Noticed since the 1980s, especially on the mainland hunting grounds (4/4). Considered an occasional and stable finding since then (3/4).
White muscle cysts	7	15	10-25	3-25	7	Noticed since 1980s -1990s (3/7). The majority of the groups noticed an increasing trend after 2000-2005 (5/7).
Liver cysts	7	2	0-3	0-5	4	Noticed since the 1990s as an occasional finding (2/4). Two groups noticed it starting from 2005 (2/4).
Swollen joints - limping	7	5	5-15	2-15	7	Noticed since the 1980s as an occasional finding (3/7). Considered more frequent in the 1990s and since 2007-2008 had decreased being occasional again (3/7). However, one group reported an increase in the limping animals since the declining period (1/7).
Sand paper	7	5	4-10	0-10	6	Noticed since the 1980s as an occasional finding (4/6). Either stable (3/7) or slightly increasing since 1990-2000 (3/7)
Hoof anomalies/infections	7	1	0-10	0-10	4	Noticed since the 1990s as an occasional finding (1/4). The majority of the groups started to notice it with an increasing trend after 2000 (3/4).
Traumatic lesions/ abscesses	7	5	3-30	0-35	6	Always noticed (6/6) with a stable (5/6) or slightly increasing trend (1/6). Due to inter- (predators including hunters) or intra-specific interactions (other caribou, especially during the rutting season), and other natural causes.

3.3.3.2. Causes of mortality

Causes of mortality described during individual interviews included predation, 'acute death', and a variety of other causes that we categorized afterward as 'other causes'. Other causes ranged from unknown causes (when partial remains of carcasses were observed), to deaths due to drowning (e.g., caribou during the fall migration), injuries due to both natural and anthropogenic causes, starvation (e.g., muskoxen stranded on islands and reported primarily in pre-decline), and *"old muskoxen"*. A proportional piling exercise was then used in group interviews to determine the proportion of muskox and caribou mortalities attributable to predation, acute death, and other causes (Appendix G).

For both muskox and caribou, from the pre-decline to the decline, there was an increase in mortalities attributable to predation (Fig. 3.4c). Although wolves were considered the primary predators of both species, the proportion of predation attributed to grizzly bears increased for muskoxen from 7% (IQR and range: 0-25; n=6) in the pre-decline to 25.5% (IQR: 25-40; range: 15-40; n=6) during the decline. Grizzly bears were also indicated as caribou predators exclusively during the decline by two groups of interviewees.

Acute mortality was observed only in muskoxen during the decline period and by 6 of the 7 groups interviewed and it was considered to contribute to the 25% of the total muskox mortality (Fig. 3.4c). One Inuk hunter described: *"There was a bunch of dead muskoxen ... They looked like they just fell down and die, it's almost like somebody came and went bang, bang, bang. But they weren't shot they just died"*.

3.3.3.3. Patterns of acute mortalities in muskoxen

Twenty-six of 38 interviewees had observed acute deaths of muskoxen. The first reported case was from the early 1980s. From the early 1980s until 2005, 6 participants reported observing a total of 9 to 12 cases. Beginning in 2010, observations of acute mortality increased and peaked in 2012 (Fig. 3.5). These observations were confirmed by individual narratives. A pilot said, *"In a normal year during the summer we would see on average a dozen carcasses, but scattered…in that big area we fly in…But then, all of the sudden, in those years '10, '11, '12, we saw a lot more* [carcasses] *and concentrated in a smaller area ... In Suxess Hills and Surrey Lake, there was at least the double of what you would see in a normal year"*.

In group interviews, acute mortalities were further characterized through proportional piling and mapping exercises. Among all the muskoxen observed dead, the 95% were adults (IQR: 85-95; range: 60-95; n=5) and 5% were juveniles (IQR: 5-15; range: 5-40; n=5) (Appendix L). The seasonal pattern and the spatio-temporal distribution of mortalities are presented in figure 3.5.

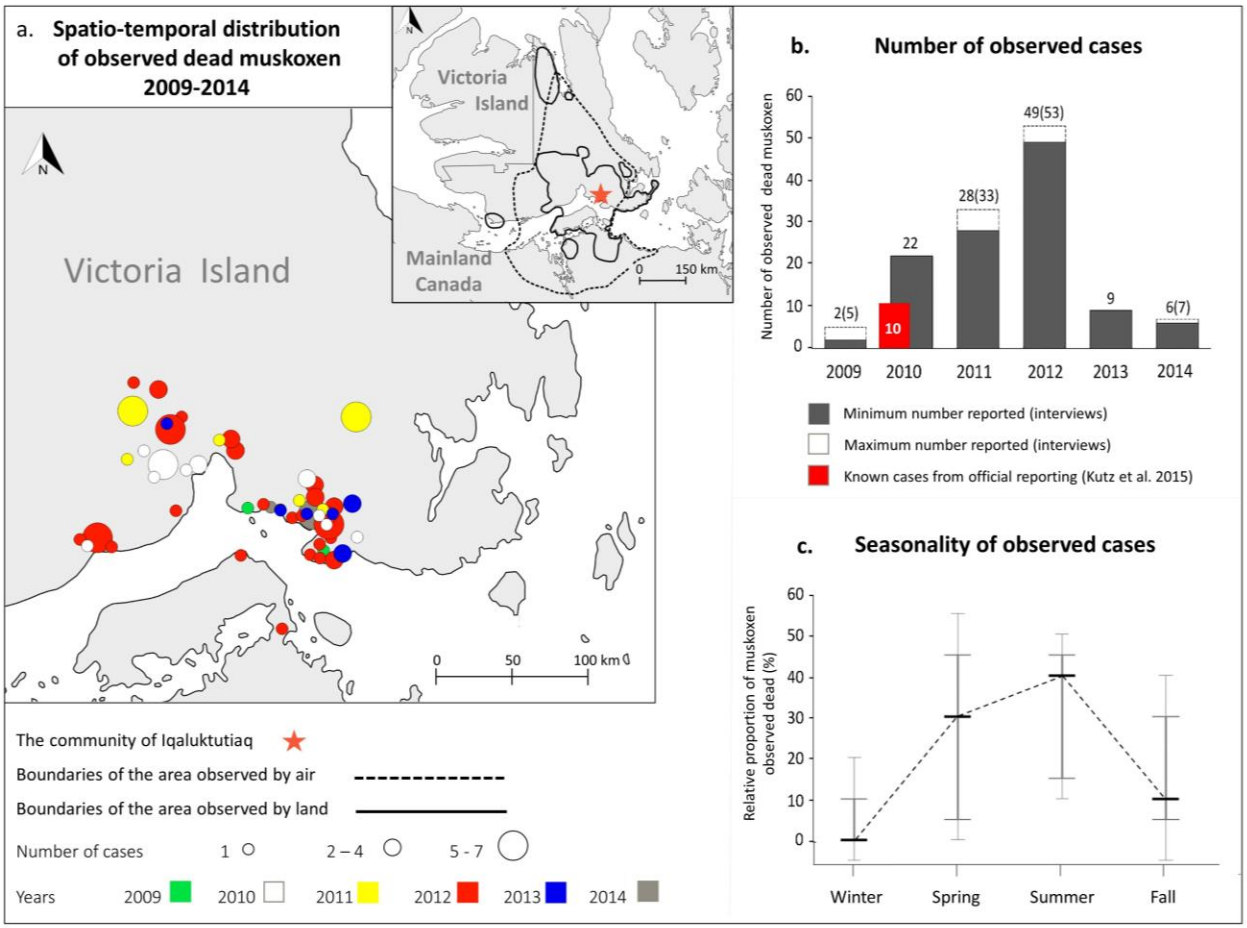

Figure 3.5. Characteristics of muskox acute mortalities observed in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada) in the decline period: (a) spatial and temporal distribution of cases; (b) number of cases from 2009 until the end of 2014; (c) relative proportion (%) of cases by season. The thick horizontal lines correspond to the medians; the distance between the thin longer horizontal lines to the interquartile range; the whiskers to the range of the data except for outliers.

3.4. Discussion

Traditional methods of wildlife population monitoring and health surveillance is logistically and financially challenging in remote settings. Through the use of well-established PE techniques (e.g., Mariner and Paskin, 2000; Catley et al., 2012), adapted to the wildlife context and implemented with a robust qualitative research design, we have demonstrated that local and ethnoveterinary knowledge can contribute valuable information on the health, status, and trends of wildlife populations as well as provide insights into possible drivers.

The data that we gathered highlighted significant population declines for both muskoxen and the Dolphin and Union caribou herd. These were characterized by poor recruitment, deterioration of body condition status, and increased observations of morbidity for both species, as well as unusual mortality events in muskoxen. These collective observations suggest declining population health of muskoxen and caribou in the study area. Here, we discuss the novel epidemiological observations that originated from this research and provide additional considerations for the broader applicability of these methods for conservation, research and wildlife health surveillance.

3.4.1. Novel epidemiological observations on muskoxen and the Dolphin and Union caribou herd

Local knowledge confirmed major population declines for muskoxen and caribou, beginning in the mid-2000s. The occurrence and magnitude of these declines reported by interviewees were consistent with the results of aerial population surveys that occurred at the same time and immediately after our study (Leclerc, 2015; Environment and Climate Change Canada, 2017). Moreover, LK indicated that the body condition of both muskoxen and caribou had deteriorated. We suggest that these data likely underestimated the magnitude of body condition decline. When analyzing the individual narratives, it became clear that while the overall body condition of muskoxen and caribou was deteriorating, the subjective scale of measure by the observers was adapting to the new reality and their assessments were made relative to that new reality. That is, the animals classified in excellent body condition during the decline period would have been classified in poorer categories of condition in the pre-decline period.

Concurrent with the declines, morbidity increased (especially for caribou), with increased observations of endemic and emerging syndromes. Some of these endemic syndromes (e.g., swollen joints and limping animals) and emerging (e.g., scabby lesions on nose and mouth) were of interest as they could be associated, among other causes, with pathogens that reduce reproductive success (e.g., *Brucella suis* biovar 4) and recruitment (e.g., orf virus) and thus may be linked to the population declines. These pathogens have recently been confirmed in muskoxen in the study area (Tomaselli et al., 2016).

Local knowledge was invaluable for learning about previously undocumented mortality events. Prior to our study, we were aware of mid-summer acute mortality events of muskoxen on Banks Island (2012-2013) and on Victoria Island (2009-2011), including 10 cases reported in 2010 within our study area (Kutz et al., 2015). The interview process documented at minimum 120 more dead muskoxen from 2010-2014, with the peak in 2012. The descriptions of these mortalities, entire carcasses, various age classes (although dominated by adults), and no evidence of predation, suggest that were similar to those described by Kutz et al. (2015), and if so, attributable to acute infectious disease. The unexpectedly high number of mortalities reported through our interviews revealed a critical deficiency in the existing standard, passive surveillance system in this region (and likely elsewhere) and the incredible value of using participatory surveillance as an ongoing tool for early detection of disease onset. Despite this value of LK, we suspect that the extent of the morbidity and mortality during this time period was still underestimated because of limitations in the search techniques, carcass removal by scavengers (although this system may have been saturated as the die-offs continued), misclassification of mortalities as primary predatory events because carcasses were scavenged, and predator removal of diseased and weak animals (see Wobeser, 2007). Additionally, carcasses of juveniles would likely be more difficult to detect and would disappear more rapidly (Wobeser 2007), thus juvenile mortality would be disproportionately underestimated.

Of all of the LK data gathered in this study, attribution of muskox and caribou mortality to predation had the widest interquartile ranges, suggesting disagreement among groups. However, grizzly bears were consistently identified as new predators, especially for muskoxen, on Victoria Island during the decline. The high level of uncertainty in the attribution of mortalities to predators could be influenced by the fact that study participants were not selected as 'predator experts' and possibly had substantially different expertise on predators. Also, we suspect that explanatory inference or perception that predators might be the primary cause of muskox and caribou declines influenced the observations of increased predation in the decline period. This could have also been overestimated if scavenging was misinterpreted as predation during the mortality events, or may also have been a real increase associated with increased susceptibility of muskoxen and caribou to predation because of poorer body condition and increased incidence of infectious diseases. Important to note is that observations of overall mortality of caribou remained stable between pre-decline and decline, while muskox mortality increased, however, this was mainly due to the increase in acute mortality.

Finally, in addition to describing the declines in both muskoxen and caribou, and changes in population structure, LK provided further insights into possible mechanisms for changing demographics. For example, poor body condition and increased burdens of disease, including syndromes consistent with brucellosis and orf, were observed and both may have played a role in the decreased trend of juveniles reported by interviewees. It is well established that body condition of the cow is directly linked to conception and calf survival rates for both species (Kofinas et al., 2002; Miller, 2003; Gunn and Adamczewski, 2003). Similarly, pathogens like *Brucella* spp. and orf virus are linked to reduced pregnancy rates and increased calf mortality, respectively (Vikøren et al., 2008; Tomaselli et al., 2016). Finally, poor condition and a high burden of disease can lead to increased direct mortality and susceptibility to predation. Together, these are all mechanisms that are likely influencing key demographic rates and ultimately, the dynamics of the declining muskox and caribou populations.

3.4.2. Key considerations for interpretation of local knowledge

Evaluation of possible sources of bias and familiarity with the local context are key for interpretation of LK. Due to their inductive nature, LK studies are likely to generate unexpected findings

(Huntington, 2000). Ensuring that the participants included in LK studies are actual experts on the subject of inquiry is essential for correct interpretation of the findings. For example, in this study, participants, selected as muskox experts, provided important insights also on caribou trends and status. Knowing that in Iqaluktutiaq muskox harvesters are also, and often primary, caribou harvesters (Tomaselli et al., 2018a) allowed us to consider the LK gathered on caribou valid. On the other hand, we believe that information regarding predators should be further explored with participants primarily selected as 'predator experts' (e.g., trappers), as these individuals might have been excluded from this study.

Knowledge of the local harvesting context, particularly how animals are butchered and what organs are consumed, is also of key importance when interpreting the relative prevalence of diseases gathered through PE. For instance, muskox harvesters included in this study did not consume muskox lungs but left them on the field with only minimal inspection (Tomaselli et al., 2018a). We thus expected that observations of abnormalities in the lungs, such as muskox lungworm, and that do not cause a pleuritis, were underestimated and may not correspond to the scientific knowledge available (e.g., Kutz et al., 2013; Tomaselli et al., 2016).

Personal experience and observation, but also explanatory inference and interpretation, as well as indirect experience and oral history, are all mechanisms that contribute to generating local knowledge (Berkes et al., 2000). Identifying those mechanisms can assist in data interpretation. For example, in this study, changes in participants' perceptions over time might have led to underestimating the magnitude of deterioration of body condition status for muskoxen and caribou in the decline period. On the other hand, changes in perceptions due to a 'biased' explanatory inference can lead to overestimation of events. With respect to predators, we think that LK data could largely overestimate the role of predators as a primary driver of the decline of prey species when the latter experience disease outbreaks and/or declining health.

Recall and 'seasonal' bias must be considered and assessed when focusing on retrospective and seasonal observations, respectively. Regarding the interpretation of seasonal data, differences in seasonal use of the land by LK holders may lead to 'seasonal bias' in the LK reported, which likely resulted in the wide interquartile range of the seasonal observations about dead muskoxen. Finally, although we cannot eliminate the possibility that recall errors occurred, especially when exploring historic events, we think that the effects of recall bias on interpretation were minimized by the application of thematic saturation, triangulation, and participants' feedback techniques.

3.4.3. Key consideration for using local knowledge

Local knowledge is well suited to serve as an early warning system to detect changes in wildlife health both at the population and individual level. In this study, LK documented major local declines of muskoxen and caribou prior to the aerial surveys, and provided higher resolution information on key demographic characteristics, as well as individual and population health. Initial LK results, suggesting a population decline, poor body condition, and increased morbidity for the Dolphin and Union caribou herd, resulted in a delay in the assessment of the conservation status of this herd by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) until population estimates could be completed through aerial surveys. Local knowledge on this herd has continued to inform this assessment, complementing recent scientific data in projecting future trends and understanding threats. As demonstrated by this case, LK is valuable for real-time monitoring of local wildlife population trends, demography, distribution, and patterns in health and disease. It can complement, inform, and target scientific population estimate/census efforts, as well as facilitate timely adaptive management actions, especially when financial restrictions limit the ability to conduct regular systematic surveys.

Additionally, observations on individual animals are valuable for early detection of emergent or re-emergent diseases and feedback into scientific monitoring and study design (e.g., see Carlsson et al., 2016). For instance, on Victoria Island, lesions in muskoxen and caribou that are consistent with orf were observed by interviewees in 2004 and between 2005 and 2007, respecively. These observations were not gathered until 2014, in the course of this LK study, and the virus itself was not definitively identified until after hunters engaged in a sample collection program reported lesions in a hunted animal, triggering a field disease investigation (Tomaselli et al., 2016). Local knowledge also identified substantial mortality of muskoxen that were undetected by the existing routine passive surveillance system. Thus, observations of resource users, when collected and analyzed in a regular systematic manner, can increase the timeliness and sensitivity of disease detection in wildlife, and greatly contribute to understanding wildlife population health and disease epidemiology.

Collaborative identification of research priorities, development of mutual trust among stakeholders, and ultimately, enhanced co-management of wildlife, are invaluable benefits derived from the implementation of participatory research for wildlife health assessment. For instance, results from this study, based on data gathered from and by the local stakeholders, were included in regional co-management plans for muskoxen and the Dolphin and Union caribou herd (see Environment and Climate Change Canada, 2017). The participatory process in knowledge generation fostered dialogue and trust between Inuit and community residents, researchers, and local and territorial organizations. These are the first steps to identify common conservation goals and solution strategies for co-management decisions, while actively promoting the *"wildlife trust administration"* paradigm as advocated by Decker et al. (2016). Finally, when Indigenous peoples are included in the process of knowledge generation, as in our study, intercultural dialogue among stakeholders and democratization of the research process are also promoted (Rist and Dahdouh-Guebas, 2006).

3.4.4. Ingredients for success

Standardized methodologies are required to appropriately collect, compile, and analyze LK, and to avoid misinterpretation. Moving beyond anecdote, the methods used in this study, which are repeatable, provided quantitative data, supported through narratives and validated through follow-up meetings, contributing critical insights into caribou and muskox population trends and health.

This study offers a pragmatic framework that can be broadly applied to other wildlife species and settings. Key ingredients for success include: i) identification of key stakeholders (i.e., local experts) and application of purposeful sampling and thematic saturation to define the sample and its size; ii) triangulation of results to improve data quality and reliability (e.g., individual and group interviews); iii) interpretation of quantitative and qualitative data together (e.g., proportional piling data and participants' narratives) as opposed to relying strictly on one source of data or the other; and finally and most importantly, iv) presentation to, and discussion with, study participants of the overall analyses and interpretations of the findings so as to avoid misinterpretation.

If disagreement arises at any level during the study, we suggest that efforts should be directed to understanding the reasons behind such disagreement, rather than focusing on achieving agreement alone. While researchers need to be flexible and ready to adapt the methods to the specific context and research questions, these procedural key points should be maintained. Scaled up and implemented consistently across a network of communities on an ongoing basis, this framework could help in understanding the status and trends of a variety of different wildlife populations across much of their range and inform conservation, monitoring, and research priorities.

While we do not provide a comprehensive list of participatory techniques (with both relative and absolute scales of assessment) applied to wildlife health, we rather offer a robust methodological approach for the collection and interpretation of LK data for wildlife population health assessment that can be transferable and adaptable to other settings and species. In addition, LK data similarly gathered and interpreted can be applied to other fields of study (e.g., ecosystem health, disease ecology). Engaging in transdisciplinary research and adapting to the wildlife context participatory techniques used in other disciplines will be a critical asset to realize the full potential of LK for wildlife population health assessment and beyond.

3.5. Conclusion

Assessing wildlife population health is rarely an easy task, due to the difficulty, if not inability, to gather and interpret data that holistically capture the dynamic and adaptive processes that characterize wildlife population health (Hanisch et al., 2012; Stephen, 2014). In our view, the holistic way that local resource users experience and interpret the natural environment makes their knowledge and perspectives pivotal for understanding the health and status of free-ranging populations, along with its drivers.

Moving beyond the long-lasting debate focused on the evaluation of LK against scientific knowledge (Gilchrist et al., 2005; Brook and McLachlan, 2005), it is time to direct our efforts to actively promote the use of these two complementary knowledge systems in a synergistic way for effective, evidence-based management. This work moves in such direction. Here we have demonstrated that LK, when gathered and interpreted in a robust way, is a reliable source of data on wildlife population health and trends that can provide new and valuable information and holistic interpretation to complement and guide scientific research and inform wildlife management.

Robust methods and interpretations, together with data validation, are key elements to ensure reliability and acceptability of LK for wildlife population health assessment. Here we have outlined procedural key points that can guide the collection and interpretation of LK, allowing the implementation of a repeatable method that minimizes subjective interpretation. We emphasize that LK studies applied to wildlife health should be undertaken as team efforts with the inclusion of experts from different fields. In our study, interpretation of the ethnoveterinary knowledge was greatly improved because the interviewer had a core knowledge in animal health and was able to explore and interpret these themes in greater depth. Similarly, the team also included experts in wildlife management and in social and participatory research methods, which ensured appropriate methodological approaches and interpretation.

Using LK to measure and understand wildlife health opens new avenues for the implementation of health surveillance programs for free-ranging species, especially in remote rural areas. Although the spatial resolution of LK may be considered a limitation when studying free-ranging populations with large home ranges, the implementation of participatory programs for wildlife health across a network of communities can offer expand the geographic scope. In addition, such approach can further foster intercommunity dialogue, and, in so doing, promote collaboration at larger scales.

Finally and, perhaps most importantly, the process of gathering LK is associated with enhanced dialogue and trust among stakeholders. This ultimately contributes to creating common grounds for collaborative actions that can greatly improve co-management and conservation of wildlife at a time where species are facing ever-increasing threats to their persistence.

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Chapter 4. Contagious ecthyma, rangiferine brucellosis, and lungworm infection in a muskox (*Ovibos moschatus*) from the Canadian Arctic, 2014

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Abstract

An adult male muskox (*Ovibos moschatus*), harvested on August 26, 2014 on Victoria Island, Nunavut, in the Canadian Arctic, had proliferative dermatitis on the muzzle and fetlocks suggestive of contagious ecthyma or orf (*Parapoxvirus*). Histopathological features of the lesions were consistent with this diagnosis. Orf virus DNA, phylogenetically similar to an isolate from a captive muskox of the Minnesota Zoo, US, was detected in the lesions by PCR using *Parapoxvirus* primers. Additionally, there was a metaphyseal abscess with a cortical fistula in the right metacarpus from which *Brucella suis* biovar 4 was isolated and identification supported by PCR. *Brucella* spp. antibodies were detected in serum. Finally, 212 nodules were dissected from the lungs. Fecal analysis and lung examination demonstrated co-infection with the lungworms *Umingmakstrongylus pallikuukensis* and *Varestrongylus eleguneniensis*. The zoonotic potential of orf and rangiferine brucellosis adds an important public health dimension to this case, particularly given that muskoxen are a valuable source of food for Arctic residents. Careful examination of these pathogens at a population level is needed as they may contribute to muskox population decline, and potentially constitute a driver of food insecurity for local communities. This case underscores the importance of wildlife health surveillance as a management tool to conserve wildlife populations and maintain food security in subsistence-oriented communities.

Keywords: *Brucella suis* biovar 4, food safety, food security, *Parapoxvirus*, *Protostrongylidae*, public health, wildlife health and disease surveillance, zoonoses.

4.1. Main body

Muskoxen (*Ovibos moschatus*) are Arctic ungulates central to Inuit culture and tradition that provide an important source of income through guided sport hunts and sale of meat, qiviut, and handicrafts (Gunn et al., 1991). Recent pathogen emergence and regional population declines are of concern from the perspective of conservation, food safety and security, and the economies of northern communities (Kutz et al., 2015). We describe a case of orf, rangiferine brucellosis, and lungworm infection in a wild muskox and the relevance of these diseases for both wildlife and public health.

On 26 August 2014 a mature adult male muskox of average body condition (2 cm back fat) was shot by a sport hunter in a remote location on Victoria Island, Nunavut, Canada (70°01.808' N, 107°34.182' W). The hunter and his guide reported bleeding scabs on the animal's muzzle (Fig. 4.1A). On 29 August 2014, when the hunters returned to the community, samples were collected from the affected area on the muskox hide and stored at -20°C. The remaining carcass was revisited by air charter and sampled in the field for histopathology, parasitology and culture.

Thirteen foci of hyperkeratosis without alopecia (up to 25 mm diameter) and one right hind coronary band ulcer (7 x 3 cm) were present on the pasterns and coronary bands, while the lesions on nasal planum were proliferative and ulcerated (Fig. 4.1A). Histologically, the lesions were consistent with orf virus infection in other ruminants (Ginn et al. 2007; Fig. 4.1B). We extracted DNA from the skin and muzzle lesions using the E.Z.N.A.® Tissue DNA Kit (Omega Bio-Tek Inc, Norcross, GA, USA) following manufacturer's protocol. Orf virus (ORFV) was detected by PCR, which targeted the major envelope protein gene (B2L), and sequences were aligned with 12 other parapoxvirus B2L sequences published in GenBank using the MUSCLE algorithm (Inoshima et al., 2000; Edgar, 2004). We constructed a maximum-likelihood phylogenetic with a relative divergence scale using the RAxML software in the program Geneious 8.1 (Kearse et al., 2012; Stamatakis, 2014). The Victoria Island ORFV sequence shared >99% nucleotide identity with an ORFV from a muskox at the Minnesota Zoo, Apple Valley, Minnesota, US (Guo et al., 2004; Fig. 4.2).

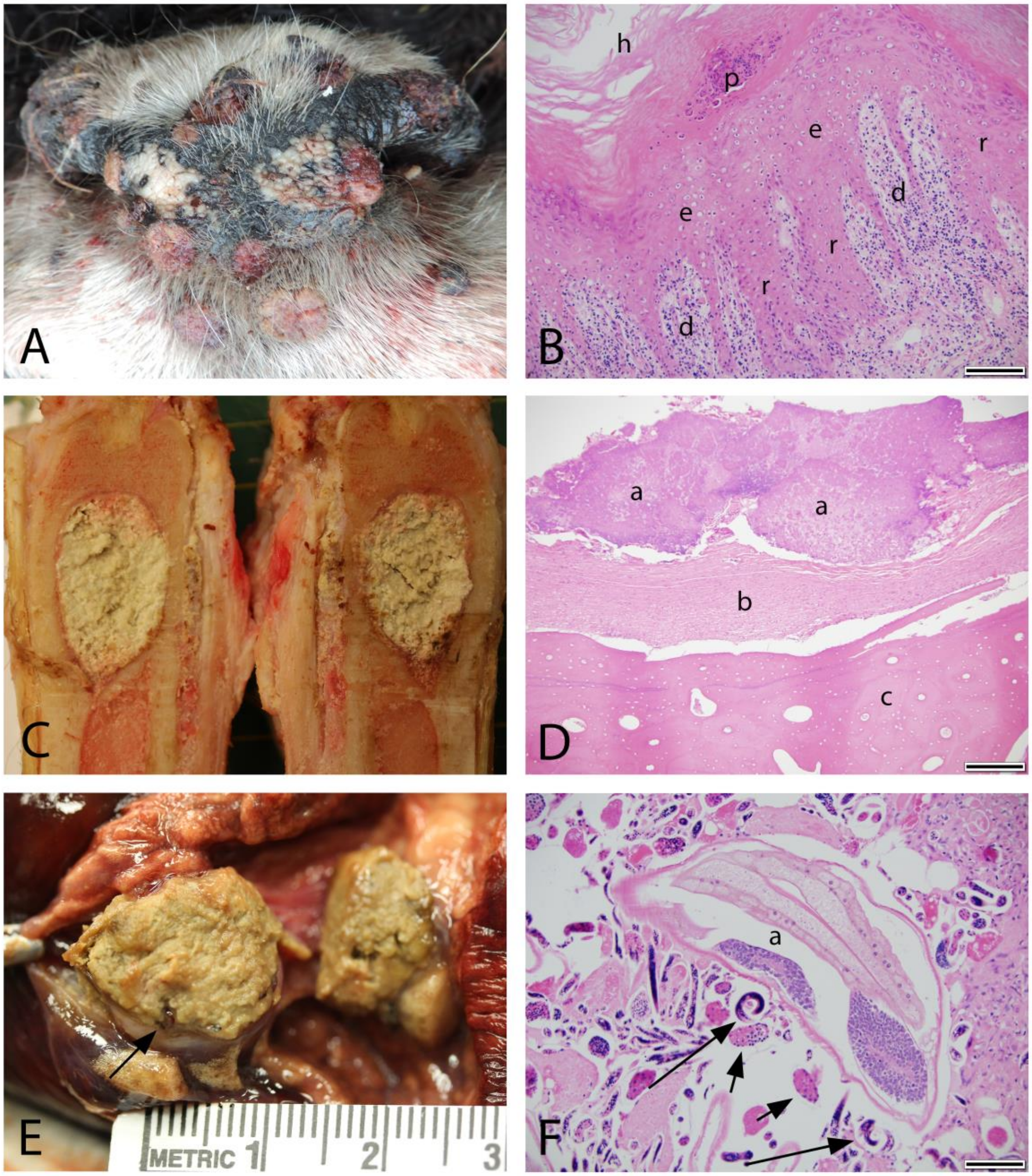

Figure 4.1. Gross pathology and histopathology of an adult male muskox (*Ovibos moschatus*) harvested on Victoria Island, Nunavut, Canada, August 2014. (A) Nasal planum: Multifocal hyperkeratosis interspersed with raised papillary to verrucous nodules often with an eroded or ulcerated and hemorrhagic surface. (B) Skin: The dermis has superficial edema, capillary dilatation, proliferation of dendritic cells, and influx of variable numbers of neutrophils, lymphocytes and plasma cells (d). The epidermis is hyperplastic with long rete ridges projecting deep into the dermis (r), hydropic degeneration characterized by vacuolation and swelling of the keratinocytes (e), intra-epidermal pustule formation (p), and hyperkeratosis (h). H&E. Bar=100 μm. (C) Right metacarpus: Sagittal section showing a medullary abscess in the metaphysis surrounded by a thin capsule of granulation tissue. (D) Right metacarpal abscess: Caseous debris containing bacterial colonies (a), abscess capsule (b), cortical bone (c). H&E. Bar=200 μm. (E) Lung nodule section: Adult nematode (*Umingmakstrongylus pallikuukensis*, black arrow) embedded in caseous debris and surrounded by a thin fibrous capsule. (F) Lung: Adult protostrongylid nematode *U. pallikuukensis* (a), larvae (long arrow), and developing eggs (short arrow). H&E. Bar=100 μm.

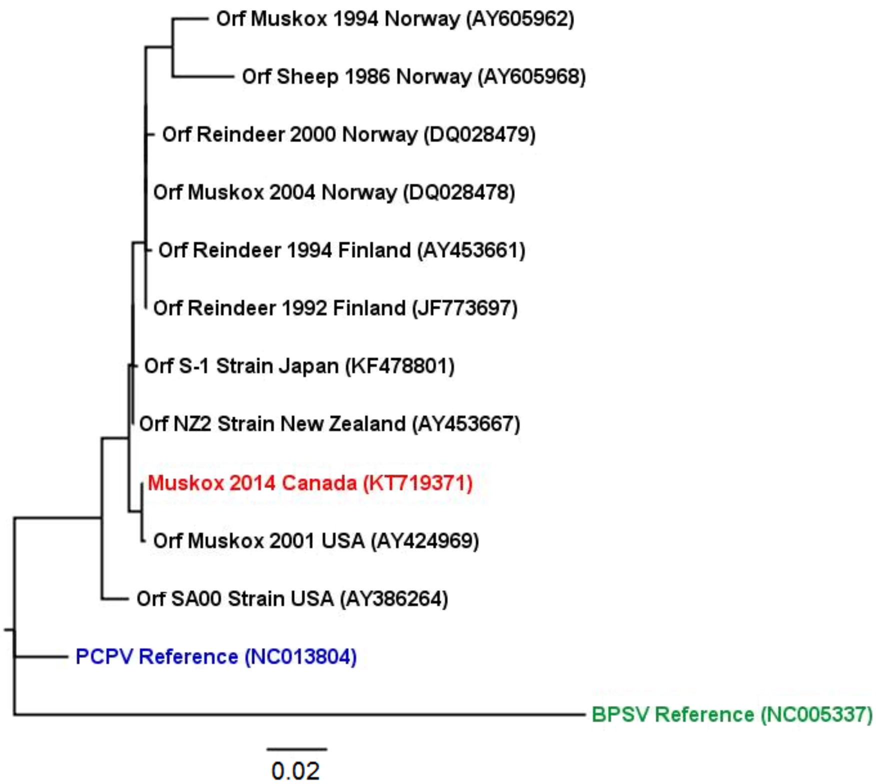

Figure 4.2. Maximum likelihood nucleotide phylogenetic tree of the major envelope protein gene (B2L) sequences from an orf virus (ORFV) identified in an adult male muskox (*Ovibos moschatus*) harvested on Victoria Island, Nunavut, Canada in August 2014, and additional *Parapoxvirus* sequences from GenBank. Viral DNA sequences are indicated by strain name/animal, year, and location of isolation, and GenBank accession numbers in parentheses. The Victoria Island ORFV sequence is shown in red, *Pseudocowpox virus* (PCPV) reference strain is shown in blue, and *Bovine papular stomatitis virus* (BPSV) reference strain is shown in green. The Victoria Island ORFV sequence shares a recent ancestor with the viral sequence identified in a muskox from the Minnesota Zoo, Apple Valley, Minnesota, US, in 2001. The scale bar indicates nucleotide substitutions per site.

A medullary abscess (3.5 cm) was found in the right distal metacarpal metaphysis connected by a fistulous tract through the cortical bone to a smaller abscess (0.5 cm) beneath the deep digital flexor tendon (Fig. 4.1C). Histologically, the abscess had colonies of Gram-negative bacteria (Fig. 4.1D). Samples from the bone abscesses and serum were submitted to the Canadian Food Inspection Agency, Brucellosis Centre of Expertise, Ottawa (Ontario, Canada). *Brucella* spp. antibodies were detected by indirect ELISA (Nielsen et al., 2004). Typical *Brucella* spp. colonies were detected at 5 days post-inoculation and identified as *Brucella suis* biovar 4 based on biotyping (Alton et al., 1988). Identification was supported by a multiplex AMOS PCR (US Department of Agriculture protocol) followed by a multiplex Bruce-ladder PCR performed in a reaction mixture containing primers (Lopez-Goni et al. 2011) and the master mix and Q-Solution supplied in a QIAGEN Multiplex PCR kit (cat. no. 206143) following the manufacturer's protocol.

A total of 212 nodules (0.5-5cm) representing 25.9% of the total lung weight, were distributed throughout the parenchyma and contained the protostrongylid *Umingmakstrongylus pallikuukensis* (Hoberg et al., 1995; Fig. 4.1E and F). A total of 574 protostrongylid larvae per gram of feces were isolated and identified as *U. pallikuukensis* and *Varestrongylus eleguneniensis* based on morphology and sequencing (Kafle et al., 2015).

Orf is caused by a zoonotic parapoxvirus with a worldwide distribution in domestic and wild ruminants and directly transmissible between hosts (Frölich, 2000). Affected individuals generally recover; however, death can occur in juveniles as a result of secondary infections or starvation (Frölich, 2000). Orf has been identified in wild muskox populations in Alaska (Zarnke et al., 1983; Afema, 2008; M. Tryland, pers. comm.) and Norway (Vikøren et al., 2008). Morbidity and mortality in calves and adults have been documented in captive muskoxen in North America and Europe (Frölich, 2000; Guo et al., 2004; Vikøren et al., 2008). Orf-like lesions on muskoxen have previously been reported by hunters on Banks Island in the Northwest Territories, Canada (M. Branigan, pers. comm.) and by residents of Cambridge Bay on Victoria Island on both muskoxen and caribou since the mid-2000s (M.T., unpubl. data; now available in Tomaselli et al., 2018b). This case is the first laboratory confirmed report of ORFV infection in a wild muskox in Canada. While contact with domestic sheep was hypothesized to have been a possible source of infection in free-ranging Alaskan and Norwegian muskoxen (Zarnke et al., 1983; Vikøren et al., 2008) and in the captive animal (Guo et al., 2004), in the present case this route of transmission is unlikely because domesticated ruminants are not present on Victoria Island. Further investigation, including obtaining more isolates from Arctic and sub-Arctic ungulates, is needed to elucidate ORFV epidemiology in Arctic wildlife.

Brucella suis biovar 4, the etiologic agent of rangiferine brucellosis, is enzootic in Holarctic reindeer and caribou (Gates et al., 1984). Typical clinical signs include stillbirth, abortion, and orchitis, leading to reproductive failure, and articular hygromas causing lameness (Forbes, 1991). In the Arctic, where caribou and reindeer represent a major source of food for communities, brucellosis is a serious public health concern

(Forbes, 1991). Brucellosis has rarely been reported in muskoxen. The disease was found in two adult male muskoxen on the Canadian Arctic mainland near Garry Lake and Kugluktuk in the 1980s (Forbes, 1991), two animals harvested on Victoria Island (Minto Inlet, NWT and Ekalluk River, NU) between 1996 and 1998 (B. Elkin, per. comm.), and in four animals from the eastern North Slope in Alaska between 2004 and 2007 (Ingebjørg et al., 2016). To our knowledge, the presentation of an intramedullary bone abscess, in the absence of bursitis or orchitis has not been previously reported. This may suggest that some infections in wild ungulates may go undetected without detailed examination including sectioning of bones. Thus, brucellosis in muskoxen is likely under-reported and may increase the risk of this zoonotic disease for hunters and consumers of traditional food.

The lungworms *U. pallikuukensis* and *V. eleguneniensis* are emerging pathogens on Victoria Island (Kutz et al., 2013). *Umingmakstrongylus pallikuukensis* is a large nematode, which forms granulomas in the pulmonary parenchyma of the host, with infection accumulating with host age (Hoberg et al., 1995). *Varestrongylus eleguneniensis* is a small nematode found deep in the airways (Verocai et al., 2014). These parasites were only recently confirmed in Victoria Island muskoxen (Kutz et al., 2013), and their distribution is expanding with increasing prevalence and intensity of infection (P.K., unpubl. data). This case has the highest *U. pallikuukensis* intensity reported for Victoria Island muskoxen (P.K., unpubl. data).

Our findings are relevant in the context of both muskox and public health, and they increase available knowledge on pathogen diversity for Victoria Island muskoxen, where population decline and unusual mortalities have been reported (Kutz et al., 2015). Orf and brucellosis may contribute to population decline by affecting recruitment and reproductive success (Afema, 2008). High lungworm intensities may have energetic costs, thus enhancing susceptibility to predators and diseases (Kutz et al., 2013). In the Arctic, rapid climate warming is having an impact on pathogen and disease transmissions by altering host-parasite interactions, and cold-adapted muskoxen are considered extremely vulnerable to these changes (Post et al., 2013; Ytrehus et al., 2015). Recent and widespread die-offs with concurrent population declines of muskoxen in the Canadian Arctic (Kutz et al., 2015), together with reports of increasing morbidity (M.T., unpubl. data; now available in Tomaselli et al., 2018b) and the detection of multiple significant pathogens in this muskox, including clinical orf in an adult animal, may suggest declining host resilience in this region that warrant further investigation.

From a public health perspective, the zoonotic potential of brucellosis and orf is important given that muskoxen are a source of food for local people, who are unfamiliar with the presence of these pathogens in local muskox populations (M.T., pers. obs.). Atypical or subclinical presentation of disease, as described here with brucellosis, may also decrease the detection of infected animals by hunters and increase the potential for exposure. Public health education is an important measure to mitigate these risks, ensuring safe harvesting practices. This case highlights the importance of thorough wildlife disease investigations undertaken by qualified health professionals in collaboration with local residents and harvesters. Such partnerships can enhance the capacity of wildlife surveillance efforts and promote both wildlife and public health.

Chapter 5. *Brucella* in muskoxen of the western Canadian Arctic 1989-2016, a transdisciplinary approach

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Abstract

Brucella serostatus was evaluated in 3186 muskoxen sampled between 1989 and 2016 from various locations of the Canadian Arctic archipelago and mainland, near the communities of Sachs Harbour and Ulukhaktok, Northwest Territories, and Cambridge Bay and Kugluktuk, Nunavut. *Brucella* antibodies were found only in muskoxen sampled around Cambridge Bay, both on southern Victoria Island and on the adjacent mainland (Kent Peninsula). Consistently with local knowledge, the apparent *Brucella* seroprevalence in the sampled muskoxen of the Cambridge Bay area increased from 0.9 % (95 % CI 0.3-2.1) in the period of 1989-2001 to 5.6 % (95 % CI 3.3-8.9) in 2010-2016. *Brucella suis* biovar 4 was also cultured from tissues of muskoxen sampled on Victoria Island near Ulukhaktok in 1996 (n=1) and Cambridge Bay in 1998, 2014, and 2016 (n=3). Overall, our data demonstrate that *B. suis* biovar 4 is found in muskoxen that are harvested for food and by guided hunts on Victoria Island and Kent Peninsula. Robust participatory epidemiology on muskox health and diseases greatly enhanced the interpretation of our Cambridge Bay data and combined are providing compelling evidence that the prevalence of *B. suis* biovar 4 has increased in this area since the population peak of the late 1990s. This study enhances the available knowledge on *Brucella* exposure and infection in muskoxen and provide an example of meaningful combination of scientific knowledge with local knowledge to better understand disease status in wildlife.

Keywords: *Brucella suis* biovar 4, serology, wildlife surveillance, archives, local knowledge, public health.

5.1. Introduction and purpose

Brucella suis biovar 4 is a Gram-negative coccobacillus that is the etiologic agent of rangiferine brucellosis, a disease that is endemic in many barren-ground caribou (*Rangifer tarandus groenlandicus*) and reindeer (*Rangifer tarandus tarandus*) populations around the Arctic (Rausch and Huntley, 1978; Tessaro and Forbes, 1986; Thorne, 2001; Godfroid et al., 2014). Rangiferine brucellosis is an important zoonosis that can result in a severe and highly debilitating disease in humans (Godfroid, 2002). For humans, exposure to *B. suis* biovar 4 occurs through direct contact with infected animals either during butchering or through the consumption of undercooked meat, viscera, and bone marrow, as well as unpasteurized milk (OIE- Office International Des Epizooties, 2016). Although the current prevalence of *B. suis* biovar 4 in people is unknown, historic data available for Alaska and Canada's Arctic highlight that rangiferine brucellosis has occurred among northern peoples who consumed caribou (Meyer, 1966; Huntley et al., 1963; Chan et al., 1989; Tessaro and Forbes, 1986; Forbes, 1991; Ferguson, 1997). Rangiferine brucellosis continues to be an important public health concern in the Arctic, a place where people largely rely on harvesting of caribou, muskoxen (*Ovibos moschatus*) and other wildlife for subsistence (CINE, 2005; Meakin and Kurvits, 2009; Tomaselli et al., 2018a).

In caribou and reindeer, *B. suis* biovar 4 can cause granulomatous lesions primarily in bones, joints, and reproductive organs, leading to reproductive failure and increased susceptibility to predation (Thorne, 2001). Evidence of *B. suis* biovar 4 exposure has been found in numerous carnivore species which prey on caribou (Neiland, 1975; Zarnke et al., 2006); and natural infection with *B. suis* biovar 4 has been sporadically described in moose (*Alces alces*) and muskoxen that are sympatric with caribou (Honour and Hickling, 1993; Edmonds et al., 1999; Gates, 1984; Forbes, 1991; Tomaselli et al., 2016). More recently, within the scope of a participatory epidemiology study on muskox health and diseases in the community of Cambridge Bay (Victoria Island, Nunavut, Canada), harvesters reported increasingly observing signs of lameness and swollen joints in muskoxen (Tomaselli et al., 2018b). Additional hunter observations for the same time period included the decline of the local muskox population and a decreased proportion of juvenile muskoxen (Tomaselli et al., 2018b).

In response to these observations, as well as the detection of a subclinical case of *B. suis* biovar 4 in a hunter-killed muskox in 2014 (Tomaselli et al., 2016), we initiated a study to determine past and current exposure to, and occurrence of, *B. suis* biovar 4 in muskoxen in the western Canadian Arctic. This study is particularly relevant given that muskoxen are an important source of food and revenue for northern communities of Canada (Gunn and Adamczewski, 2003; Kutz et al., 2017; Tomaselli et al., 2018a). We drew on a large sample size of archived sera from harvested and live-captured muskoxen from several locations of the western Canadian Arctic as well as 'contemporary' samples collected through our ongoing hunter-based muskox health sampling program in Cambridge Bay and Kugluktuk (Nunavut, Canada). The aims of this study were to investigate over time and space the *Brucella* status of muskoxen, using serology and opportunistic sampling, and to combine and interpret (triangulate) the scientific knowledge from this study with the available local knowledge on muskox health and diseases.

Besides increasing the available knowledge on the occurrence of brucellosis in muskoxen, this study illustrates how the process of triangulation that is commonly used in participatory veterinary surveillance (i.e., cross-checking data using independent methods and sources; see Mariner and Paskin, 2000) can improve understanding of disease occurrence in wildlife.

5.2. Methods

5.2.1. Blood sample collection and *Brucella* antibody testing

Whole blood and/or blood-saturated filter paper (FP) strips were collected from muskoxen that were hunter-harvested (n=3161), chemically immobilized (n=17), found dead (n=7), and euthanized (n=1) between 1989 and 2016 in various locations of the Canadian Arctic archipelago and mainland, near the communities of Sachs Harbour (SH, n=1822) and Ulukhaktok (UL, n=405), Northwest Territories, and Cambridge Bay (CB, n=864) and Kugluktuk (KU, n=95), Nunavut (Table 5.1; Fig. 5.1). During and prior to 2012, the vast majority of the samples were collected during commercial muskox harvests that occurred regularly on Banks and Victoria Islands near SH, CB, and UL, whereas near KU, samples were collected in conjunction with subsistence harvests and live captures. After 2012, the majority of the samples were obtained through hunter-based sampling programs that were organized in CB and KU in association with outfitted hunts and subsistence harvests. A small number of additional samples were collected during opportunistic disease investigations near CB. Near KU, the collection of samples occurred on the mainland near the community, except for 24 and three muskoxen that were sampled on the southwest corner of Victoria Island (Lady Franklin Point) in 2010 and 2015, respectively. While the majority of the muskoxen sampled near CB were harvested on Victoria Island, 11 of the muskoxen sampled in 2016 were harvested on Kent Peninsula, on the adjacent mainland.

Hunters collected whole blood and/or blood-saturated FP strips from harvested muskoxen, immediately after the animals were shot. Serum or plasma was obtained by collecting venous blood (jugular or femoral) into a Vacutainer® tube with (i.e., ethylenediaminetetraacetic acid, EDTA) or without anticoagulant (for plasma and serum, respectively). In some cases, sterile falcon tubes were also used for the collection of whole blood. Filter paper samples were obtained by saturating the full length of Nobuto filter strips (Advantec MFS Inc., Dublin, California, USA) in venous blood as described by Curry et al. (2011). Immediately after collection, blood-saturated FP strips for each animal were placed into an antimicrobial-lined envelope (Quality Park, St. Paul, Minnesota, USA), except for the 19 FP strips collected in SH in 2008, which were stored in regular envelopes without antimicrobial-lining. For live-captured muskoxen, serum samples were obtained by collecting venous blood via jugular venipuncture into Vacutainer® tubes after animals were chemically immobilized (Harms et al., 2012).

In the field, tube-collected blood was centrifuged for approximately 10 minutes at standard speed and aliquots of serum or plasma were kept at -20 °C until tested. Immediately after field collection, blood-saturated FP samples were stored at -20 °C or air-dried overnight. All FPs were received at Faculty of Veterinary Medicine, University of Calgary (Alberta, Canada) and were stored air-dried or at -20 °C until testing (Curry et al., 2011, 2014a). Prior to testing, any frozen FP strips were also air-dried overnight at room temperature (Curry et al., 2011). One fully saturated FP strip for each dried sample was then re-suspended in phosphate-buffered solution following the protocol described by Curry et al. (2011) to obtain a FP elution estimated at 1:10 serum concentration. These were stored at -20 °C until antibody analysis.

For the seven muskoxen that were found dead near CB in 2015, blood samples (FP strips and/or Vacutainer® tubes) were obtained from any site available for collection (i.e., heart, neck, leg). The times of death for these animals were estimated to be a few to several months prior to sample collection, and they had remained on the tundra under ambient temperatures below 0 °C until sampled. Although they had remained 'cool', the carcasses were in varying states of decomposition and scavenging, and the blood collection site thus depended on the state of carcass preservation. Samples were stored at -20 °C until elution if necessary (FP), and antibody analysis.

A set of sera included in this study (CB 1989-2001; KU 1991; UL 1994-1999; SH 1999-2012) had been tested shortly after collection for *Brucella* antibodies using the buffered plate agglutination test (BPAT) for screening as described by the Office International Des Epizooties (OIE, 1996) (Table 5.1). Standard tube agglutination test (STAT) (Stemshorn, 1985) was additionally used only for the CB collection of 1989. Sera that tested positive in the screening phase were further tested using ancillary tests: the complement fixation test (CFT) (Stemshorn, 1985), or iELISA (Nielsen et al., 1994) and/or competitive enzyme-linked immunoassay (cELISA) (Nielsen et al., 1996) (Table 5.1). Sera were considered positive for *Brucella* antibodies if they remained positive after the ancillary-supplemental testing. Analyses were performed at the laboratories of the Canadian Food Inspection Agency (Brucellosis Centres of Expertise) in Lethbridge and Ottawa (Alberta and Ontario, Canada) except for sera collected near KU in 1991, and CB in 1989 and 1991. These were tested at the Health of Animals Laboratory in Saskatoon (Saskatchewan, Canada) following the same protocol.

The remaining sera, FP eluates and plasma samples (CB 2010-2016; SH 2008, 2012; KU 2010, 2014-2016) were tested for *Brucella* antibodies with a protein A/G indirect enzyme-linked immunoassay (A/G iELISA) (Nymo et al., 2013). Among the A/G iELISA-tested samples, there were 29 paired serum and FP samples (n=20 SH 2008, n=1 CB 2014, n=6 CB 2015, n=2 CB 2016). The paired serum and FP samples of the muskox harvested in CB in 2014 are from the case described in Tomaselli et al. (2016). The archived blood samples that were obtained from that case were here newly tested with the A/G iELISA. Additionally, 93 BPAT-tested sera from the SH collection 2008 (n=34) and 2012 (n=59) were also retested by A/G iELISA (Table 5.1). Testing was performed blindly on both paired samples and BPAT-tested sera. The A/G iELISA testing was performed in 2017 at UiT – The Arctic University of Norway, Research Group for Arctic Infection Biology (Tromsø, Norway).

5.2.2. Serology data analyses

There is no information regarding the sensitivities and specificities of the tests used in this study for the detection of *Brucella* antibodies in muskoxen, therefore, cut-off values derived for reindeer and caribou (Gall et al., 2001; Nymo et al., 2013) were used. To assist with the interpretation of the A/G iELISA results, we report the percentage of positivity of the blood samples tested relative to the caribou bacteriology and serology positive control (%P = [optical density sample/ optical density positive control] × 100; Nymo et al., 2013). We compared the average %P values of the A/G iELISA negative and positive blood samples with the %P of the samples that were bacteriology positive (n=2) and negative (n=1). We calculated the apparent prevalence (AP) together with the 95 % confidence intervals computed using the Clopper-Pearson method (Brown et al., 2001).

For data analyses and interpretation of samples collected in the CB area, we categorized the data into two time periods based on local knowledge gathered from the community in 2014 (Tomaselli et al., 2018b). Interviewees from CB defined a ‘pre-decline’ from the 1990s to mid-2000s, and a ‘decline’ period from mid-2000s to the end of 2014 and onwards (Tomaselli et al., 2018b). The decline period was characterized by a major decrease in the number of muskoxen, and particularly the proportion of juveniles, as well as increasing observations of muskoxen with *Brucella*-like clinical signs such as swollen joints and lameness (Tomaselli et al., 2018b).

5.2.3. Tissue collection for pathology and microbiology analyses

During the commercial harvests in UL in 1996, and CB in 1998, veterinarians inspected muskox carcasses and tissue samples with lesions that had *Brucella* infection listed as possible differential diagnosis were obtained from three and eight carcasses, respectively. Samples were stored and submitted frozen (-20

°C) to the Canadian Wildlife Health Cooperative (CWHC) (University of Saskatchewan, Saskatoon, Canada) for further pathological and microbiological testing.

In 2016, gross lesions consistent with *Brucella* infection were detected in two adult female muskoxen near CB (one sick animal that was euthanized by the Wildlife Officer and one that was harvested for subsistence). Samples were collected, stored at -20 °C and submitted for further testing to the CWHC (University of Calgary) and to the Canadian Food Inspection Agency Brucellosis National Reference Laboratory (Ottawa, Ontario, Canada). We also include here microbiology results of a previous case summarized in Tomaselli et al. (2016) that was hunted on Victoria Island (CB area) in 2014 and from which we had paired serum and FP samples also included in this study.

5.3. Results

The only blood samples that tested positive for *Brucella* antibodies were from hunter-harvested (n=20) and euthanized (n=1) muskoxen near the community of Cambridge Bay, both on Victoria Island and on Kent Peninsula, mainland (Table 5.1 and Fig. 5.1). *Brucella* antibodies were found by BPAT and confirmed by CFT in five sera collected on Victoria Island in 1996 and 1998 (Table 5.1). The CFT titers were 1/80 (n=2), 1/160 (n=1), and 1/640 (n=1) for 1996 and 1/2560 (n=1) for 1998. *Brucella* antibodies were also found by A/G iELISA in muskoxen sampled on Victoria Island between 2010 and 2016 (16/291) and on Kent Peninsula, mainland, in 2016 (1/11) (Table 5.1 and Fig. 5.1). We further analyzed the serology data available for the CB area separated into the 'pre-decline' and 'decline' periods defined though participatory epidemiology. For muskoxen sampled in the period 1989-2001 ('pre-decline'; BPAT-tested samples), the overall apparent *Brucella* seroprevalence was 0.9 % (5/562, 95 % CI 0.3-2.1), whereas, in the following sampling period 2010-2016 ('decline'; A/G iELISA-tested samples), the overall apparent *Brucella* seroprevalence was 5.6 % (17/302, 95 % CI 3.3-8.9).

For the SH area, sera from six and two animals sampled in 2008 and 2011, respectively, were classified positive on BPAT and negative on the confirmatory tests performed (iELISA and/or cELISA)

(Table 5.1). All other samples (SH, KU, UL) tested were classified negative for *Brucella* antibodies on BPAT (Table 5.1).

To assist with the interpretation of the A/G iELISA results, we report in Table 5.2 the %P of the blood samples that were bacteriology positive (n=2) and negative (n=1). The %P of the rest of the negative and positive A/G iELISA-tested samples is also reported for comparison (Table 5.2). Regarding the 29 paired serum and FP samples tested with the A/G iELISA, there was a complete agreement on the *Brucella* serostatus of paired samples from the same animals: they were all seronegative except for three animals sampled near CB that were positive in both the FP eluates and sera. Regarding the comparison between diagnostic tests, the archived sera from SH 2008 (n=34) and 2012 (n=59) that were negative with the BPAT at the time of collection were also negative when retested with the A/G iELISA.

Of the 14 muskoxen that had post mortem lesions compatible with brucellosis (including the case described in Tomaselli et al., 2016), four cultured positive for *B. suis* biovar 4 (Table 5.3). All culture-positive animals were from Victoria Island, one near UL in 1996 (a commercially-harvested muskox) and the remaining three near CB in 1998 (a commercially-harvested muskox), 2014 (a sport-hunted adult male; Tomaselli et al., 2016), and 2016 (a euthanized adult female) (Fig. 5.1). For the *Brucella* culture-positive muskoxen that had coupled serology results, *Brucella* antibodies were detected in paired sera and FP eluates that were tested with A/G iELISA (n=2) but were not detected in the one serum that was tested with BPAT (CB 1998; Table 5.3).

Table 5.1. Blood samples of muskoxen (S, serum; FP, filter paper; P, plasma) included in the study. Blood samples were obtained as follows under 'type' of sampling: a, commercial harvest; b, sport hunts; c, found-dead; d, subsistence harvest; e, euthanized; f, live-captures. The total number of animal sampled is indicated with N; while, the total number of samples and type of samples is specified under each test performed; finally, N(+) indicates the number of positive blood samples that were found after the screening tests and the confirmatory tests (CFT, iELISA, cELISA) and/or new test (A/G iELISA) performed. Tested filter paper samples (FP) that had paired serum samples (S) are indicated in parenthesis

Muskoxen sampled				*Screening test*			*Confirmatory and new tests*				*Final status*
Location	**Year**	**Type**	**N**	**BPAT**	**STAT**	**N (+)**	**CFT**	**iELISA**	**cELISA**	**A/G iELISA**	**N (+)**
Sachs Harbour	1999,2000,2003,2006	a	846	846^{S}	-	0	-	-	-	-	0
Sachs Harbour	2008	a	671	668^{S}	-	6^{S}	-	4^{S}	6^{S}	$34^{S,1}$, 51^{FP} (20 paired)	0
Sachs Harbour	2011	a	243	243^{S}	-	2^{S}	-	-	2^{S}	-	0
Sachs Harbour	2012	a	62	62^{S}	-	0	-	-	-	62^{S}	0
Ulukhaktok	1994, 1996	a	315	315^{S}	-	0	-	-	-	-	0
Ulukhaktok	1999	a	90	90^{S}	-	0	-	-	-	-	0
Cambridge Bay	1989	a	20	20^{S}	20^{S}	0	-	-	-	-	0
Cambridge Bay	1991	a	20	20^{S}	-	0	-	-	-	-	0
Cambridge Bay	1993, 1995, 2001	a	246	246^{S}	-	0	-	-	-	-	0
Cambridge Bay	1996	a	130	130^{S}	-	4^{S}	4^{S}	-	-	-	4^{S}
Cambridge Bay	1998	a	146	146^{S}	-	1^{S}	1^{S}	-	-	-	1^{S}
Cambridge Bay	2010	a	55	-	-	-	-	-	-	55^{P}	3^{P}
Cambridge Bay	2011	a	76	-	-	-	-	-	-	76^{FP}	2^{FP}
Cambridge Bay	2012	a	42	-	-	-	-	-	-	14^{S}, 28^{FP}	1S
Cambridge Bay	2014	b	59	-	-	-	-	-	-	1^{S}, 59^{FP} (1 paired)	1S, 4^{FP} (1 paired)
Cambridge Bay	2015	b,d,c	28,8,7	-	-	-	-	-	-	6^{S}, 43^{FP} (6 paired)	1S, 5^{FP} (1 paired)
Cambridge Bay	2016	b,d,e	25,1,1	-	-	-	-	-	-	2^{S}, 27^{FP} (2 paired)	1S, 2^{FP} (1 paired)
Kugluktuk	1991	d,f	21,17	38^{S}	-	0	-	-	-	-	0
Kugluktuk	2010	d	24	-	-	-	-	-	-	24^{FP}	0
Kugluktuk	2014	d	16	-	-	-	-	-	-	16^{FP}	0
Kugluktuk	2015	d	13	-	-	-	-	-	-	13^{FP}	0
Kugluktuk	2016	d	4	-	-	-	-	-	-	4^{FP}	0

[1]34 sera were tested also with BPAT at the time of collection

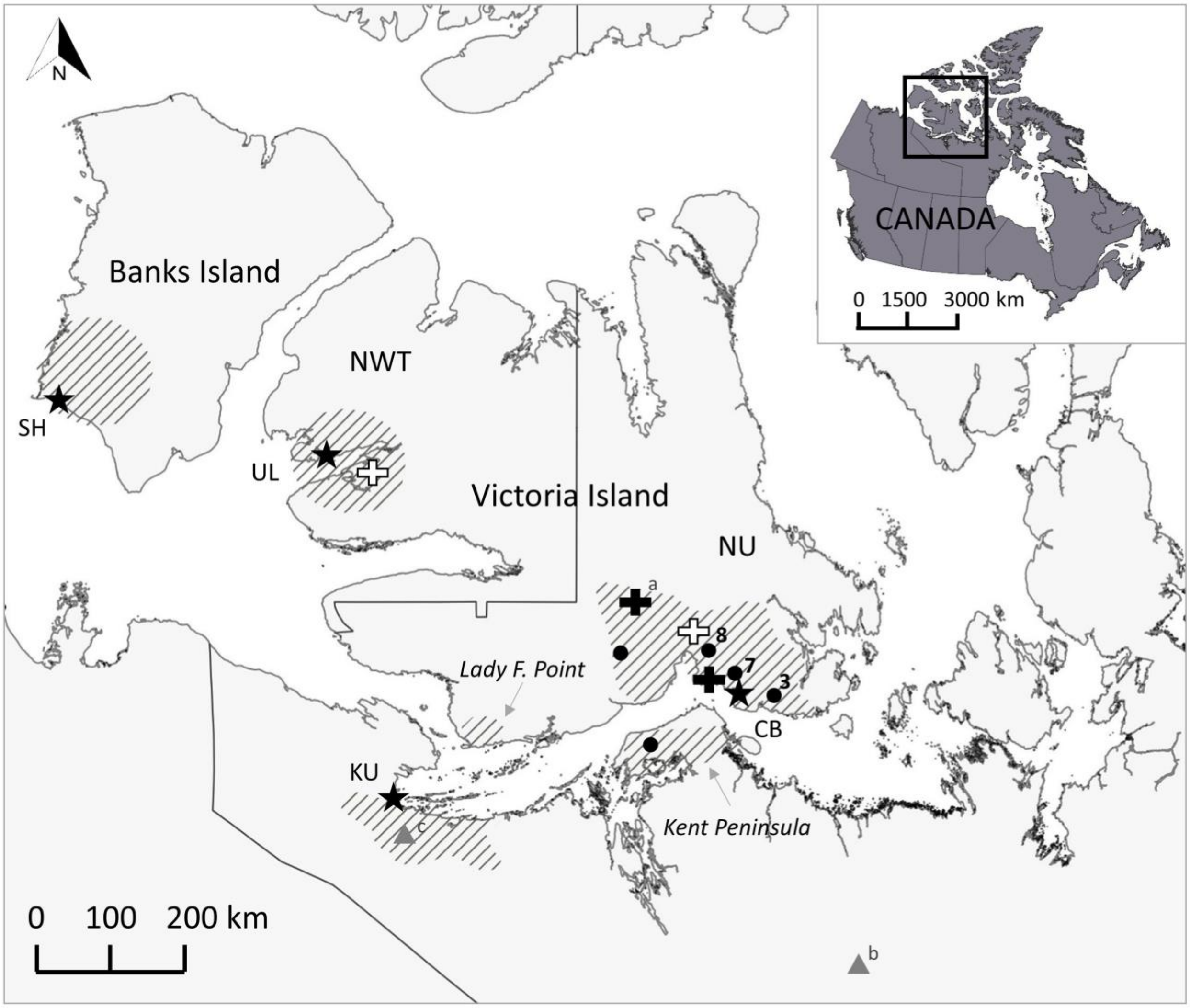

Figure 5.1. Area of study showing the locations where the samples were collected (line pattern fill) in proximity of the communities of Sachs Harbour (SH) and Ulukhaktok (UL), the Northwest Territories, and Cambridge Bay (CB) and Kugluktuk (KU), Nunavut (marked with a star). Locations of the *Brucella* positive muskoxen are marked with a black dot (only serology-positive blood samples), white cross (only microbiology positive tissue samples in which *Brucella suis* biovar 4 was isolated), and black cross (serology-positive blood samples coupled with microbiology positive tissue samples in which *B. suis* biovar 4 was isolated; with the letter a we refer to the microbiology result described in Tomaselli et al., 2016). When a georeferenced location represents more than one animal, a number indicates the sample size. For completeness, we finally indicate with grey triangles the locations of two male muskoxen from which *B. suis* biovar 4 was isolated in tissue samples and that are available in the published literature (b, Gates, 1883; c, Forbes, 1991).

Table 5.2. Percentage of positivity (%P) of muskox sera (S), filter paper eluates (FP), and plasma (P) that were classified positive or negative by A/G iELISA. For each sample the %P was computed relative to the positive control used on the same plate (%P = [optical density sample/optical density positive control] × 100) where the positive control was from a microbiology and serology positive caribou (Nymo et al., 2013). The first 3 samples were from animals confirmed by microbiology as either positive or negative for infection with *Brucella suis* biovar 4. For the remaining samples confirmatory microbiology was not available (n/a), thus are identified as positive or negative based on the A/G iELISA. For these samples the mean value is reported and the standard deviation (SD) and the number of samples tested (n) are specified in parenthesis.

Sample identification	**Status**		***%P***		
	A/G iELISA	***B. suis* biovar 4**	**S**	**FP**	**P**
Hunted male, CB 2014	Positive	Positive [a]	37.43	40.40	-
Euthanized cow, CB 2016	Positive	Positive	41.58	25.68	-
Hunted cow, CB 2016	Negative	Negative	0.65	0.64	-
Remaining samples - positive	Positive	n/a	12.24 (n=1) [b]	29.88 (SD 5.18; n=12)	11.28 (SD 3.35; n=3)
Remaining samples - negative	Negative	n/a	0.51 (SD 0.11; n=115)	0.59 (SD 0.18; n=326)	0.67 (SD 0.24; n=52)

[a] Tomaselli et al., 2016; [b] Fund-dead cow, CB 2015 (%P in paired FP sample=36.97)

Table 5.3. Microbiology and serology status of samples (tissues and blood, respectively) collected from muskoxen that had gross lesions with *Brucella* infection listed as possible differential diagnosis. Serology status of muskoxen was determined by BPAT on sera ([1]), A/G iELISA on paired sera and filter papers eluates ([2]), or was not available (n/a).

Location	Year	Identified lesion	Status	
			B. suis **biovar 4**	**Serology**
Ulukhaktok	1996	Lymphadenitis	Negative	Negative [1]
Ulukhaktok	1996	Nephritis, splenitis, lymphadenitis	Positive	n/a
Ulukhaktok	1996	Lymphadenitis	Negative	Negative [1]
Cambridge Bay	1998	Skin abscess	Negative	Negative [1]
Cambridge Bay	1998	Squamous cell carcinoma	Negative	Negative [1]
Cambridge Bay	1998	Lymphadenitis	Negative	Negative [1]
Cambridge Bay	1998	Lymphadenitis	Positive	Negative [1]
Cambridge Bay	1998	Fat abscess	Negative	Negative [1]
Cambridge Bay	1998	Lymphadenitis	Negative	Negative [1]
Cambridge Bay	1998	Lymphadenitis	Negative	Negative [1]
Cambridge Bay	1998	Lymphadenitis	Negative	Negative [1]
Cambridge Bay	2014	Metatarsal abscess	Positive [a]	Positive [2]
Cambridge Bay	2016	Bilateral abscesses in the vagina	Negative	Negative [2]
Cambridge Bay	2016	Granulomatous mastitis, endometritis, lymphadenitis, nephritis	Positive	Positive [2]

[a] Tomaselli et al., 2016.

5.4. Discussion

Our results, using contemporary and archived samples and data collected over almost 30 years for the western Canadian Arctic demonstrate that *B. suis* biovar 4 is increasingly found in muskoxen on Victoria Island and Kent Peninsula on the nearby mainland. In addition, for the muskoxen of the Cambridge Bay area, serology data combined with the available local knowledge (Tomaselli et al., 2018b) provide compelling evidence that the prevalence of *B. suis* biovar 4 has increased since the population peak of the late 1990s. Although *Brucella* antibodies were not detected in the muskoxen sampled on Banks Island and the Kugluktuk area on the mainland, we cannot conclude that these locations are free of *B. suis* biovar 4 due to the limitations of study design discussed later in this paper and in absence of robust participatory epidemiology for triangulation. Our work confirms the importance of archived samples for understanding disease status and emergence in wildlife (Mörner et al., 2002; Hoberg et al., 2008; Ryser-Degiorgis, 2013) and emphasizes the critical importance of triangulating different data sources (i.e., scientific and local knowledge) to improve this understanding in absence of perfect tests and study design (Tomaselli et al., 2018b), which are often difficult, if not impossible, to achieve when studying diseases in free-ranging animals (e.g., Wobeser, 2007; Godfroid et al., 2010; Gilbert et al., 2013; Ryser-Degiorgis, 2013). In a remote setting, such as the Arctic, this approach of acquiring data from multiple sources (sampling, local knowledge, archival collections) can greatly strengthen future monitoring and surveillance efforts for rangiferine brucellosis and beyond.

As typical of wildlife disease serological surveys, we encountered several challenges for the interpretation of serological data. Limitations that need to be considered are linked to changing methodologies for *Brucella* serology screening and, most importantly, the lack of test validation. For example, although BPAT is one of the tests recommended by the OIE to screen for brucellosis in cattle with a sensitivity of 100 % in this species (OIE, 2016), the sensitivity of BPAT is unknown in muskoxen. When BPAT was validated to screen for brucellosis in other species, the sensitivities varied from 98 % in reindeer (Gall et al., 2001) to 86 % in bison (Nielsen and Gall, 2001) and 77 % in sheep (same subfamily muskoxen belong to; Nielsen and Gall, 2001) leading to varying percentages of false negative results. Additionally, although the confirmatory tests used (i.e., CFT, iELISA, cELISA) all have a sensitivity of 100 % for the detection of *Brucella* antibodies for caribou (Gall et al., 2001), they were used in series and not in parallel with BPAT; thus the overall sensitivity did not improve. We can't exclude, therefore, that positive sera might have been missed in samples screened by BPAT; this possibility is reinforced considering that *Brucella* antibodies were not detected by BPAT in the serum of one muskox that was culture-positive for *B. suis* biovar 4 (CB 1998; Table 5.3).

With reference to the newly performed A/G iELISA, this test has been used extensively to screen for *Brucella* in muskoxen and other Arctic wildlife (Nymo et al., 2013, 2016). The A/G iELISA has been validated for *Brucella* antibody detection in blood of reindeer and caribou (sensitivity 100 %, specificity 99.3 %; Nymo et al., 2013) but not for muskoxen. In the present study, however, we observed a clear difference in the %P values (thus OD values) of the blood samples that were scored as negative or positive with A/G iELISA, which aligned with the %P of the blood samples of the culture positive and negative muskoxen (Table 5.2). Therefore, although the A/G iELISA has not been validated for muskoxen using a conventional methodology, the potential misclassification of the serostatus of the samples tested with A/G iELISA (i.e., inadequate cut-off value, cross-reacting agents) is unlikely in this study.

One important challenge in this study was the use of different sample types (FP, serum, plasma). We were fortunate that paired FPs and sera were available for a subset of animals. The 100 % results agreement obtained in paired FPs and sera indicates that FPs are valid samples for *Brucella* screening by A/G iELISA for muskoxen. These findings are consistent with what Curry et al. (2011) reported for caribou using iELISA. For the future, the easily implementable FP sampling can be an asset for increasing the field surveillance capacity for *Brucella* in harvested muskoxen. In this species, FPs might also be promising for ELISA screening for other pathogens as described for caribou (Curry et al., 2011, 2014a, b).

The change in testing approach over the sampling period 1989-2016 reflects the evolution in laboratory diagnostics for *Brucella* serology screening. We were able to compare the results from the A/G iELISA and BPAT testing for a subset of sera. The agreement between the two tests (100 % in our subset of samples) makes us more confident in the results reported in this study despite the absence of test validation. In this study, culture data have been invaluable for further interpretation of the serology testing. Animals that were culture positive for *B. suis* biovar 4 also were serologically positive by A/G iELISA. In contrast, one animal was negative on BPAT but positive by culture. In this case, the bacterium was isolated in a lymph node but we cannot exclude that it was an early infection in which IgG are not yet produced. For future surveillance efforts, we suggest to prioritize the A/G iELISA for serology screening of *Brucella* in muskoxen. Combined implementation of serology with pathological and microbiological examinations will be essential for the future improvement of serology testing.

We only detected seropositive muskoxen in the Cambridge Bay area, both on Victoria Island and on Kent peninsula mainland. Our results suggest an increasing seroprevalence in this area, however, we are comparing BPAT-tested samples (1989-2001) with A/G iELISA-tested samples (2010-2016). To consider this increase valid based on our serology data alone, we have to assume that the tests have similar sensitivities and specificities and that the population tested is comparable in the two periods (i.e., same proportion of adults and juveniles, males and females). Based on our data and available knowledge, we cannot fully confirm these assumptions, thus limiting our confidence, based on serology data alone, that *Brucella* seroprevalence has truly increased. However, the triangulation of our serology data with historic and current participatory epidemiology and scientific data available for the same area provide supporting evidence that *B. suis* biovar 4 might truly be an increasing issue for muskoxen on Victoria Island. Culture data from our study confirm that *B. suis* biovar 4 is present in Victoria Island muskoxen. Additionally, the participatory epidemiology data gathered from Cambridge Bay harvesters align with what we would expect in a population where *B. suis* biovar 4 is circulating: a population decline with a decrease in the proportion of young animals suggesting reproductive failure, and typical *Brucella*-like syndromes such as swollen joints and limping animals (Tomaselli et al., 2018b). Furthermore, historic scientific information available for the Cambridge Bay area on muskoxen and sympatric caribou also supports that brucellosis may be increasing in this location. Blood samples from 120 muskoxen and 62 caribou of the Dolphin and Union herd collected between 1986 and 1990 on the southeastern Victoria Island were negative for *Brucella* antibodies (Gunn et al., 1991), however, a recent serological study of the Dolphin and Union caribou herd suggests that *Brucella* is now present in this species as well (Carlsson et al., submitted). Whether the presence of *B. suis* biovar 4 in muskoxen on Victoria Island is associated with a spill-over event from the seasonally sympatric Dolphin and Union caribou herd, or if it has been circulating independently in muskoxen, cannot be determined based on our data. Finally, although the role of *Brucella* in the recent population declines remains uncertain, it has been implicated as influencing population dynamics elsewhere. For example, in the closely monitored caribou population of Southampton Island (Nunavut), the overall decline and decreased pregnancy rates were temporally associated with increasing *Brucella* seroprevalence (Campbell, 2013). Additionally, increased *Brucella* seroprevalence was also found in a declining muskox population in Alaska (Afema et al., 2017). Further studies, including modeling, are required to understand the potential role of *Brucella* in the decline of the muskox population on Victoria Island.

We did not detect *Brucella* antibodies in the muskoxen sampled near Sachs Harbour (Banks Island) and Kugluktuk (mainland). However, given the lack of validation for muskoxen of the serology tests used and the small sample size (for the KU area), we cannot say definitely that brucellosis is absent from those areas. For Banks Island samples, although we cannot exclude that BPAT screening failed to detect *Brucella* antibodies, we are more confident in our results given a larger sample size and the fact serological testing was paired with veterinary post-mortem inspections of carcasses which did not found evidence of brucellosis (B. Elkin, pers. comm.). On Banks Island, muskoxen do not have contact with barren-ground caribou (the most common hosts for the bacteria) but share their range with the Peary caribou (*Rangifer tarandus pearyi*) (Nagy et al., 1996). To date there is no reports of rangiferine brucellosis in Peary caribou on Banks Island (Species at Risk Committee, 2012), however, there has been limited testing of this species for *Brucella* (B. Elkin, pers. comm.) and local knowledge on brucellosis has not been documented. On the contrary, on the mainland, including the Kugluktuk area, available data already suggest that *B. suis* biovar 4 is present in muskoxen (Gates et al., 1984; Forbes, 1991; Gunn et al., 1991; Fig. 5.1) as well as in sympatric barren-ground caribou (Gunn et al., 1991; Carlsson et al., submitted). For the future, documenting local knowledge from key informants from Sachs Harbor and Kugluktuk will aid in better understanding historic and contemporary *Brucella* status of muskoxen in those areas. This is of great relevance especially for Banks Island given the continued and rapid decline of muskoxen (Kutz et al., 2017) even after our samples ended for this location.

5.5. Conclusion

Rangiferine brucellosis is a serious disease in the Arctic, a place where healthy and sustainable wildlife contribute to healthy communities (Meakin and Kurvits, 2009; Tomaselli et al., 2018a). Our study demonstrated that *B. suis* biovar 4 is present in muskoxen on Victoria Island and the adjacent mainland that are commonly harvested for food and by guided hunts. Given the pathogenic potential of this bacterium for both human and wildlife (Godfroid et al., 2002; 2013), and the association of *Brucella* with population declines elsewhere, it is important to strengthen the surveillance for rangiferine brucellosis in muskoxen, and understand its epidemiology and impact. Here we provide evidence that a transdisciplinary approach that combines scientific and local knowledge can strengthen the surveillance capacity for rangiferine brucellosis in the Arctic. Only for of the Cambridge Bay area we were able to achieve greater understanding of *Brucella* status in muskoxen through the process of triangulation of data derived by active sampling, archived collections, and participatory epidemiology. The same level of understanding was not possible for the other locations included in this study. This confirms that inference of disease status by relying on serology alone is challenging for wildlife. Moving forward we encourage wildlife professionals to systematically collect local knowledge, an invaluable source of information on wildlife health and diseases (see Tomaselli et al., 2018b). Local knowledge gathering will promote dialogue and collaboration among stakeholders (Tomaselli et al., 2018b). In the Arctic, we anticipate that this collaboration will aid in improving both the co-management for muskoxen and the prevention of *B. suis* biovar 4 exposure in people, promoting healthy communities and sustainable wildlife populations.

Chapter 6. Wildlife surveillance: from global challenges to local solutions, learning from the muskox project in Canada's Arctic

Chapter intended for submission to the

Revue Scientifique et Technique Office International des Epizooties.

6.1. Introduction

Veterinary surveillance is defined by the World Organization for Animal Health (OIE) as *"the systematic ongoing collection, collation and analysis of information related to animal health, and the timely dissemination of this information so that action can be taken"* (OIE, 2017). For wildlife, veterinary surveillance is recognized as an important activity to support informed decisions for conservation of biodiversity, wildlife management, as well as protection of animal and human health (Deem et al., 2001; Peterson and Ferro, 2012; Ryser-Degiorgis, 2013; OIE, 2014; Stephen, 2014; Decker et al., 2016). Since 1993, when the Working Group on Wildlife Diseases was established, the OIE has called on the international community to strengthen its capacity for wildlife surveillance (OIE, 2010). Implementing wildlife surveillance, however, is inherently difficult due to the many logistical and technical challenges that exist when working with free-ranging animals, including difficulties in accessing animals and knowing population characteristics, limited ability for implementing ideal sampling methods and study design, and rare availability of species-specific validated tests (Skerratt et al., 2007; Wobeser, 2007; Ryser-Degiorgis, 2013; OIE, 2014). Altogether these limitations can increase the risk of producing results, or surveillance outputs, that are difficult to interpret for wildlife and consequently of using resources ineffectively or sub-optimally.

Approaches that bridge multiple disciplines have been advocated as strategies to enhance the surveillance capacity for wildlife (Hoberg et al., 2008; Ryser-Degiorgis, 2013; Stephen, 2014). Increasingly, traditional and local knowledge and community-based tools are being utilized in wildlife health and disease monitoring and research (e.g., Eamer, 2004; Brook et al., 2009; Huntington, 2011; Chen et al., 2012; Johnson et al., 2015; Iverson et al., 2016; Carlson et al., 2016; Henri et al., 2018). However, a transdisciplinary approach that can promote the systematic implementation of wildlife surveillance has yet to be proposed. Here we illustrate how participatory surveillance (PS) adapted and applied to free-ranging wildlife allows for implementation of an effective transdisciplinary strategy for gathering and interpreting data, mitigating many of the challenges faced by wildlife surveillance while developing a system that is relevant locally. We support our reasoning by presenting and discussing lessons learned from the "Participatory Muskox Health and Disease Surveillance Project" piloted in the community of Cambridge Bay, in the Canadian Arctic.

Participatory surveillance (PS) is a form of risk-based surveillance that developed in the 1990s from participatory rural appraisal and highly improved the surveillance capacity for livestock diseases in developing countries (Catley et al., 2012; OIE, 2014). Central to this approach is the knowledge of livestock owners regarding the diseases affecting their animals (Mariner and Paskin, 2000; OIE, 2014). Interviewing local informants is the key component of PS systems and typically improves the overall sensitivity and timeliness of the surveillance (Mariner and Paskin, 2000; OIE, 2014). A variety of participatory exercises implemented throughout the interview process (e.g., mapping, proportional piling, timeline, seasonal calendar) enable gathering the ethnoveterinary knowledge (EVK) of local informants in the form of semi-quantitative epidemiological data, or participatory epidemiology (PE) data, that are essential to find and describe hazards or diseases (Catley et al., 2012). The PE data gathering process is generally followed by clinical examination of the animals, targeted sampling, and field or laboratory diagnostics (Mariner and Paskin, 2000; Catley et al., 2012; OIE, 2014). Such conventional veterinary diagnostic methods are used to confirm and further characterize diseases, increasing the specificity of the surveillance (Catley et al., 2012; Mariner and Paskin, 2000). When PS is fully applied, the knowledge of local stakeholders is also used to define local needs and priorities that help improving or shaping veterinary programs and intervention measures (Mariner and Paskin, 2000; Jost et al., 2007; OIE, 2014).

Strong reliance on local knowledge systems makes PS a highly flexible tool which can be successfully applied also for veterinary surveillance of wildlife in those settings characterized by the presence of local informants (Tomaselli et al., 2018b). Gathering and interpreting data on wildlife, however, come with its own set of needs and challenges. Interviews and PE methods need to be adapted to gather reliable wildlife-oriented data and limited access to animals makes sampling wildlife more challenging compared to sampling livestock, therefore, specific strategies have to be designed according to the context.

In this paper, we illustrate how concepts and methods of the PS tradition were adapted to assess health and disease status of wild muskoxen (*Ovibos moschatus*) in the Canadian Arctic. This Arctic is one of the world's most remote and sparsely settled areas and residents, of which the majority are indigenous peoples, largely rely year-round on harvesting of renewable resources including wildlife (Myers et al., 2005; CINE, 2005; Meakin and Kurvitz, 2009). In the North, wildlife surveillance is critical to support food security and safety, and co-management for the sustainability of harvested wildlife; yet it can be remarkably difficult to implement. In this remote area, undertaking scientific surveys on wildlife is logistically challenging and extremely expensive (Mallory et al., 2018). However, with their extensive and holistic knowledge about the environment and the animals they depend on, northern peoples are the key informants of the system and can contribute important information to wildlife surveillance, just as livestock owners are the key informants of PS for livestock diseases in rural communities (Tomaselli et al., 2018b).

Besides providing a practical example, we discuss general recommendations on PS applied to wildlife, including a framework for data gathering and interpretation that combines local knowledge with scientific knowledge. The overview of our work and lessons learned will be particularly relevant for a variety of stakeholders working on wildlife in different settings who wish to implement or restructure their programs in a participatory and locally relevant manner. We believe that this is a promising approach towards enhancing the surveillance capacity for wildlife as advocated by the OIE.

6.2. The study system

Our work took place in the community of Cambridge Bay on Victoria Island, Nunavut where muskoxen are harvested year-round for both subsistence and revenue by community residents (Tomaselli et al., 2018a). Up until recently, the veterinary surveillance for muskoxen in the Cambridge Bay area consisted mainly of standard passive surveillance coupled with active abattoir surveillance when the annual commercial harvests of muskoxen were operating (from the 1990s until 2012). Throughout the years, there have also been sporadic efforts to establish baseline health and disease data on the animals (e.g., Gunn et al., 1991; Salisbury et al., 1992; Blakley et al., 2000; Kutz et al, 2000; Wu at al., 2010; Checkley et al., 2012). Despite these surveillance and monitoring efforts, the epidemiological knowledge on muskoxen available prior to our study was limited and fragmented, making it difficult to understand the health status of muskoxen in the area, detect changes and promptly act with adequate measures. Updated demography data were also unavailable as the last population survey was performed in 1999 (Gunn and Patterson, 2012).

There were, however, concerns regarding the health status of muskoxen in the area due to evidence of declining numbers of muskoxen which led to the suspension of the annual commercial harvest in 2013; the isolation from a few dead muskoxen of *Erysipelothrix rhusiopathiae*, a pathogen associated with large-scale mortality outbreaks of muskoxen elsewhere (Kutz et al., 2015); and the emergence in muskoxen on Victoria Island of two lung nematodes, *Varestrongylus eleguneniensis* and *Umingmakstrongylus pallikuukensis*, suggesting changing host-parasite interactions in the area (Kutz et al., 2013a).

6.3. The "Participatory Muskox Health and Disease Surveillance Project" in Cambridge Bay

In 2013, we started this project in response to the concerns outlined above. We adapted concepts and methods of PS to our context with the intent of developing a strategy for data gathering and interpretation that could be implemented long-term, progressively adapting to local needs. The objectives of this pilot surveillance project were to document historical and contemporary baseline information on muskox health and disease outcomes in the study area, more rapidly detect unusual events, suggest hypotheses concerning changes in health outcomes and, finally, produce information that could improve public health strategies. First, we strengthened existing collaborations with territorial and local stakeholders and added new ones. Then, we developed and piloted different surveillance activities, or surveillance components, aimed at combining local knowledge with scientific knowledge.

We started by collecting local knowledge by conducting semi-structured interviews of key informants. We then co-designed with hunters a hunter-based sampling program of regularly hunted muskoxen. Based on the outcomes from these surveillance activities, two other components followed in the form of field disease investigations and targeted scientific studies. The different components implemented in this project influenced each other, creating a surveillance plan that drew on different knowledge systems and was both flexible and adaptive (Fig 6.1). All surveillance components were fully implemented between 2014 and 2016; hunter-based sampling continued beyond 2016 and is still ongoing. In the following section we provide a brief description of each surveillance component implemented and the overall output of the surveillance.

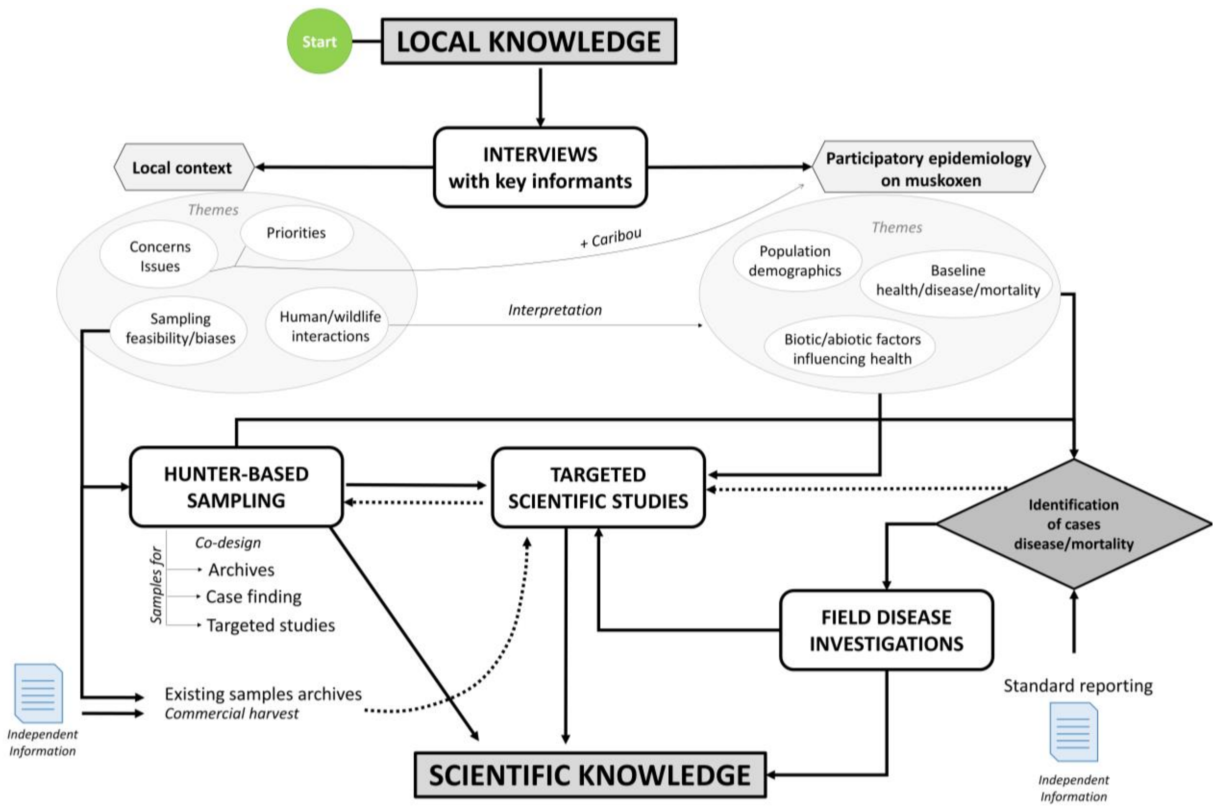

Figure 6.1. Process map illustrating the participatory framework for data gathering and interpretation implemented for the veterinary surveillance of muskoxen (*Ovibos moschatus*) in the community of Cambridge Bay on Victoria Island (Nunavut) in the Canadian Arctic. The main surveillance component activities, which refer to either the local knowledge system or the scientific knowledge system, are indicated inside rounded rectangles; black solid lines represent the main connections among activities (thinner lines are used for visualizing connections or explain features within a single component); black dotted lines refer to the secondary connections or feedback connections within the process.

6.3.1. Interviews with key informants

Semi-structured interviews of key informants were conducted to gather data on the local context and missing contemporary and historic PE data on the status of muskoxen in the study area (see Tomaselli et al., 2018 a, b). In our context, local informants included muskox hunters, elders, abattoir workers, and float-plane pilots (see Tomaselli et al., 2018 a, b). Exploring the local context allowed for identification of local priorities and concerns which further influenced the PE data gathering process. For example, we discovered concurrent concerns on the status of caribou (*Rangifer tarandus*) in the area, which led us to adapt the PE gathering process to include caribou. Evaluating sampling feasibility helped us to develop the hunter-based sampling program, to understand other opportunities to access biological samples, and to identify the sampling biases associated with different strategies. Exploring the interactions between key informants and muskoxen was critical for the correct interpretation of PE data (i.e., knowing butchering practices is important to correctly interpret observation of diseases) and for improving strategies for wildlife co-management and protection of public health (see Tomaselli et al., 2018a).

For this surveillance component, we developed a strategy for data collection and interpretation that combined robust qualitative and PE methods, obtaining a reliable output through an interview process characterized by individual and group interviews (data gathering process) and feedback sessions (data validation process) (Tomaselli et al., 2018a, b). For a comprehensive description of the interviews refer to Chapter 2 (i.e., exploring the local context) and Chapter 3 (i.e., gathering PE data on muskox/caribou health and diseases).

6.3.2. Hunter-based sampling program

This surveillance component enabled the ongoing collection of biological samples from regularly hunted muskoxen across a spatial and temporal scale that would not have been possible otherwise. Compact, lightweight sampling kits were co-designed with the hunters for collection of a standardized set of samples with customization for local field conditions. Samples were selected to enable the continuity of existing monitoring projects (e.g., lungworms' range of expansion; see Kafle et al., 2018), the implementation of new research (e.g., determination of stress hormones levels in muskox wool; see Di Francesco et al., 2017), and construction of sample archives for use in subsequent targeted studies. The hunter-based sampling included identification of animals with abnormal lesions or the direct collection of abnormal tissues, resulting in improved case finding. Local knowledge informed specific targeted studies leading to modification of sampling kits to enable the collection of additional samples. For example, in response to observations of increased teeth abnormalities, the lower jaw was added to the list of samples. A monetary compensation for sample collection was also set in response to hunters' feedback.

6.3.3. Field disease investigations

Field disease investigations have been undertaken throughout the program when cases of disease/mortality were identified. Identification of cases was made possible mainly through interviews with key informants and the hunter-based sampling, but also through standard reporting. Prompt implementation of field activities was essential to identify pathogens of relevance for both muskoxen and humans (i.e., orf virus, *Brucella suis* biovar 4) and to elucidate mechanisms of muskoxen disease and mortality. Field disease investigations were carried out by a trained veterinarian (MT).

6.3.4. Targeted scientific studies

Hunters' observations gathered through interviews, hunter-based sampling results, and field disease investigation findings helped to define further surveillance and research priorities that were realized through targeted scientific studies. These studies were also made possible owing to samples available through existing archives and ad hoc modification of the sampling kits (i.e., inclusion of extra samples). Prior to developing this program, we were aware that archived samples from previous surveillance efforts (commercial harvests) were available; however, interviews with key informants proved critical to better understand the study population from which those samples were taken.

6.3.5. The surveillance output

The surveillance program increased our understanding of the health status of muskoxen in the area and provided important historical information that previous surveillance and monitoring efforts failed to capture. This helped us to identify changes in the health and disease status of muskoxen, confirm disease, and inform future surveillance priorities and intervention strategies for improving wildlife co-management and protection of public health.

Interviews provided missing data that described over a temporal scale the population under surveillance including PE data on demographics, body condition status, mortality and morbidity, as well as relative prevalence, trends, and occurrence of endemic and emerging syndromes. Through PE we discovered that by the end of 2014 the number of muskoxen had decreased by 85% (interquartile range: 75-90) compared to the population peak of the late 1990s and, within this time period, young muskoxen (calf plus yearling) in particular had declined (Tomaselli et al., 2018b). Population estimates available after our study confirmed the decline and its magnitude for the area (Leclerc, 2015). Through PE, possible mechanisms to explain demography changes were also elucidated and included increasing syndromes that can negatively influence survival and recruitment (e.g., deterioration of body condition, *Brucella*-like syndromes, orf-like lesions) and mortalities consistent with a disease outbreak. Through the interviews, we retrospectively identified at minimum 120 dead muskoxen for the period 2010-2014, a stark contrast compared to only 10 cases found in 2010 through passive surveillance (Tomaselli et al., 2018b; Kutz et al., 2015).

Findings from interviews, hunter-based sampling and field disease investigations were combined to identify and then confirm cases of disease, involving pathogens of relevance for both wildlife and human health (Tomaselli et al., 2016). For example, although hunters had observed orf-like lesions in muskoxen since 2004, the pathogen itself was not identified until a hunter who participated in the hunter-based sampling program observed the same lesions in a muskox he sampled, triggering a field disease investigation that lead to orf virus being isolated for the first time in the area in 2014 (Tomaselli et al., 2016). Since then, through our program orf virus has been detected in more muskoxen that have been harvested and found dead, including juveniles (Tomaselli M. and Dalton C., unpublished data). Through field disease investigations, *Brucella suis* biovar 4 was also confirmed in an adult bull in 2014 and an adult non-pregnant cow in 2016 (Tomaselli et al., 2016; 2018c).

Altogether these data informed targeted scientific studies to further identify diseases and presence and trends of pathogens relevant in the system. For example, a targeted scientific study to assess the status of *Brucella* in muskoxen from 1989 to 2016 was implemented (see Tomaselli et al., 2018c). This study combined knowledge from key informants with data derived by conventional veterinary diagnostics (i.e., serology and microbiology), providing compelling evidence of increasing *Brucella* in muskoxen of the Cambridge Bay area (Tomaselli et al., 2018c). Other targeted studies that are still ongoing include a serosurvey for *Erysipelothrix rhusiopathiae* (pathogen involved in mortality outbreaks; Kutz et al., 2015), the assessment of trace elements and contaminants levels, the evaluation of incisor breakage and teeth abnormalities, and a phylogenetic study on orf viruses identified in muskoxen through our program.

Interviews with key informants helped us better define local needs, design surveillance activities, interpret surveillance data, and inform interventions (see Tomaselli et al., 2018a). For example, our work emphasized that muskox decline is causing negative impacts to the community at the nutritional, economic, and socio-cultural levels, highlighting important areas for interventions that may be neglected (Tomaselli et al., 2018a). Importance of, and challenges for, maintaining traditional management practices also emerged from the interview process, highlighting another area for intervention for improving current co-management strategies. Specific interactions that can facilitate human exposure to zoonotic diseases were also elucidated, providing information of direct use for public health interventions (see Tomaselli et al., 2018a).

Finally, interviews with key informants helped identify local needs and priorities for other species. For example, concerns on the health status of caribou strongly emerged during the interview process; therefore, PE data were collected also for caribou, which was not planned from the start (Tomaselli et al., 2018b). Following our interviews, a hunter-based sampling program for caribou has also been established in Cambridge Bay.

6.4. Lessons learned, limitations to consider and recommendations for future implementation

The inclusion of PS in surveillance systems for livestock diseases is known to strengthen the performance of the system (Mariner and Paskin, 2000; OIE, 2014). Using our program as an example, we offer here preliminary considerations regarding the performance of PS applied to wildlife. We discuss how the different surveillance components and their combination contributed to strengthening the following surveillance quality attributes: sensitivity, timeliness, specificity, accuracy, flexibility, usefulness, and ownership. Our preliminary evaluation is based on the qualitative assessment of the above attributes, following the guidelines proposed by the OIE (2014). Finally, we discuss specific limitations of our project and provide recommendations for future implementation of wildlife participatory surveillance both in our context and elsewhere.

6.4.1. Preliminary considerations on surveillance performance

Gathering knowledge from key informants can increase the overall sensitivity of the surveillance and the timeliness of events' detection also for wildlife. More importantly, for wildlife, these qualities apply not only for identifying hazards (i.e., diseases, mortalities) but also population data such as demographics. Demography data are particularly important for free-ranging wildlife because they are direct indicators of population health (Wobeser, 2007; Stephen, 2014; OIE 2014). In our program, PE made the structure and trend of the muskox population readily available and moving forward it can continue to assist acquisition of real-time population data that is of immediate relevance for management. This is especially important for harvested wildlife because demography data from PE can allow for timely adaptation of harvest rates in response to population changes, avoiding the risk of unsustainable harvests. For example, the 15 year gap between consecutive surveys meant that the harvest rate set when the muskox population was at its peak was still applied when the population was declining (see Leclerc, 2015) and this likely exacerbated the magnitude of the muskox decline for the Cambridge Bay area.

Regarding hazards, increased sensitivity and timeliness apply to those events that are recognizable and are likely to be detected, many of which are context dependent. This is why understanding the local context, including how human interact with wildlife, is an integrative part of the PE data gathering and interpretation process. For example in our setting, PE data greatly underestimated lesions localized in the lungs of muskoxen because hunters in Cambridge Bay do not consume and only minimally inspect lungs of muskoxen; this information was documented through interviews that explored the local context (Tomaselli et al., 2018a). The ability of the interviewer(s) to identify different disease presentations also directly influences the sensitivity and timeliness of the system (OIE, 2014). In our program, the interviewer who gathered PE data had a core knowledge in animal health and was able to explore and interpret the ethnoveterinary knowledge of participants in greater depth, improving the performance of the system (Tomaselli et al., 2018b).

As a whole, the participatory surveillance system proved to be flexible and able to rapidly adapt to changing needs. Particularly, both the interviews and the hunter-based sampling proved to be highly flexible surveillance components. For example, during the interview process, concerns regarding caribou arose as a collateral finding. Thanks to the flexibility and adaptability of the PE component of the surveillance, we were able to gather additional critical information on caribou, which was not planned initially. In a long-term surveillance, interviewing key informants can enable to understand processes in a holistic and adaptive way by simply exploring new themes and including new key informants, addressing new questions and priorities that arise from both the local and scientific knowledge. In our program, also the hunter-based sampling proved to be a flexible tool. For example, access to new samples (i.e., jaw, liver, kidney, muscle) from the harvested muskoxen was possible through ad-hoc modifications of the sampling program, with this further enabling targeted scientific studies.

Altogether the scientific knowledge components of the surveillance (i.e., hunter-based sampling, field investigations, targeted studies) ensured increased specificity of the system to an extent that PE data alone could not have achieved. Although diagnostic tests are the primary means of enhancing the specificity of the surveillance in PS applied to livestock diseases, (Mariner and Paskin, 2000; Jost et al., 2007; Catley et al., 2012), narrowing of PE case definitions is also an important means of increasing specificity (Jost et al., 2018). For free-ranging wildlife, however, we cannot narrow PE case definitions and enhance the specificity of the surveillance to the same extent as is possible for livestock, because of the limited ability to closely observe individual animals and follow development of symptoms. Due to this limitation, diagnostic testing may be even more critical for PS systems when applied to wildlife to enhance their overall specificity. In our program, biological samples were made available for testing thanks to the hunter-based sampling and field disease investigations that were promptly implemented following reports of disease/mortality. For wildlife surveillance, rapid implementation of field investigations is extremely important because carcasses can be easily scavenged and opportunities to find relevant pathogens easily missed (Wobeser, 2007). Prompt field disease investigations can, therefore, contribute to increasing the specificity of the surveillance for wildlife.

However, it is important to remember that diagnostic tests and sampling design come with limitations and especially for wildlife these aspects are often exacerbated (Wobeser, 2007; OIE, 2014; Tomaselli et al., 2018c). These limitations may be difficult to be fully evaluated for wildlife, with the risk of producing surveillance outputs that are neither accurate nor representative. One major strength of PS applied to wildlife lies in the ability to interpret results by triangulating the output of surveillance components that access different knowledge systems (i.e., local and scientific knowledge). In participatory research, triangulation refers to the process of cross-checking data using independent sources and methods (Mariner and Paskins, 2000; Catley et al., 2012). This is a simple yet powerful method to increase data quality and accuracy (OIE, 2014). In our program all components of the surveillance contributed synergistically to increase the accuracy of the system. For example, triangulation among data sources and methods allowed one to better understand occurrence and trends of *Brucella* in muskoxen of the Cambridge Bay area. This would not have been possible if we had to rely on only one of the surveillance components implemented (see Tomaselli et al., 2018c).

A typical feature of PS is that resource users are empowered in the system, which in turn fosters a sense of ownership in the process that can reflect positively on sustainability (Mariner and Paskin, 2000; OIE, 2014). However, empowerment of local users is directly linked to their level of participation in the system (Catley et al., 2012; OIE, 2014). In our project, resource users actively participated in different surveillance components (i.e., interviews and hunter-based sampling) and informed others (i.e., targeted studies and field investigations). In this program, participation was not intended as a 'passive' process but was rather an 'interactive' process (Pretty et al., 1995). That is scientists and resource users engaged in joint data gathering and interpretation and learned from each other. This process led to 'self-mobilization' which is the next and highest possible level of participation (Pretty et al., 1995). By the end of our pilot program, local stakeholders proposed and started initiatives independently, therefore participation here was an active and transformative process that fostered positive change. When developing PS programs, we encourage professionals to consider early on this aspect aiming at achieving active levels of participation (see Pretty et al., 1995).

The usefulness of a surveillance program is typically difficult to assess since different stakeholders are likely to have different perceptions about the utility of the surveillance output depending on their specific priorities and needs (OIE, 2014). In the Arctic, however, the effective use of indigenous peoples' knowledge is greatly valued and for wildlife management is made mandatory by land claims agreements (e.g., Nunavut Wildlife Act, 2003). Our participatory surveillance has been considered useful by several stakeholders both at the federal, territorial and local levels given that the participatory process promoted the effective inclusion of local perspectives to generate the surveillance output, while promoting trust and dialogue among stakeholders. The data generated by our program have been formally included in wildlife co-management plans and status assessment process (e.g., ECCC, 2018), and have been used for improving public health interventions. In our program, local resource users identified local concerns and priorities, and informed strategies that are locally relevant for improving food security, sustainability of the economy, and inter-generational knowledge exchange (see Tomaselli et al., 2018a). This knowledge is now available and can be utilized to influence positive change within the community.

6.4.2. Limitations to consider

This project has been carried out as part of a doctoral research project and has not been formalized within a surveillance plan. Although the developed activities have the potential to be continued long-term, the overall project, and the associated benefits, can easily cease if the surveillance program is not institutionalized within the local governance system. This project required time to build successful collaborations on the ground, willingness of people to participate and share their knowledge, and a project leader with specific training in wildlife health and diseases, wildlife field disease investigation, and qualitative research methods. Although these are not limitations per se, it is critical to consider the time commitment required to maintain existing and develop new local collaborations; and personnel with specific expertise will be necessary for continuing such a project, including experts in wildlife health and disease and qualitative research methods, as well as local program coordinators.

This project has been undertaken over a relatively short-time period and the interview process for documenting local knowledge occurred only twice. To make the system continuously relevant and effective, interviews should be performed regularly so that real-time PE data could allow for the implementation of effective adaptive management. Finally, the hunter-based sampling that was implemented was limited to the outfitted guided hunts, meaning that only adult male muskoxen have been sampled. In the future, this activity could be extended to other types of hunts, such as subsistence hunts and community harvests, allowing one to obtain samples representative of other segments of the study population (i.e., sub-adult muskoxen and females). Although this program contributed important information that improved our understanding of muskox health in the area, the implementation of other analytical tools that were not specifically used in this project (e.g., modelling using local knowledge and scientific knowledge; see Grant et al., 2016; Bélisle et al., 2018) will contribute to further enhancing the surveillance output.

6.4.3. Recommendations for future implementation in the Arctic and beyond

In Cambridge Bay, local and territorial stakeholders have expressed interest in continuing the program and allocating resources for its long-term implementation. Stakeholders should build on this pilot program within a formal and comprehensive surveillance plan that outlines surveillance purposes, objective(s), activities, and resources, as well as stakeholders' expectations and roles, plans for local capacity building and training, communication and evaluation, and expected use of surveillance output (see OIE, 2014; RISKSUR project website, www.fp7-risksur.eu). Formalizing a surveillance plan is essential not only to comply with best surveillance practices but also to avoid uncoordinated efforts that can generate fragmented information, ultimately failing to inform decision-making. Surveillance activities should be adapted to changing context and needs, wildlife population(s) under surveillance, and resources available. In Cambridge Bay a similar approach has been implemented for both muskoxen and caribou in neighbouring communities to increase the geographic scope of the surveillance. Implementing PS across a network of communities is particularly important for wildlife with a large home range because triangulation of the surveillance output among communities can further improve data accuracy and representativeness. However, to be effective, such efforts need to be coordinated. Further multi-stakeholder discussions across communities and jurisdictions will help coordinate PS across community networks within a formal surveillance strategy.

We propose a pragmatic working framework that can help in the development of PS for wildlife health and goes beyond out setting and study species (Fig. 6.2). We recommend to always prioritize the gathering of local knowledge. This phase is implemented through semi-structured interviews with key informants and aims at understanding the local context and gathering missing epidemiological information in the form of PE data on the wildlife population(s) under study (Fig. 6.2). Data on the local context influence the PE data gathering and interpretation process. It is also functional to understanding feasibility and biases associated with sampling and can directly inform or help shape intervention strategies (Fig. 6.2). The surveillance team tasked with collecting local knowledge-based data should be knowledgeable about the ethical principles that apply when gathering knowledge from people, qualitative and PE methods and techniques (see Participatory Epidemiology Network for Animal and Public Health PENAPH website, www.penaph.net), and wildlife health and diseases. It is essential to collaborate with local organizations for the development of this phase including the identification of key informants. To gather reliable data, define sample size until thematic saturation is reached, apply triangulation (e.g., individual and group interviews), analyze information through thematic analysis, and validate interpreted data with participants (Tomaselli et al., 2018a, 2018b).

If a hunter-based sampling program can be implemented, it is then necessary to evaluate which samples and information are needed to meet surveillance objectives. If limited resources are available for laboratory analyses, co-design and implement with hunters a sampling program that allows for establishing sample archives and gathering information on and samples from abnormal lesions from harvested animals (Fig.6.2). Generally, blood samples can be easily collected and archived even in challenging settings (e.g., filter papers used for collection and storage; see Curry et al., 2014a), if additional sample collection and archival is feasible, refer to the PE data to identify which additional tissues are valuable. When resources are made available, archived samples can be accessed for implementing targeted scientific studies. The hunter-based program should be viewed as a flexible surveillance tool that can be modified over time to fulfill surveillance objectives. Any modifications should be discussed with hunters to enable continued co-design of the program and open communication among stakeholders, which ultimately influence the sustainability of the sampling program.

Interviews with key informants and hunter-based sampling are likely to increase the reporting of the events consistent with overt disease or mortality, as well as the submission of abnormal tissues that require immediate analyses (Fig.6.2). Being prepared to quickly implement field investigations and laboratory analyses is essential to increase the specificity of the surveillance system (see Tomaselli et al., 2016). Linking local surveillance to existing broader (territorial or national) wildlife surveillance systems can be beneficial to achieve this goal. For example, in Canada all Provinces and Territories can easily access veterinary diagnostic expertise on wildlife diseases through the Canadian Wildlife Health Cooperative (see CWHC website, www.cwhc-rcsf.ca).

In the proposed system, knowledge derived from interviews, field disease investigations and hunter-base sampling is functional to identify and prioritize targeted scientific studies (see Tomaselli et al., 2018c). The feedback among surveillance components can contribute to using resources available effectively. Both the local knowledge and the scientific knowledge are likely to generate further questions and priorities which can be explored using the same approach that combines the knowledge of key informants (i.e., exploring new themes) with targeted sampling and analyses (Fig.6.2). The surveillance system, therefore, keeps evolving and has the potential to quickly adapt to local needs.

Finally, for non-harvested wildlife, the system can still be implemented even though the hunter-based sampling is not likely feasible. For instance, for the purpose of a study on shorebirds which are seasonally migratory birds and not harvested in our context, people who spend lots of the spring and summer time on the land are likely to observe shorebirds and can serve as key informants for the surveillance (e.g., geese harvesters, people involved in egg or berry picking or even fishing). Although it is unlikely that one could compile detailed PE on shorebird diseases (i.e., lesions localized in internal organs), one could still gather critical data on population status and trends, productivity, overt mortality/disease, and holistic understanding of factors associated with shorebird population health. Active sampling and laboratory analyses can be implemented following reports of overt mortality/disease. Therefore, although the hunter-based sampling might not be feasible for non-harvested wildlife, a PS system will provide a data-rich output that enables evidence-based interventions.

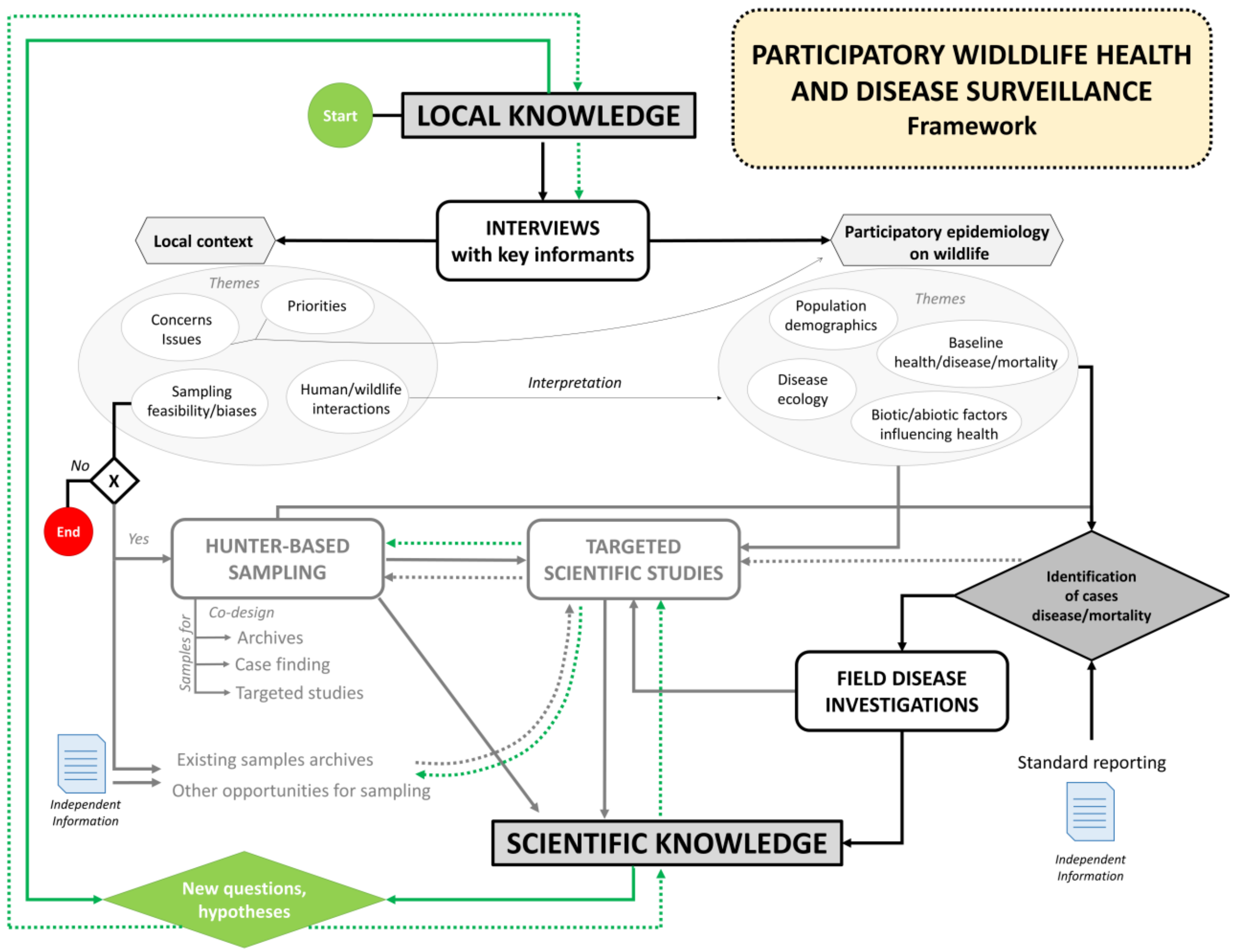

Figure 6.2. Process map describing the general participatory framework for data gathering and interpretation on wildlife health. The main surveillance component activities, which refer to either the local knowledge system or the scientific knowledge system, are indicated inside rounded rectangles; black solid lines represent the main connections among activities (thinner lines are used for visualizing connections or explain features within a single component); black dotted lines refer to the secondary connections or feedback connections within the process; green solid lines represent the flow lines generated by the surveillance output leading to a new starting point (green diamond) for the data gathering/interpretation process; finally, green dotted feedback lines represent the following iterations of the data gathering/interpretation process. Gray rounded rectangles and gray flow lines indicate the portion of the surveillance that is subjected to the availability of biological samples and, therefore, may not be implementable (e.g., non-harvested wildlife); conversely, the components that are likely to be always implementable, given allocation of resources, are indicated in black.

6.5. Conclusion

Participatory surveillance can be successfully implemented for assessing health and disease status of free-ranging muskoxen in the Arctic. The combination of local knowledge and scientific knowledge within a participatory framework can enhance the output and performance of wildlife surveillance. Based on the lessons learned throughout our program, we illustrated a framework for data gathering and interpretation that can be implemented for both harvested and non-harvested wildlife in settings where users of renewable resources are present and local informants on wildlife health can be identified. This approach is therefore well suited but not limited to remote rural communities that largely depend on harvesting of wildlife for subsistence.

Participation of resource users is key to the surveillance. It should not be viewed as merely functional to gathering PE data on wildlife populations but should be structured within the program with the intent to promote a bottom-up process that can foster positive change. Local users, therefore, participate in the surveillance by co-designing the system and co-interpreting its output together with other stakeholders, including scientists. The derived outcome is a surveillance program customized to local needs that can help one understand local issues under a holistic lens and foster dialogue among stakeholders for developing effective interventions.

In the Guide to Terrestrial Animal Health, the OIE presents PS as a tool for increasing veterinary surveillance capacity for livestock diseases, especially in developing countries (OIE, 2014). Participatory surveillance can also be successfully applied to free-ranging wildlife. This approach can contribute significantly to enhancing wildlife surveillance capacity in many settings as advocated by the OIE. Finally, for marginalized settings where both wildlife populations and indigenous communities are increasingly challenged by rapid changes (such as in the Arctic), wildlife participatory surveillance can be an effective tool for improving the resilience of social-ecological systems.

Chapter 7. Conclusions: summary and future directions

Common impediments to gathering and interpreting field data on wildlife health significantly limit the ability to carry out effective wildlife surveillance (Wobeser, 2007; Stallknecht, 2007; Artois et al., 2009; Ryser-Degiorgis, 2013). By combining and adapting methods from other fields of study, this research has presented a novel participatory approach that overcome challenges associated with gathering and interpreting field data on wildlife health, contributing to the development of participatory wildlife health surveillance.

The work for this study was undertaken in – and with the active participation of – the community of Cambridge Bay in the Canadian Arctic to understand health and disease outcomes of muskoxen, and demonstrated that local knowledge (LK) applied to wildlife health assessment can enhance the ability to undertake veterinary surveillance of wildlife populations even in remote and logistically challenging settings. It also made clear that LK combined with scientific knowledge (SK) can improve the quality of surveillance outputs. In particular, this study has provided evidence that: local resource users can contribute critical holistic knowledge of wildlife health, complementing data derived by conventional scientific investigations; the combination of both knowledge systems, LK and SK, can compensate for their respective individual uncertainties; and, participation of local users in wildlife surveillance can facilitate the inclusion of local perspectives in decision-making.

The approach presented herein, including the participatory framework developed for the collection and interpretation of wildlife health data (see Chapter 6), is clearly also relevant for and applicable to wildlife health monitoring and research. The application of this approach has been strongly emphasized here for wildlife health surveillance for two reasons. First, the knowledge of local stakeholders can inform the development of a variety of interventions, customized to the local setting and needs; without a surveillance system in place this knowledge is unlikely to effectively influence decision-making. Second, the responsibility, and consequently the accountability, for wildlife health is typically fragmented across multiple agencies and organizations (Kuiken et al., 2005; Stitt et al., 2007; Grogan et al., 2014). Without a formal surveillance plan, there is a risk that the information that is generated is not used to its full potential and opportunities for improving the management/conservation of wildlife and the protection of public health could be missed.

The preceding chapters have explored in depth the contribution of LK, SK, and the combination of both for health assessment of muskoxen in the Cambridge Bay area, and discussed the broader applicability of this approach for improving veterinary surveillance of wildlife populations. Limitations and biases to address for the interpretation of both LK and SK on wildlife health have also been presented. This concluding chapter highlights the key contributions of this research and discusses potential future directions for both the specific setting in which the research was undertaken and the broader field of study.

7.1. Cambridge Bay and the muskoxen, moving forward

This study provided critical missing information to elucidate the status and changes in the health of muskoxen in the Cambridge Bay area and contributed to improving current knowledge on pathogen diversity, including zoonoses. This research elucidated possible drivers for the decline of muskoxen on Victoria Island, providing critical information to build on for future studies and offering important points for consideration.

This study confirms that in the North, understanding the health of harvested wildlife matters greatly, and the ability to do so proactively rather than reactively can lead to better outcomes for both people and wildlife. Moreover, it demonstrates that, in the Arctic, the implementation of participatory wildlife health surveillance is achievable, can be cost-effective compared to conventional methods by capitalizing on available LK, and can improve the existing systems of wildlife co-management by promoting greater direct participation of resource users.

Local knowledge has proved to be a valuable tool for documenting the demography of both muskoxen and caribou (specifically the Dolphin and Union caribou herd). Moving forward, the continued documentation of demography data gathered from LK will allow for adaptive management of harvest rates and more timely response to population changes than can be realized by awaiting the completion of traditional scientific surveys. In the future, collection of detailed LK on calf production and survival, and reproductive behavior can further explain mechanisms of the decreased recruitment documented in this study for both muskoxen and the DU caribou (see Chapter 3).

As noted in Chapter 6, in Cambridge Bay, interviews of key informants have been undertaken only twice; it is therefore recommended that LK should be further documented, building on existing information and further probing aspects that can influence the fitness of muskoxen (e.g., biotic and abiotic factors influencing health). In doing so, it will be important to prioritize those themes that will allow for SK derived from targeted studies to be complemented. Additionally, improving the understanding of the role of large predators (i.e., wolves, grizzly bears) in the decline of both muskoxen and the DU caribou will be a relevant consideration. Management of predators (i.e., predator control) is already in place and documenting robust LK to fill knowledge gaps on predators will help to further inform evidence-based management. Other participatory tools can be utilized to clarify temporality of events and hypothesize possible causal webs (e.g., temporal lines, Venn diagrams, matrix scoring). Moreover, tools derived from other disciplines, for example ecological modeling, may provide opportunities to further combine LK with SK, improving the surveillance output (see Grant et al., 2016; Bélisle et al., 2018).

Finally, interventions for both wildlife management and public health can be informed by the results of this study. For example, this work highlighted that muskoxen are important not only for food security and the local economy, but also for the continuity of Inuit culture and traditions by promoting the connections amongst generations, particularly those between youth and Elders (see Chapter 2). These aspects may be overlooked by current management. In fact, although the overall harvest rate has been recently lowered on Victoria Island to promote the recovery of the muskox population, the three management zones of the Nunavut portion of the island have been unified under a single zone (Leclerc, 2015). Therefore, if the harvest pressure will be concentrated around the community instead of being uniformly distributed within the management zone, the current strategy may prevent the increase of muskoxen around Cambridge Bay and, consequently, the social and cultural benefits derived through the connection between people and muskoxen.

Other aspects that are of immediate relevance for management relate to the documentation of local concerns of harvesters interviewed. As noted in Chapter 2, concerns about improper harvesting practices (e.g., harvesting the wrong animals, discarding certain parts of harvested animals) have been documented through this study. It is recommended that these community-level concerns be further explored and for collaborative management strategies to be developed that align with Inuit culture, practices, and beliefs. This work is particularly relevant at present, given that a co-management plan for muskoxen is currently under development in the Kitikmeot region of Nunavut. Finally, given this study has documented the presence of zoonotic pathogens in muskoxen (i.e., orf virus, *Brucella suis* biovar 4), widespread mortality outbreaks possibly associated with zoonoses (i.e., *Erysipelothrix rhusiopathiae*), and butchering practices that can increase the risk of human exposure to zoonoses (i.e., collection of the fetus from the womb of harvested pregnant cow), appropriate public health messaging should be implemented to mitigate the risks of pathogen exposure for humans without discouraging the consumption of nutritious and traditionally appropriate country foods.

It is clear that the information generated by this study has the potential for additional future applications. To ensure the information is used to its full potential, it is recommended that a surveillance plan be prioritized in the near future, utilizing the knowledge generated and the partnerships developed through this program. As highlighted in Chapter 6, further multi-stakeholder discussions will be necessary to achieve this goal, including the development of PS for muskox health (and other prioritized species; e.g., DU caribou) across a network of communities.

7.2. Participatory wildlife health surveillance, a promising field of study

This doctoral research contributes to developing the field of participatory wildlife health surveillance, allowing the systematic application of LK for understanding and monitoring the health of wildlife populations. This approach has the potential of significantly improving the capacity for undertaking wildlife surveillance especially in those settings where it is also urgently needed (e.g., remote communities based on subsistence harvest of wildlife). The health of wildlife populations intersects with the health of humans, domestic animals and the environment (Aguirre et al., 2002). Participatory wildlife health surveillance can be an effective tool to explore health within interrelated interfaces, enabling the application of One Health and Eco Health principles, which are advocated for within the veterinary and wildlife professions yet difficult to be effectively applied (Rostal et al., 2012; Gibbs, 2014).

Similarly to other fields of study in which participatory research is applied (see Reed, 2008; Catley et al., 2012), in participatory wildlife health surveillance it will be important to focus on the process of participation rather than the mere application of participatory tools. In PE and PS programs applied to livestock, it has been emphasized that critical consideration on the level of participation achieved is often overlooked (Catley et al., 2012). However, this aspect is crucial because the level of participation has a direct influence on the outcomes of programs, and also opens dilemmas about the use, and misuse, of this term (Catley et al., 2012). Discussion centered on the meaning of "participation" in PS programs becomes important and should not be overlooked in participatory wildlife surveillance.

Continuing to learn from other participatory traditions, including advances realized in PE and PS applied to livestock diseases in developing countries, will be crucial for the future development of this field and for enhancing the transdisciplinary application of knowledge systems. Participatory wildlife health surveillance provides a renewed opportunity for the veterinary profession to strengthen its role in wildlife health, leading collaborations across multiple disciplines and stakeholders. Recognizing that participatory epidemiology and surveillance are rarely integrated into veterinary education at present, it will be important to equip future generations of veterinarians with these skills to enable them to more effectively service wildlife health moving forward.

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APPENDIX A

Interview guide used during the individual interviews with study participants from the community of Iqaluktutiaq (Nunavut, Canada) – part 1

INDIVIDUAL INTERVIEW Interview #:______

Date: ___________

Hello! Thank you for agreeing to be interviewed. As you already know the purpose of this study is to collect traditional and local knowledge about muskoxen in order to inform a program for monitoring muskox health. Here I have an outline of questions I would like to ask you. And I will take some notes during our conversation. Feel free to add any comments whenever you wish. Can we start?

First of all I would like to record some **general information**

Interviewee	Inuit	non-Inuit	
	Elder	non-Elder	
	Hunter	Outfitter	Other(s): _________
Active hunter	Yes	No	
Gender	Male	Female	
Age	_________	years old	

1) Are you part of the HTO? Yes No
2) Where were you born?
3) How many years have you lived in this community? __________ years
4) Do you hunt/handle muskoxen? Yes No

Probes, if hunt:

i) When did you start to hunt muskoxen?

ii) What kind of hunts do you participate in?

Subsistence community sport commercial

iii) How many animals per year? When do you hunt?

Subsistence	# _________	when _________
Community	# _________	when _________
Sport	# _________	when _________
Commercial	# _________	when _________

iv) What kind of muskox do you hunt?

Subsistence	type of animal:	adult	young	calf	male	female
Community	type of animal:	adult	young	calf	male	female
Sport	type of animal:	adult	young	calf	male	female
Commercial	type of animal:	adult	young	calf	male	female

Probes, if handle …:

i) When did you start to handle muskoxen?

ii) Who hunts the muskoxen that you handle? Which type of hunts do these muskoxen come from?

Subsistence community sport commercial

iii) How many muskoxen do you handle per year? And when?

Subsistence	# _________	when _________
Community	# _________	when _________
Sport	# _________	when _________
Commercial	# _________	when _________

iv) What kind of muskoxen do you handle?

Subsistence	type of animal: adult	young	calf	male	female
Community	type of animal: adult	young	calf	male	female
Sport	type of animal: adult	young	calf	male	female
Commercial	type of animal: adult	young	calf	male	female

5) What do you do after you hunt a muskox? How do you process the carcass in the field and what do you leave out in the land?

Now, I would like to talk to you about what **muskoxen mean for your community**

1. Are muskoxen important for you and your community? Yes No

Probes: Why are important? Why not?

2. Were muskoxen important in the same way in the past? Yes No

Probe: If no, why not?

Now, I would like to talk to you about your **food habits**

1. Do you eat country food/ food from the land? Yes No

Proportional piling (present vs. past-childhood)

2. Which types?

Proportional piling (present and ask if changed from the past and how, why)

3. How do you store muskox meat?
4. What part of muskox do you eat? How? Cooked Frozen Dried Other(s):_______

Now, I would like to talk to you about your **concerns about muskoxen**

1. Do you have any concerns related to muskoxen? Yes No

Probe: If yes, what are they?

2. Do you have any concerns about butchering, handling or eating muskox meat? Yes No

Probe: If yes, what are they?

(The interview guide continues with other questions to capture participants' observations on muskox health and ecology. The additional questions are provided in Appendix M and the data gathered are summarized in Chapter 3.)

APPENDIX B

Selected quotes from study participants from the community of Iqaluktutiaq (Victoria Island, Nunavut, Canada) offering conjoint perspectives on the importance of muskoxen and the impact of their decline

Interviewee	Theme	Quote
Interviewee 03 Inuk Elder Non-active hunter Female, 64 years old	*Sociocultural value (aesthetic value and psychophysical well-being)*	*"I miss their presence out there, because I love watching them. You know, spring comes and we used to watch the muskox head butting because they are going after the same female…I used to see them so close to Cambridge Bay, but* [now] *they are gone further away…I hope to see them before winter comes again…when you don't see muskox it is kind of lonely. It is lonely when you don't see part of your animals that roam close by your community"*
Interviewee 05 Inuk Elder Non-active hunter Female, 84 years old	*Nutritional value (food security)*	*"Muskox have always been our meat, an important source of food that we used to share with families. Muskox were always there also when other foods were scarce; but now muskox are scarce!"*
Interviewee 11 Inuk hunter Male, 51 years old	*Economic value (community employment and revenue)*	*"I think for the community muskox is important because it employed hunters, haulers, and abattoir workers when they had the muskox harvest…and I say had because they haven't had the muskox harvest for about two years, three years now I think. Kitikmeot Foods used to have an annual muskox harvest so they could process hamburger, stew meat, jerky, whatever they could process at the meat plant here. But in the last couple of years it's been harder to find muskox close to the community"*

Interviewee 12 Non-Inuk hunter Male, 59 years old	*Sociocultural value (aesthetic value)*	*"…live muskox themselves* [are a value]*! Before…you could see muskox just across the bay here….to the tower and where the old stone church is* [you could see muskoxen] *regularly, and if you took a quad from Cambridge Bay up to Mount Pelly you could see lots of muskox or, if you took a quad from Cambridge Bay out to Gravel Pitt, you would often see muskox. That* [having muskoxen] *was a bit of a draw because people would come here just to see muskox and you could just quad or ride a bike and see some…* [Now] *we don't have the presence of muskox close to town the way we were used to…but* [in the past, when there were lots of muskoxen around] *it was quite nice, people used to love to come here to see muskox… I have camped with people at Grainer Lake and it was just nice to camp with a few local families and the kids and we would take a walk to see some muskox just on a side of a pond. So we enjoyed them, but it was definitely people visiting Cambridge Bay who would say ‹‹Oh, can we get a ride out to Mount Pelly to see some muskox?›› So it was both local people enjoying seeing muskox and of course people from out of town who had never seen one and were thrilled if they'd see one…* [But now] *we don't have the presence of muskox close to town the way we were used to…Personally I will never get tired of seeing muskox. They look so nice and they have such a nice temperament…I found they are very, very nice animals!"*
Interviewee 14 Inuk hunter Male, 42 years old	*Sociocultural value (aesthetic value)*	*"… This week it was the first time I have seen muskoxen* [nearby my cabin] *and we were used to see them pretty consistently* [before]. *It was great to see something out on the land. It was great!"*

Interviewee 15 Inuk hunter Male, 37 years old	*Nutritional value* *(food security)*	*"I really cut down the number of muskox I hunt per year now, because we have to go really far away to hunt muskox and I just lost the interest in hunting them: hauling them back for 45-50 miles can be pretty tough…I just have a quad I don't have a skidoo!"*
Interviewee 15 Inuk hunter Male, 37 years old	*Sociocultural value* *(intergenerational connection)*	*"I have learned from Elders that muskox are important and I am the next* [generation] *after the Elders…It is important that younger generations try to keep the tradition, but muskox herds are dwindling"*
Interviewee 17 Non-Inuk hunter Male, 49 years old	*Transition from importance to concern*	*"There is no question that people have been noticing a decline in the population* [of muskoxen]. *We used to have muskoxen and there were times when you cloud see them walking on the airport roads…that's how many they were in this area. I think that they were important to people before the decline in the population…now I think people are more concerned about where they are gone and what happen to them"*
Interviewee 21 non-Inuk summer resident (pilot) Male, 61 years old	*Economic value* *(community revenue and business opportunities)*	*"Muskox represent 40 to 50% of my revenue…it is important for the economy and business…last year there was a fairly bit change from the previous years and this year was a massive change* [description of muskox decline] *… you know next year I am thinking to cancel the muskox hunts or reduce them a lot because I don't feel comfortable having clients coming from far away and not having muskox around"*
Interviewee 23 Inuk hunter Male, 48 years old	*Sociocultural value* *(aesthetic value)*	*"It is nice to see them* [muskoxen] *out there. The land looks kind of empty without muskoxen"*
Interviewee 25 Inuk hunter Male, 56 years old	*Nutritional value* *(food security)*	*"It* [the muskox] *is very important to us, because: what other meat sources do we have besides caribou? ...Maybe they* [muskoxen] *were the only source of meat before caribou*

		really started coming around to the island. It was quite long ago, probably in the 60s…I don't know how the [muskox] *population is now, because you rarely see them, you would be lucky to see them now…It is getting harder to get country food. You know, we are starting now to lose our animals and we will probably won't have more muskox pretty soon, that's what I think…And also our caribou* [have] *disappeared…One year we didn't really see muskox around, we were travelling around everywhere and we didn't see any muskox…I think it was three years ago, and other people were talking about it too…so we didn't hunt muskox that one year"*
Interviewee 26 Inuk Elder Male, 60 years old	*Sociocultural value (Inuit culture and tradition)*	*"In the past they* [muskoxen] *were part of the tradition…but now the young generation is losing the tradition…they don't know how to hunt and consume them properly…both muskox and caribou….and it hurts* [me] *to see that"*
Interviewee 26 Inuk Elder Male, 60 years old	*Nutritional value (food safety) and health concern*	*"There is a lot of Elders that still want muskox meat and they want it on a yearly basis and they are the ones that consume most of the muskox meat….But I am noticing now that there is a lot of muskox that are diseased… you know I am starting to open up the carcass, take the organs out, and check the lungs, the liver and the meat. I noticed something unusual, you know some of them have big joints,* [I see that] *in muskox and a lot in caribou"*
Interviewee 27 Inuk hunter Male, 31 years old	*Economic value (community revenue and business opportunity, community identity)*	*"When we do the sport hunts, that is a big income for the community and also the commercial harvest with the meat plant brings in some good money to the community, plus it also highlights our community when we produce some of the different kind of meat* [and export the meat] *to the world market, and you see* [that the meat is] *coming from here. It brings interest into our community...but* [now] *muskox are declining!"*

APPENDIX C

Average consumption of country foods and store-bought foods in the annual diet of study participants from the community of Iqaluktutiaq (Victoria Island, Nunavut, Canada)

Here we present the results that describe past and current annual relative consumption of country foods vs. store-bought foods reported by participants though proportional piling exercises.

The reader should note that interviewees were purposefully selected and the majority were active hunters. Therefore, the data presented here cannot be generalized because of the risk of overestimating the current consumption of country foods at the community level. We believe that these data should be interpreted with caution due to the biased sample, the small sample size, and the technique used (proportional piling) that provide a quantitative estimation based on personal perception. Nonetheless, we think that the data captured here are worth reporting and can help to further understand the characteristics of Inuit and non-Inuit participants we worked with.

Inuit

There were notable differences in the annual relative consumption of country foods and store-bought foods by Elders (n = 9) and adult Inuit (n = 14), so here we report data separately for each age group. All nine Elders interviewed reported that during their childhood country food accounted for 97% their annual diet (interquartile range, IQR: 95-100), and the remaining 3% (IQR: 0-5) consisted of store-bought foods. For current annual food consumption, in contrast, three Elders reported that their diet was equally divided between country foods and store-bought foods, while the other six Elders, whether they were active hunters or not, continued to rely largely on country foods for 93% (IQR: 90-95) of their annual diet. These contrasting current diets are likely associated with a variety of factors, including ability to hunt, hunting habits of the extended family network (especially for Elders who are not active hunters anymore), personal preferences, the availability or accessibility of country foods and store-bought foods, and sharing networks among family and friends.

A full exploration of factors that produced these dietary differences over time fell outside the scope of the current study, but here we provide perspectives offered by two Elders who, although both are still active hunters, consume different quantities of country foods in their annual diet. One Elder (Interviewee 9) who still relied almost exclusively on country foods explained, *"I like to eat more country food than store-bought food. I eat almost all the time country food; I don't buy food from the Northern or Coop* [local stores]. *I buy only sugar, tea, coffee, and butter, and jam, and the naphtha, the gas, and kerosene for the heater. I don't buy food, I like country food all the time:* [country foods are] *cheaper!"* Conversely, another Elder (Interviewee 16), who, at the time of the interview relied on store-bought foods for half of his annual food intake, explained that *"when I was a child I was eating mostly country food, 90%* [of my annual food intake] *...When I was a child there was not much available at the store*. *I started eating less* [country foods] *when the stores started getting bigger and there were other types of food available at the store, probably in the 60s."*

The country food consumption of the adult Inuit interviewees had declined from 73% (IQR: 60-90) in their childhood to a current consumption of 35% (IQR: 25-50). Reasons given for the decline in country food consumption include living permanently in the community, being employed in stable jobs, changes in households, lifestyle, food habits and time availability, and changes in the local availability and distribution of wildlife. This last theme emerged from the narratives of an Inuk subsistence harvester (Interviewee 25). He explained, *"it is getting harder to get country food. You know, we are starting now to lose our animals and we probably won't have more muskox pretty soon, that's what I think…and also our caribou* [have] *disappeared".* Other quotes that offer perspectives regarding the decline over time in country food consumption are reported in Table S3 (provided below).

Non-Inuit

We note here that the "southerners" interviewed had adapted to the northern lifestyle and to the consumption of country foods: *"I do personally eat country food and I* [have] *a lot of interest in eating country food…The lifestyle is different here from the South. When you came up North you adapt yourself* *to the way of living and the way you eat …so the wild game becomes part of your interest and your habit."* (Interviewee 1).

Depending on several factors, including reasons for the change of residence, the amount of country foods consumed varied quite noticeably among interviewees. For example, Interviewee 12, who moved to Nunavut *"to learn the traditional and contemporary Inuit hunting and fishing, and traveling skills out in the land"*, reported that 70% of his annual food consumption was country foods, whereas the other non-Inuit residents interviewed reported that country foods accounted only for 20% (IQR: 19-21) of their annual consumption.

Table S3. Selected quotes from study participants offering perspectives on the motivations for country food consumption.

Interviewee	**Quote**
Interviewee 08 Inuk hunter Male, 35 years old	*"When I was growing up we were eating a lot of country food. I remember every meal we had fish or caribou…* [the change happened] *when I moved out of my parents' place and moved in my own place"*
Interviewee 09 Inuk Elder Active hunter Male, 69 years old	*"I like to eat more country food, than store-bought food. I eat almost all the time country food, I don't buy food from the Northern or Coop* [local stores]. *I buy only sugar, tea, coffee, and butter, and jam, and the naphtha, the gas, and kerosene for the heater. I don't buy food, I like country food all the time:* [county foods are] *cheaper! I like county food, I eat them almost all the time…The important thing is that country food is the best!"*
Interviewee 10 Inuk hunter Male, 46 years old	*"In the past we mostly lived off the caribou, the fish and the small game, probably the shift* [in county food vs. store-bought food consumption] *happened when we moved to Cambridge Bay permanently"*

Interviewee 13 Inuk hunter Female, 52 years old	*"When the seal and fox fur prices dropped, my dad was forced to look for work* [in the community] *rather than be a trapper and a hunter ...When he got a job in the community we spent less time harvesting and more time in town"*
Interviewee 16 Inuk Elder Active hunter Male, 63 years old	*"When I was a child I was eating mostly country food, 90%* [of my annual food intake]*...When I was a child there was not much available at the store.* [I started eating less country food] *when the stores started getting bigger and there were other types of food available at the store, probably in the 60s"*
Interviewee 19 Inuk hunter Male, 45 years old	*"These days, now, we buy most of the food at the store, but in the past when I was growing up it would be vice versa. The transition happened when we came permanently in the community"*
Interviewee 20 Inuk hunter Male, 57 years old	*"When I was a kid I was getting way more country food. Now that I have a bit of money myself I get more store food"*

APPENDIX D

Selected quotes from study participants from the community of Iqaluktutiaq (Victoria Island, Nunavut, Canada) representing the muskox-caribou prey switch mechanism

Interviewee	Quote
Interviewee 10 Inuk hunter Male, 46 years old	*"When there is hardly any caribou around, that's when I hunt the muskox to fill the freezer"*
Interviewee 11 Inuk hunter Male, 51 years old	*"The last muskox I got for myself, for subsistence, was probably 2003….In the early 90s the caribou started migrating through the community. So I didn't really hunt too much muskoxen after that because every fall the caribou would come through, within arm's reach of the community. So* [there was] *less reliance on muskox when the caribou were close to town,* [around] *September October, during the fall migration…and then in the summer time we used to go across over to the mainland, around Ellis River and Foggy Bay, for caribou hunting. So there wasn't really a reliance on muskox because we were able to go over the mainland during the summer when there's no caribou around here* [Cambridge Bay]*… This year if I don't get any caribou between now and September I might think of getting a muskox …being people more reliant on caribou and living off the caribou, it was nice to have a change to muskox, but I prefer caribou over the muskox; and I think that is true for most people!"*
Interviewee 19 Inuk hunter Male, 45 years old	*"It* [muskox] *was our food when we had no choice but get a muskox because we had hard time finding caribou"*
Interviewee 22 Inuk hunter Male, 30 years old	*"I guess that the main thing is that if the caribou won't be around, I will get few more muskox every now and then, and* [I will do the same also] *to have a switch of meat, to have a different taste from caribou"*
Interviewee 23 Inuk hunter	*"…when I was growing up, in my childhood and my teens* [in the 70s]*, you would rarely see muskox. You would have to travel for quite a while, if you travelled out*

Male, 48 years old	*in the land for a few days you would see some, but they weren't too numerous then…During the 80s, in my early 20s, I would get one per year and then during the 90s was when they were very plentiful and I would get four or five per year, that was through my 30s; and then from 2000 to 2010, I have only got one per year because that's when there were lots of caribou near town. There were so many caribou around here that people stopped hunting muskoxen. I was still hunting them* [muskoxen] *but I would take only one per year and maybe a small one…And then, since 2010 to this year* [2014], *I started getting more again because the caribou stopped* [being] *so plentiful. Starting around 2010 it's been getting harder and harder to find caribou, so I have been going back to muskox again, getting two muskox a year since 2010 and this year* [2014] *I would probably get zero caribou and four muskoxen…The caribou are too far now"* *"…when there is lots of caribou around, muskox would take a second seat…when there were lots of caribou around, I would replace my read meat with caribou instead of muskox…all I did was to replace most of my read meat with the caribou; and now, when the caribou are gone again and they are getting harder to get, I am replacing the caribou meat with muskox meat…in the spring time, just to get the flavor of caribou again, I might go to the mainland and get one* [caribou] *there. But I would rely on muskox again, because I don't mind muskox, but some people do not like muskox and they would go where the caribou are even if it is further away…but lately we have to look more than usual* [to find muskoxen] *because there are not as many as they used to be in the past. For about the last four years or so, since 2010, they seem to be less around here. You can still get them, but you might have to go for a couple of trips before you see one"*
Interviewee 30 Non-Inuk hunter Male, 34 years old	*"I eat more caribou than muskox, I think you have found that from most people around here that they prefer caribou. If they have a choice between caribou and muskox, they always take caribou"*

APPENDIX E

Selected quotes from study participants from the community of Iqaluktutiaq (Victoria Island, Nunavut, Canada) describing harvesting and butchering activities of muskoxen, as well as, historical and contemporary meat storage and consumption habits

Interviewee	Theme	Quote
Interviewee 03 Inuk Elder Non-active hunter Female, 64 years old	*Subsistence harvest (traditional harvesting practices)*	*"I remember we had only one* [muskox] *per season. That was the Inuit costume: to respect the land and the animals … and other animals that some other Inuit people might want to catch somewhere…we cached only one to share with the family in our little village…just to respect the animal"*
Interviewee 03 Inuk Elder Non-active hunter Female, 64 years old	*Subsistence harvest (traditional meat storage)*	*"Traditionally, in the summer you had to dry almost everything and put it away for winter…In the fall, when the weather is cooling off they* [the ancestors] *liked to put the muskox meat in the ground…you form a circle in the rocks and you put the meat in the formed circle and you cover it again with more racks and rocks and rocks so that animals that roam around don't get into it…that is called aging and caching…So they go back home and save that meat for later…they come back in the spring to pick it up so they have something to eat and share with families…"*
Interviewee 03 Inuk Elder Non-active hunter Female, 64 years old	*Subsistence harvest (carcass utilization)*	*"The Elders like to have the feet, they cooked and cooked and boil and boil the meat until they can rip off the meat or the skin and they eat the inside of the tendons. That's their delicacy!"*

Interviewee 09 Inuk Elder Active hunter Male, 69 years old	*Subsistence harvest (traditional meat storage)*	*"Long time ago, old people they liked the muskox all the time…when they were born, my parents used to eat them* [muskoxen] *all the time,* [that was] *long time ago around 1900…My parents were eating lots of muskox, drying them out during spring time …* [they] *put them away, cashed them in the rocks, piled them up* [during] *fall time* [with] *rocks to cover them to protect* [the meat] *from wolverines and wolves"*
Interviewee 09 Inuk Elder Active hunter Male, 69 years old	*Subsistence harvest (traditional harvesting practices)*	*"Every time I see five animals in one herd I don't shoot it, when they are really lots, maybe 10 or 15, then I get one…when I was young my dad told me: ‹‹you can't shoot a muskox when there are only just a few* [animals] *in one* [herd]*››. You never know what might be happening …and when the young ones are coming out, March, April, May, you can't shoot them, never do that. They are important! To keep the little ones is important!"*
Interviewee 09 Inuk Elder Active hunter Male, 69 years old	*Subsistence harvest (butchering practices)*	*"You keep the hide and the meat, just throw their guts away, and keep the liver, heart, and stuff like that and everything you need….I skinned them out* [in the field], *I take the guts out, and the hides off, and the heads….I will use the hides: when they dry they are always good for rugs or foams. They are the best one because they don't get wet…I leave the lungs and the guts out there* [on the land]. *I open the guts and leave it wide open so that the foxes could eat it. I don't leave it* [the guts] *like that* [closed], *you cut it up and open it up, so that the fox could eat it, or the wolf. Clean them out is better!"*
Interviewee 12 Non-Inuk hunter Male, 59 years old	*Subsistence harvest (hunting preferences)*	*"It depends if you want lots of qiviut in the hide you catch one* [muskox] *in March when they are nice and full* [of qiviut]*; in November they won't have very much qiviut in the coat but if you don't have any muskox meat and you want it through the winter I could catch a small juvenile animal in the fall time, and if I want a lot of qiviut in the hide to use for bedding I will catch one in March. I have done both….Probably more in March than in*

		November….November they are nice and light though! So if you are going to use them for bedding, David Kaomayok who has passed away now said: ‹‹Get one in November, because they are nice and light! ››; so, you know, when you are taking them from the boat or your Kamotik [sled]*, it is not as heavy to haul around"*
Interviewee 14 Inuk hunter Male, 42 years old	*Subsistence harvest (butchering practices)*	*"I butcher the muskox on the land and by the time I get home the animal is in around a dozed pieces. Some people take them back just gutted but I don't like that…I leave on the land usually the spine, the hooves, the guts, the lungs…I don't eat any of the internal organs except the heart…the head sometimes I do* [take it]*, and sometimes I don't: sometimes I take the tongue out and I leave the head* [on the kill site]*, and sometimes I take the hole head back* [home]*…the kidneys sometimes I take them, only when they are really fat, if they are surrounded by fat I take them, if it is kind of lean, it doesn't look too good to me and I leave them….the hides sometimes I leave them on the land, but I usually take them"*
Interviewee 15 Inuk hunter Male, 37 years old	*Subsistence harvest (butchering practices, transportation)*	*"I leave on the land the guts, the intestines…sometimes* [I leave also] *the hooves* [on the land]. *You know I try to minimize the weight* [to haul back] *from the kill site to home…I bring the organs* [liver, heart, kidneys, lung] *back, dogs really love the inside of the muskox"*
Interviewee 16 Inuk Elder Active hunter Male, 63 years old	*Subsistence harvest (carcass utilization)*	*"In the past the lungs were taken home too but nowadays are left behind…in the past we used dogs so everything was taken home"*

Interviewee 19 Inuk hunter Male, 45 years old	*Sport hunts (butchering practices, carcass utilization)*	*"They* [sport hunters] *are used to take like 50 pounds of meat, but the rest, the four legs, are brought back to town; but the back straps and tender loins they* [sport hunters] *usually take them… The* [sport] *hunters take back the hide, the cape* [part of the skull that support the horns], *and sometimes they take the jaw, for the European mount. But most of the time it is a full body mount, so you have to keep the hoofs on the hide as well. I would say 85% of the times is full body mounts…The jaw is taken for the European mount, maybe it is just 1% of the hunters. It is very weird that they will do European mount,* [it might happen] *only one* [time] *every few years…In the field, the inside stomach and the rib cage and all the internal organs* [are left]. *We mostly take the legs, the back straps and the tenderloins back"*
Interviewee 20 Inuk hunter Male, 57 years old	*Subsistence harvest (butchering practices, transportation, carcass utilization)*	*"I butcher the muskox out on the land and quarter it on the land…No* [I don't bring back the internal organs] *I leave out on the land the guts, the stomach, the heart, the lungs, the liver. If it was caribou I would bring back the liver but not in a muskox. I bring back the head, but I use to leave out the lower feet and bring back the hide"*
Interviewee 22 Inuk hunter Male, 30 years old	*Subsistence harvest (butchering practices, transportation, carcass utilization)*	*"I leave out there the gut parts, I take back the hide. The hide is useful and the head too. The rest of the meat is brought back in four quarters and the rib cage…we take the heart back, the liver not so much on a muskox - more on the caribou. I have never seen too many people eating the lungs or the liver on a muskox, more of the caribou. The kidneys are left too…We leave the lower legs and the hooves, there is not much use* [for them] *and they are also pretty heavy too"*
Interviewee 23 Inuk hunter Male, 48 years old	*Subsistence harvest (butchering practices, transportation)*	*"Most of the times I leave the hide out there, but sometimes if somebody tells me he wants a hide I will bring it back and give it to them but I don't need any more muskox hides and I*

		don't know anyone that does…It is very heavy, it must weight one hundred pounds and especially if you hunt on a quad it is heavy to bring back, so I just leave it out there"
Interviewee 23 Inuk hunter Male, 48 years old	*Subsistence harvest (butchering practices, carcass utilization)*	*"I have five dogs at home so I will bring everything back, all I leave* [on the land] *is the stomach content and the stomach lining and about 50% of the times I will leave the skin because I have no use for the hide, but I usually bring back the head home, but I haven't done anything with it…I usually give those* [heads of harvested muskoxen] *away to the carvers…We eat the heart, we eat the liver, I feed the lung and the trachea to the dogs, and any other cuttings, including the bones and kidneys, go to the dogs…I don't eat the tongue - I leave it in the head… the hooves: I will bring them back because the dogs likes to chew on the hooves; and when I debone the carcass, all the bones go to the dogs"*
Interviewee 25 Inuk hunter Male, 56 years old	*Subsistence harvest (butchering practices, transportation, carcass utilization)*	*"I butcher the muskox on the land, and I leave* [on the land] *the head, and the intestine… We leave the hide - it is too heavy, and there is no demand for the hides, I don't know why… I will* [also] *leave the lungs, the liver and the kidneys, but we take the heart and the tongue and all the fat from the stomach area that there is inside* [the abdomen]. *And we will keep the feet, the meat is soft there"*
Interviewee 26 Inuk Elder Active hunter Male, 60 years old	*Subsistence harvest (hunting preferences)*	*"I catch at least two muskox per year, but when an Elder ask me to go get a muskox for him, then I do it for him …* [I prefer to hunt] *in the fall time, I know the calves are born in April and I prefer* [to hunt muskoxen] *probably in October-November, by that time they are still fat. For myself I prefer to get adult females, sometimes a really young bull…but if an Elder ask me,* [if] *he or she wants a calf, then I will get a calf if they want it. They mostly have to choose what they want"*

Interviewee 26 Inuk Elder Active hunter Male, 60 years old	*Subsistence harvest (butchering practices, carcass utilization)*	*"We take* [back home] *all the quarters* [of the muskox carcass], *the hide, the head, all the back straps, the rib cage. You know there is not too much meat left* [on the land]*…Sometimes the* [abdominal] *organs, when they have a lot of fat, then I take all the fat off and I take all of that, just the fat, we don't take the organs…The heart sometimes we take it …and the liver sometimes we take it. I know when the liver it is not good in a muskox: I just slice it open and look inside, you know, when there is a lot of white spots on it, I know it is not good and it happen most of the times…We don't bring the lung back on a muskox, it is too huge and we don't have a container. On the muskox we leave the kidney and the organs, but for the caribou we basically take everything…you know the caribou is smaller than the muskox"*
Interviewee 27 Inuk hunter Male, 31 years old	*Subsistence harvest (butchering practices)*	*"Sometimes when it is really cold out like -40 or -50* [°C], *I shoot it* [muskox] *and put the whole thing* [carcass] *on the sled and haul it back to town and then, you know,* [I] *go in the house warm up and have a coffee, and then skin it* [the carcass] *outside of the house. Then wait a bit till the guts get a little bit hard and then take them with the shovel and bring them out of town. You know* [this happen] *when it is too cold out, or I travel with someone that can't handle the cold really well"*

APPENDIX F

Interview guide used during the individual interviews with study participants from the community of Iqaluktutiaq (Nunavut, Canada) – part 2

Note: as per standard practice in qualitative interviewing, the questions were tailored for each participant, this document provides sample questions for each theme that were explored in the interview process.

INDIVIDUAL INTERVIEW

Interview #:______

DATE: __________

Hello! Thank you for agreeing to be interviewed. As you already know the purpose of this study is to collect traditional and local knowledge about muskoxen in order to inform a program for monitoring muskox health. Here I have an outline of questions I would like to ask you. And I will take some notes during our conversation. Feel free to add any comments whenever you wish. Can we start?

GENERAL QUESTIONS

First of all, I would like to record some <u>information</u>

Record general information about interviewee including observational experience regarding muskoxen, hunting experience, and hunting areas used.

(For this section of the interview guide see Appendix A of Chapter 2)

OBSERVATIONS ON MUSKOX HEALTH AND ECOLOGY

Now l would like to talk to you about your observations on <u>muskoxen in their natural environment.</u>

1. Where do you usually see muskoxen? Have you noticed any difference between summer and winter?
   Mapping exercise.

Probes: How many herds? How big are the herds?

2. Have you noticed any change in the number of muskoxen and where you find them?

Probes: What kind of change?
When did you start to notice the change?
Why do you think this has happened?

3. Have you noticed any other change in the land and the animals?

Probes: What kind of change?
When did you start noticing the change?
Why do you think this has happened?

Now I would like to ask you some questions about the <u>health of muskoxen</u>

1. Do you think muskox herds around here are doing well? Yes No

Probe: Why? Why not?

2. Do you have any concerns related to muskoxen? Yes No

Probe: If yes …. What are they?

3. For you, what are the factors that influence muskox heath?

Probe: Do you think that these factors you listed have changed over time? Why?

Now I would like to ask you some questions about <u>diseases of muskoxen</u>

1. Do you know about any traditional names that describe syndromes or diseases in muskoxen? Yes No

Probes: If yes ...

What are they and what do they mean?

2. Have you ever seen dead muskoxen in the wild? Yes No

Probes: If yes ...

Can you describe what you saw?

When and where? *Mapping exercise*

How many animals did you observe dead?

What kind of animals? adult young calf male female

3. When you were out in the land, have you ever thought a muskox was sick? If yes, why?

Probes: Can you indicate the location on the map and when it happened?

Can you describe what you saw?

How many animals did you observe?

What kind of animals? adult young calf male female

4. What about the animals that you hunted so far? Have you observed any strange things when you butchered them? Yes No

Probes: If yes ...

Can you describe what you saw?

Where and when was that?

What kind of animal? adult young calf male female

Is this a common finding in the animals you hunted, so far? Yes No

Have you observed any changes over time in the animals? *Open question followed by picture exercise*

FINAL QUESTION

1. Is there anything else that you would like to mention?

Thank you very much for taking the time to answer these questions. If you have any concerns you can contact me. My email address is matilde.tomaselli@ucalgary.ca

Thank you very much! I want to thank you on behalf of all the team working with me at the University of Calgary.

APPENDIX G

Methods of the group interviews performed with study participants from the community of Iqaluktutiaq (Nunavut, Canada)

In this section, we report the participatory exercises performed during the group interviews following their order of implementation. All the exercises were performed first referring to muskoxen, then to caribou. In the proportional piling exercises, we used a fixed amount counters (0.5kg of beans) as the unit of measure to assist participants in identifying proportions. At the end of the exercises, we used a measuring cup with a percentage scale to measure the counters. Once the percentages were determined, participants were asked if they agreed with the final results. Although it never happened in this study, if disagreement occurred, we planned to repeat the exercise. Additional note on the proportional piling technique used is provided at the end of this appendix.

Determining demography of muskoxen and caribou

Determining relative abundance

Drawing exercises and proportional piling exercises were used in the group interview setting to explore the perceived muskox and caribou population abundance and their changes over time in the Iqaluktutiaq area. First, participants were provided with a sheet of paper (approximately size A0) with a timeline on the horizontal axis from 1960 to 2014 (1960-2010: 5 year intervals; 2010-2014: 2 year intervals) and a vertical axis in percentage, from 0-100, corresponding to relative abundance with the highest abundance equivalent to 100%. Participants were asked to collaboratively draw lines representing the fluctuation over time of the relative abundance of muskoxen and caribou (separately). Participants were free to modify the timeline, starting when they were more comfortable with their own observations; however, they were asked to maintain proportion when drawing the lines. For analysis and interpretation, the estimates of the relative population abundance were extrapolated from each graph, for each available year (1960-2014). The data were then plotted in a scatterplot and the trend in the data was visualized using the best-fit line (cubic model). Given that all participants reported in recent years a major decline in both muskoxen and caribou, we were able to define two periods, one just prior the declining phase (called 'pre-decline') when both ungulate populations were considered to be at their peak, and one from the start of the decline to the time of the group interviews (called 'decline'). Subsequent exercises used these two defined periods, 'pre-decline' and 'decline' as reference points.

Determining relative population declines

Subsequently, proportional piling exercises were used to quantify the proportion of population decline in both ungulate species. Counters were used to represent muskox and caribou population sizes in the pre-decline period, when they were at their peak in abundance. Participants were then asked to divide the counters to reflect their perception of muskox and caribou population sizes at the time of the group interviews (end of 2014).

Determining group size and distribution

Participants were also asked to indicate for both ungulate populations the average size of the herds (number) and the average distance between them (miles) in the defined periods. No pre-defined values were provided, but participants were free to indicate a value or an interval for both variables. Where applicable (muskox herds), the answers were categorized a posteriori for analysis for both the variable 'size of the muskox herd' (1: ⩽10 a; 2: >10-30 a; 3: >30 animals), and the variable 'distance between muskox herds' (1: <5 m; 2: ⩾5-10 m; 3: >20 miles); otherwise, they were qualitatively assessed (caribou herds).

Determining group sex and age structure

Participants were asked to divide the counters according to their perceptions of the average proportion of adults versus juveniles (calves plus yearlings) that they observed during the pre-decline and decline periods. Participants were asked to further divide the proportion of adults into males vs. females, and the proportion of juveniles into calves vs. yearlings in both pre-declining and declining periods.

Determining body condition of muskoxen and caribou

Participants were asked to divide the counters into 4 predetermined categories (excellent, good, fairly good, and poor) according to their perception of the average body condition status of the animals that they had hunted or observed during the pre- and the decline periods. Further probing was also used to define participant perceptions regarding the depth in centimeters of the subcutaneous back fat in the hunted individuals. This parameter is used as an estimate of the body condition of wild ungulate species (Riney 1960). Hunters in the community of Iqaluktutiaq are familiar with the measurement of the subcutaneous back fat depth (measured at the rump by cutting into the carcass) because they were previously asked, by the Department of Environment of the Government of Nunavut through the local Wildlife Officers, to record and report it on a voluntary basis in the harvested ungulates.

Determining morbidity and mortality of muskoxen and caribou

Determining relative morbidity and mortality

During the group interviews, participants were asked to divide the counters according to the perceived relative proportion of healthy, diseased, and dead animals within the observed muskoxen and caribou. The exercise was repeated for the pre-decline and decline periods, and first in muskoxen and then in caribou.

Determining relative prevalence of diseases

Baseline data about specific lesions and or syndromes (hereafter referred as diseases) noticed in the hunted or observed muskoxen and caribou in the area of study were gathered through the individual interviews (see interview guide in Appendix S1). Pictures of specific lesions were provided either to confirm participant's observations or to assist the interviewee in disease identification with specific examples. The pictures provided were representative of muskox and caribou diseases as described in available literature. During the group interviews, participants were provided with a listing of diseases which had been generated from all of the individual interviews, and were next asked to identify which diseases they had personally encountered. They were also free to add new observations of diseases that were not included in the provided list. Participants were then asked to divide the counters, which represented the totality of the identified diseases in both the hunted and observed muskoxen/caribou, according to the relative occurrence of each disease during the decline period. Additional probing questions were asked in an effort to understand when participants started to observe each disease and its trend over time (increasing, decreasing, or stable).

Determining relative proportions of causes of mortality in muskoxen and caribou

As a further probing on the previous exercise, participants were asked, in both periods under consideration, to further divide the counters that represented the relative proportion of dead animals observed into additional categories, with the aim to classify the mortality as 'predation', 'acute deaths', and 'undetermined/other causes'. Participants were also asked to provide a description of the cause/s of death for those animals that had been categorized under undetermined/other causes of mortality. Additionally, they were asked to further divide counters representing predation as the cause of mortality according to the predator species thought to be involved. 'Acute deaths' was defined as the presence of one or more carcasses lying on the ground within the same geographical area, with the following specific characteristics: carcass/es intact or only minimally scavenged, death/s occurred recently (within few weeks), and not attributable to predation or hunting. A picture of a dead muskox with a presentation consistent with the previous description was provided with the intent to assist the interviewees in the case identification.

Determining patterns of disease outbreaks in muskoxen

During the group interviews, when 'acute mortality' was reported (only in muskoxen), specific probing exercises (proportional piling and seasonal calendar) were implemented with the intent to gather information on age characteristics and seasonality of those specific deaths. First, participants were asked to divide the counters, which represented all of the 'acute deaths' observed in the muskox population, according to the relative proportion of adults vs. juveniles (calves plus yearlings) observed. Then, participants were asked to define a seasonal calendar and divide the counters according to the average proportion of animals observed dead in these seasons.

In addition, all participants (n=38) were asked to indicate on the provided maps the location, number, age, year, and season for the muskoxen observed dead with a presentation consistent with 'acute mortality'. The reported location, in form of points or polygons, were transposed digitally and analyzed spatially using the software ArcGis 10.2. To avoid double counting, we excluded from the analysis the cases reported by independent interviewees with same geographical and temporal location (year and season), and similar age and sex class characteristic (adults vs. juveniles, females vs. males). For this reason, we excluded from the total counts 5 cases observed by Interviewee 21 in 2010, 4 cases reported by Interviewee 28 in 2011, 1 case observed by Interviewee 1 in 2012, and 2 cases reported by Interviewee 7 in 2012.

Proportional piling technique

The proportional piling is a well-established technique essential for the collection of participatory epidemiological data (Mariner & Paskin 2000). A fixed number of counters, generally 50 or 100 beans, are used as the unit of measure to assist participants in identifying proportions (Mariner & Paskin 2000). In this study, we used 0.5 kg of beans as a fixed volume of counters so as to allow the operator performing the interviews (MT) to measure the counters rapidly using a measuring cup with a percentage scale, rather than counting the beans one by one (Fig.G.1).

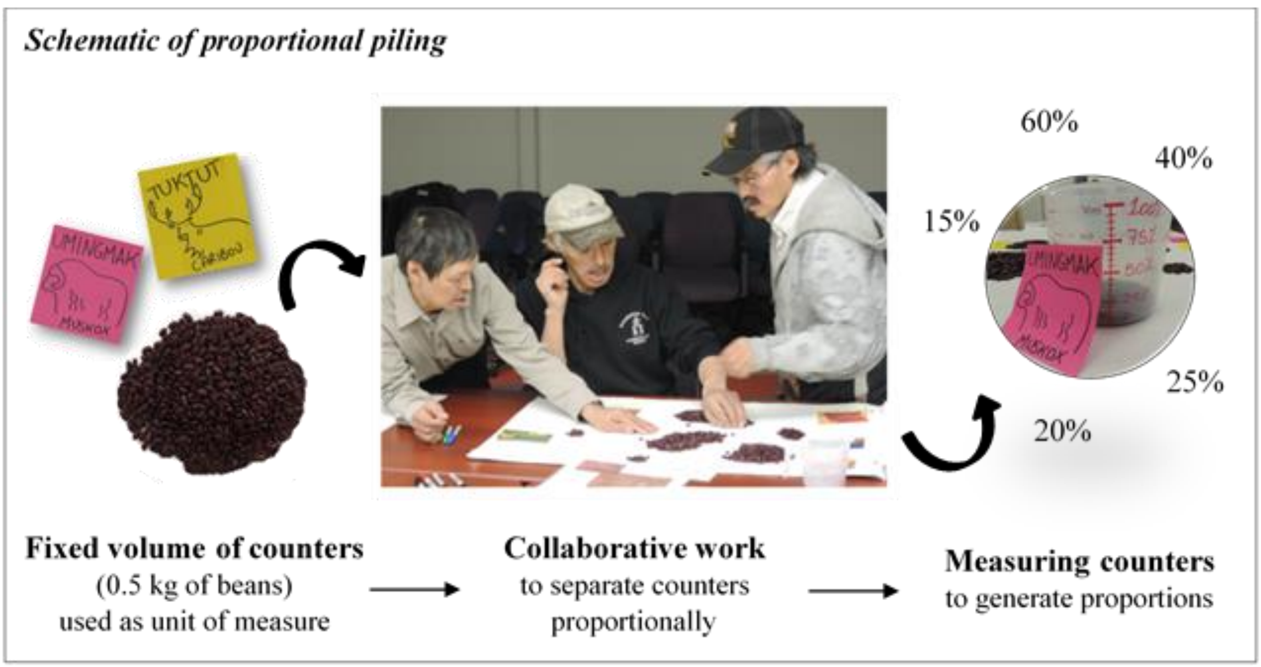


Figure G.1. Schematic representation of the proportional piling technique used in the group interviews performed with participants of the community of Iqaluktutiaq (Victoria Island, Nunavut).

APPENDIX H

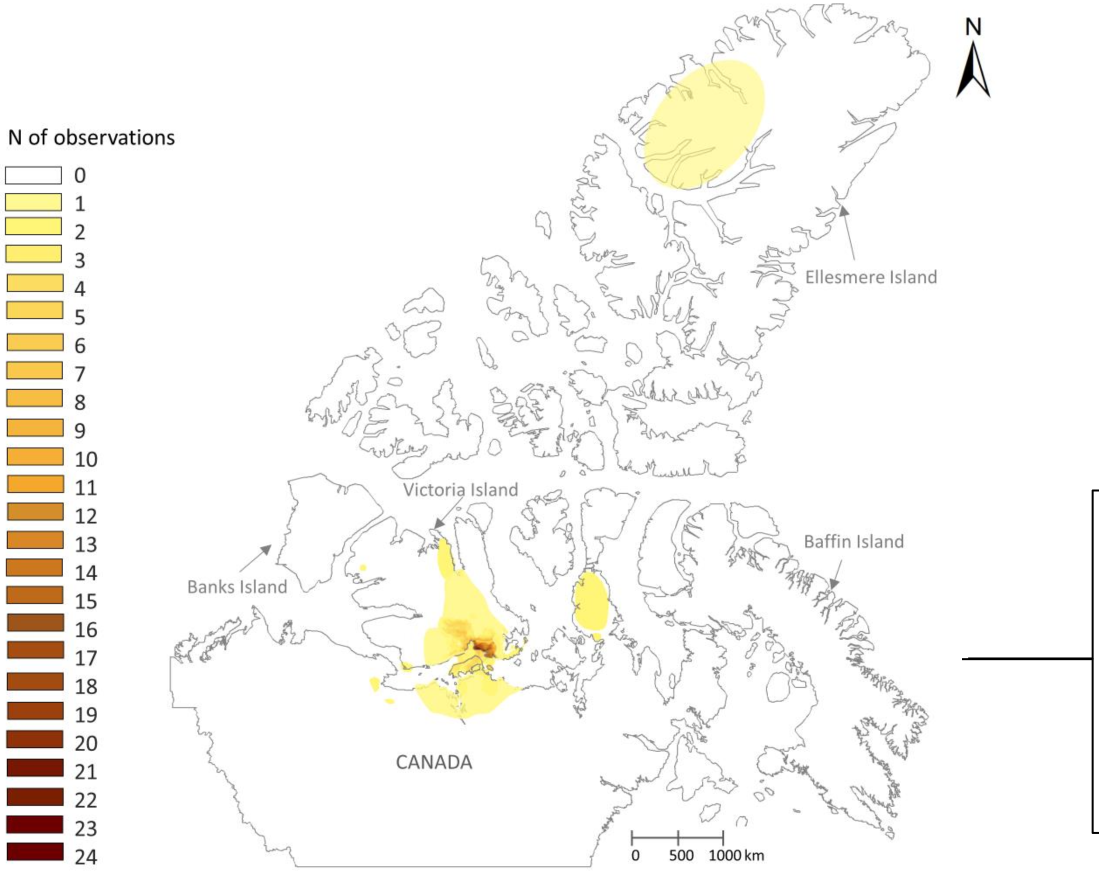
Area observed by interviewed participants from the community of Iqaluktutiaq (Nunavut, Canada)

In individual interviews, we asked participants to highlight on maps (scale 1:500,000) that were covered with mallard transparent sheets their hunting grounds, observations on spatial distribution of muskoxen and caribou, location of dead animals when appropriate (acute deaths in muskoxen), and any other relevant observations. For each participant, the georeferenced areas indicated were then transposed digitally as polygons or points using the software ArcGis 10.2. Among the 30 individual interviewees, 24 provided this information on the maps: 22 year-round community residents and 2 summer residents (commercial floatplane pilots). The georeferenced areas provided by each participant were then transformed into raster that had a set value of 1. We then superposed the raster of all participant to create heat maps that describe the observation pressure on the land operated by the interviewees included in this study, or in other words the area observed by our participants. The final georeferenced area originated provided the spatial context to interpret the data gathered in this study, and we refer to it in the main paper as ‘area of observation’.

The same process was repeated in the group interviews so as to confirm that the observations captured in this second phase referred to the same area. All group interviewees participated in the mapping activity. Each group was considered as one unit, with a total of 7 groups sampled. Results were comparable.

Area of observation

Figure H.1. Spatial extent of the area observed by individual interviewees (n=24).



A. Area observed by land (n=22)

B. Area observed by air (n=2)

Figure H.1.A. Individual interviews: area observed by land (n=22).

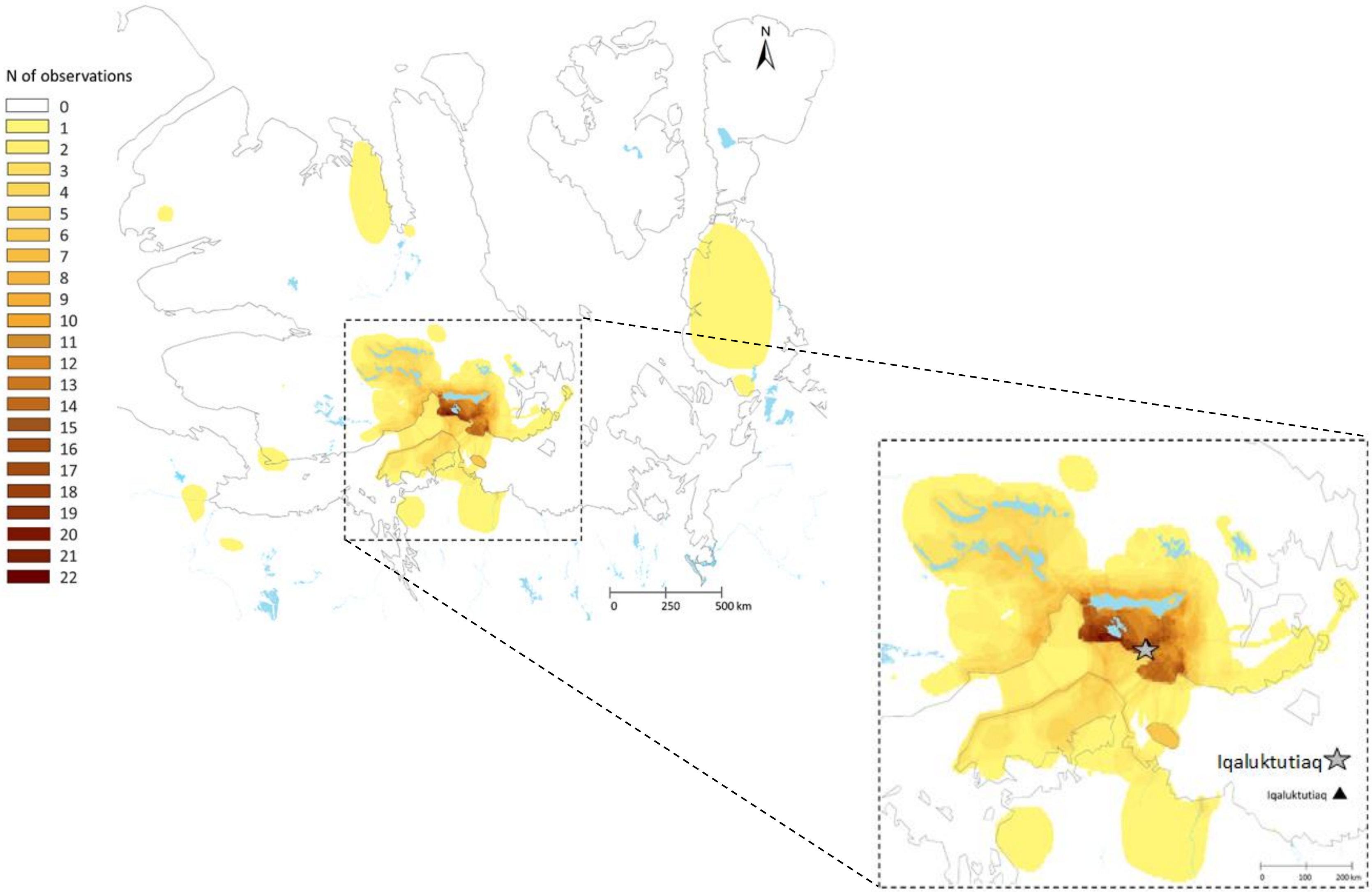


Figure H.1.B. Individual interviews: area observed by air (n=2).

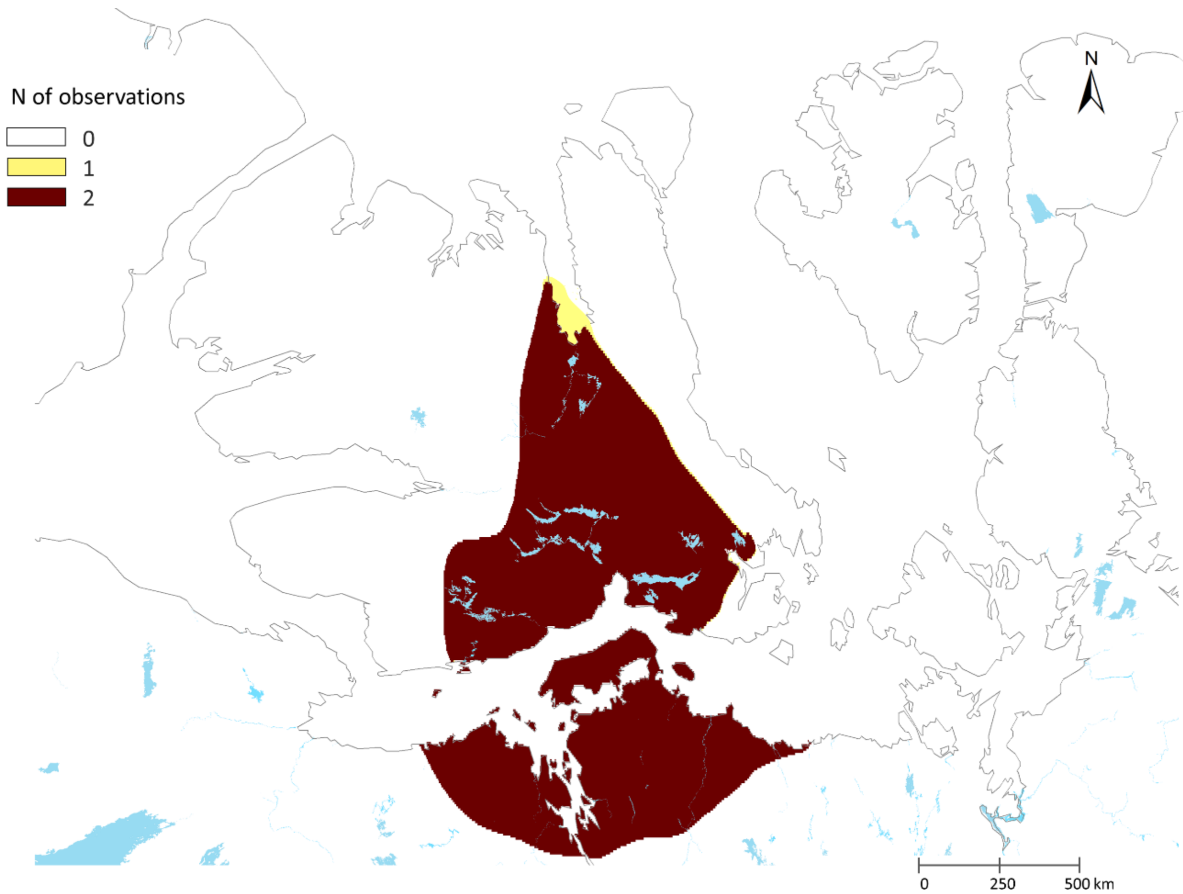
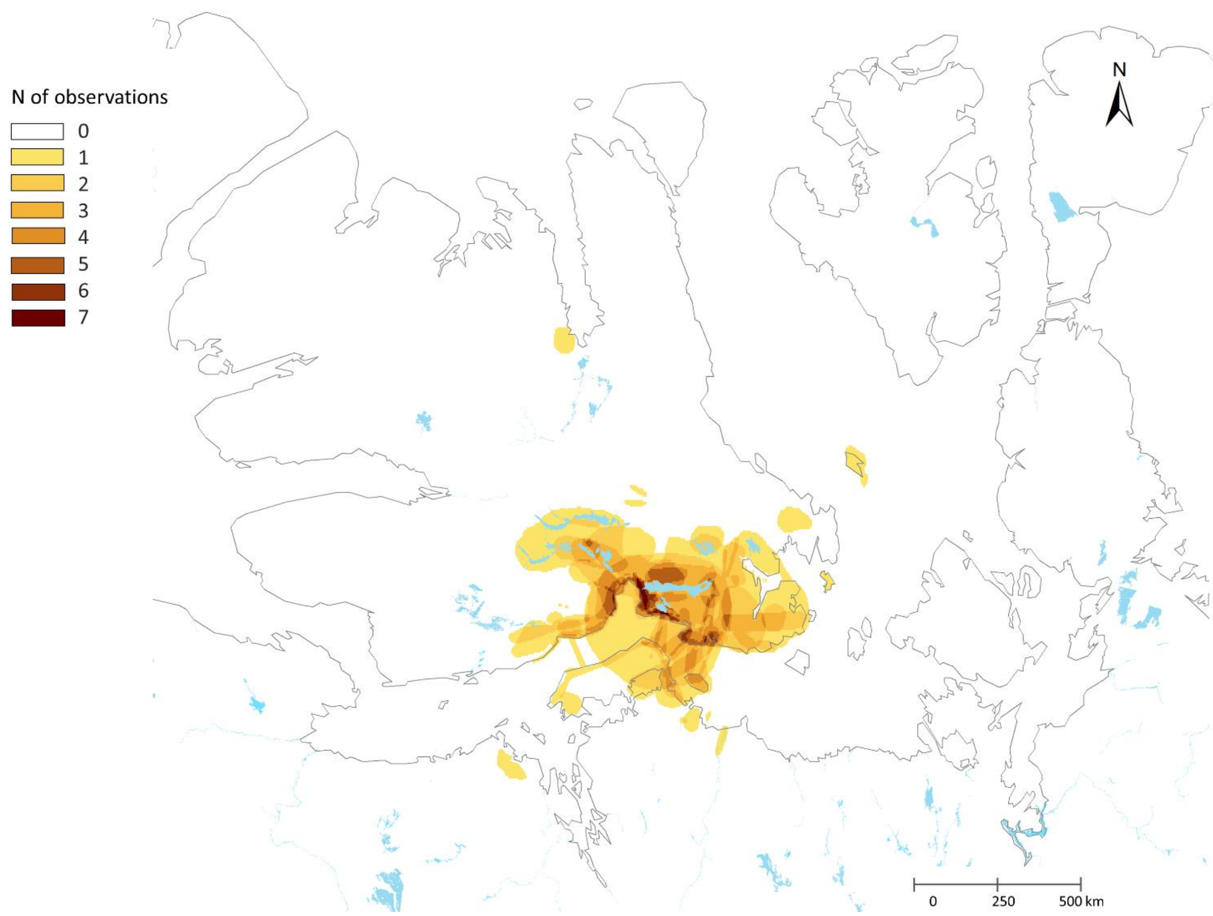


Figure H.2. Spatial extent of the area observed by group interviwees (n=7). For comparison with results from individual interviews.



APPENDIX I

Individual interviews: selected quotes from participants that represent muskox abundance over time in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada)

Interviewee	Quote
Interviewee 03	*"I used to see* [muskoxen] *even near the tower, Mount Pelly or even the Dew line…They were so close, I always take pictures. They were so close to the cabin. But nowadays I don't see them anymore, they are so far away….and it is sad that I don't see muskoxen in my community anymore. I don't know if they went further away because of other animals that roam in the area. I don't know, but I hope they will come back."*
Interviewee 06	*"Before, I was used to see muskoxen all over in the island…anywhere! ... They* (muskoxen) *were everywhere…all over the island…Right now they* [muskox number] *are really changed…we don't see muskoxen anymore. The numbers are way down."*
Interviewee 07	*"I was used to see muskoxen almost all over. Since 4 or 5 years ago there are less muskoxen"*
Interviewee 09	*"It is different* [now]. *The first time I moved here* [late 80s] *there used to be a lot of muskox: lots all over and closer to town. Now it is hard to see* [them]. *In 1987-88 used to be lots of muskox, in summer time too you could see them anywhere…In 1987- 88 there were loots* [emphasis on lots] *of muskox all over. Now it is different! You don't see them anymore around. There is something wrong, I really don't know why…Right now when I go out at Starvation Cove, I look there and: nothing! I don't see them anymore. There used to be lots there, but not anymore. Gone!"*
Interviewee 11	*"In the early 80's the muskox were plentiful, I remember that in the 70s* [they] *were very hard to find and in the 80s you can find them all over the places…In the 90s was the same thing: you could see them all over the places whenever you were out hunting"* *"I have never got a muskox anywhere else, just in the vicinity of Cambridge Bay area… I have never had to go really that far from home…I mean I travelled long ways before, but I never passed this vicinity to get a muskox. It's always been in this general area of*

	Cambridge Bay: Kitiga Lake, Ferguson Lake, Kiaktaktok, Anderson Bay, Wellington Bay, Kitigaiuk."
	"We used to be able to see muskox driving behind the DEW line station along the road, we used to be able to see muskox in each side [of the road]. *Going to Mount Pelly you would see muskox on either side of the road and in behind mount Pelly. But in the last 2 to 3 years it seems that there is hardly any more muskox in the usual places"*
	"Last time that I saw lots of muskox was four, maybe 5 years ago. We went up caribou hunting in the fall time [northern Ferguson lake area] *and look around with the binoculars and we saw herds of muskox; and then the next year we went out and there were virtually no muskox to see. It was 2010-2011 I think, around that time. It seemed that they just all disappeared!"*
Interviewee 13	*"Muskoxen in the early times I lived here* [15 years ago] *were all over…In the last couple of years I have noticed less and less* [muskoxen] *coming close to the community…and even we go quite away* [Kent Peninsula or Byron Bay] *we don't see them… even travelling as far as we did this summer and this spring we didn't see much muskox. We saw maybe 1 or 2…this year was the most drastic* [decline], *we noticed last year too, last year we saw 1 or 2 and even our friends they said they didn't see muskox."*
	"There used to be more muskox together, bigger herds. Now they are not around"
Interviewee 14	*"In the 90's there was hundreds of muskoxen …there were a lot! I hadn't been in this area for a while, since late 90s and then when I moved here* [seven years ago] *I said WOW there's way less muskox. In the last seven years the number got down big time. The change is dramatic…The worst got around three years ago, then was when really started to get bad"*
	"When I first took my son [muskox] *hunting here* [personal hunting area on the west side Wellington Bay] *the same year we came* [2007], *there was decent amount of muskox but nothing crazy…. there was a fair amount but not as much I thought that would be…maybe there were around 20% - 30% less muskoxen I thought that would be. But now it is very, very noticeable, it's without a doubt way less….And 3-4 years ago is when it became very noticeable".*

Interviewee 17	*"Within the last ten years is when it started to be more difficult to see herds [of muskoxen] and then more recently within the last 3 to 5 years I would say that it is extremely difficult to find certainly any larger, and if you do find muskox they are usually loners or very small herds"* *"Overall in my travels the concentration of muskoxen was pretty high back ten years ago, and today you will be lucky to see one, it's ridiculous! It was not that long ago that the population of muskox on the island seems pretty healthy, robust and then now, in a relatively short period of time it is completely gone, disappeared"* *"A An old fellow here in town told me a story once: when he was a kid growing up here his family used to camp somewhere along the coast around Byron Bay and he got up one day, he was just a kid, he got out the tent and he noticed an animal that he had never seen before, and he asked his father what it was, and his father said it was a muskox. So he grew up in this area but he had never seen a muskox before, and it was back in the early 40s based on his age"*
Interviewee 21	*"In the 60s there was hardly any muskox, almost none. We used to have a lodge on Charles Lake. It used to be an Arctic outpost camp….We didn't hunt at that time. But it was the biggest thing the all summer to see one muskox walk into camp at that time* [1960s]…*And then my dead he sold this one* [lodge at Charles Lake] *and started this other one* [High Arctic Lodge on Surrey lake] *in 1971…And over the years we were seeing more and more and more muskox up until three years ago… it's just been a steady increase. Last year was like an eye opener and this year was a big decrease, huge!"*

APPENDIX J

Individual interviews: selected quotes from participants that represent caribou abundance over time in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada)

Interviewee	Quote
Interviewee 07	*"Caribou and muskoxen are slowly declining…*[the decline in caribou] *is due to changes in grazing areas and permafrost lifting. About 4 or 5 years ago* [I have noticed the start of the decline]*"*
Interviewee 08	*"Caribou had declined. Usually I go hunting every spring and I go out almost every day looking for caribou, or geese, or ducks, and I don't recall any caribou this spring. It is the first time in all my life that I don't recall a caribou in the spring. All my hunting life anyway* [he started hunting in the late 1980s]*." "I didn't catch any* [caribou] *this year in the usual spring hunting areas. Their* [caribou] *number are way down! This year* [2014] *I have noticed the number are way down but last year* [2013] *you could see the decline for the caribou. In spring and fall I was used to see 120, 150* (caribou) *in a herd, maybe even more, but in the last couple of years herds have dropped down to like 20 to 50* [animals]. *I used to see big herds, but the herds have gotten smaller for the caribou. I started to see these changes maybe from fall 2012"*
Interviewee 11	*"In the early 80s caribou were really far from Cambridge Bay. In the early 90s the caribou started migrating through the community…every fall the caribou would come through, within an out scratch of the community, around September, October during the fall migration…*[but] *since three years ago I don't see as many caribou. I think that their migration patter has changed more towards the east and more towards the west".*
Interviewee 12	*"Caribou have changed their migration route, so that they are bypassing town by more kilometers in the past two years. I couldn't say that they are going to a different area, but I certainly hear that there are lots of caribou crossing over the west side of Kent Peninsula and even in Queen Maud Gulf…they are not crossing opposite from town anymore"*

Interviewee 13	*"People are having hard time getting caribou. We travelled so far last year and zero caribou. Last year we have noticed decline in the caribou number in the usual area and in the fall* [fall 2013] *they disappear sooner than expected. Even in the spring time people are seeing further over to the east side.*
Interviewee 14	*"Caribou are declining as well, so that's a big thing that is noticeable. This spring, in May, I didn't see one caribou track in 70 miles of coast* ['usual areas' where the caribou were migrating through to reach the calving grounds]. *Around five years ago the caribou started going down. It* [the number] *was really high when I moved here* [7 years ago], *and even before that fifteen years ago there were lots of caribou around. And now there are way less, way less...Now they could be moving, but I don't know I don't think so. This is a lot of coast, it is a big chunk of what they migrate and that really shocked me when I didn't see anything"*
Interviewee 15	*"I was used to find caribou not too far from here* [the community], *just maybe 2 miles out of town there were caribou out there in spring. Hardy now. Two years ago during spring time we went pretty much 90 miles in a skidoo trail but we didn't see nothing: not caribou and not even muskox…In a skidoo trail like this I was expected to see let's say 60, 70 animals"*
Interviewee 16	*"There were very few caribou in the past …I was in the gulf of Boothia, but it was the same as here…there were very very few caribou…only the plenty of caribou started showing around only 30 years ago"*
Interviewee 17	*"Even for caribou the number started to decline in the past 10 years, and more recently within the past 3 to 5 years again they are very, very difficult to find, especially in the past 3 years…you could drive to Cambridge Bay out to the end of the road at the Gravel Pitt area and I recall years where there be thousands of caribou migrating during the fall time to the ocean getting ready to cross over on Kent Peninsula…I in particular recall the experience to drive with the snow machine through the herd and they wouldn't care, I could touch them from the snow machine and as far as I could see was full of caribou…this particular case was probably 15 to 20 years ago… Within the last 5 years you would still able to go out into this area here: along Kitiga Lake, Augustus hills and you would have*

	no problems running into herds of 15 to 20 animals. Now you may see nothing in this area, you might have to go as far as Ekalluk River. A lot of the hunters more recently have actually just been going down to the mainland"
	"In those years [late 1990s] *they were abundant and now there is just nothing around"*
Interviewee 18	*"This area here* [form Byron Bay through 30 miles river] *was like a nursery for caribou: cows and calves. You wouldn't see that many bulls in there, but during the summer you would see lots of cows and calves and I hardly saw any this summer* [2014]*"*
Interviewee 20	*"Caribou they used to come down this way in the past, but they mostly coming across here* [north Ferguson lake] *coming all the way down* [to Andersen Bay]*….*[this is because] *there are too many hunters just go out too early and going around this way* [Starvation Cove and Wellington Bay areas] *now…hunters just go out too early, and caribou migrate around this way* [north Ferguson lake] *and they are going more on the east side"*
Interviewee 22	*"You normally would see* [caribou] *herds of a hundred, two hundred, three hundred, maybe more in a herd; and for two three years I haven't seen big herds of caribou around, so either they are changing their migration routes or I don't know…the caribou population either went down or they moved, or they are spread apart. It is hard to say…In the past you would see hundreds walking along the Augustus shore line but we haven't seen that in the past three years. Maybe the odd group of 25 or 50 in there but we haven't seen a big herd of hundreds for a couple of years...I haven't seen anyway….we might see more in terms of groups but smaller groups"*
Interviewee 23	*"There is less animal* [muskoxen and caribou] *grazing now…I was travelling around this summer* [2014] *and I noticed that the grass is tall this year and it is not trampled down, lots of willows, even the caribou moss is coming back because there is nothing eating it, you know the little yellow moss it is growing it's everywhere. This year I started to notice it particularly"*

Interviewee 26	*Every spring and every fall hundreds of caribou were crossing the ice. Then* [caribou] *started to decline and now there are not even 200 animals coming on the island* [meaning in the vicinity of the community]*…Muskox too are declining, there were lots and lots around and now there are barely any close by".*
Interviewee 27	*"I have just noticed that the caribou and muskox are declining…I started to notice the decline of the caribou around 06 and 07 I guess…it was at the same time* [of the muskox decline]*"*

APPENDIX K

Group interviews: participants' perceptions of the relative proportion (%) of adults (males and females) and juveniles (yearling and calves) in the observed muskoxen and caribou in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada) during the pre-decline and decline periods

	Pre-declining period				*Declining period*			
	N	Median	IQR	Range	N	Median	IQR	Range
Adult muskoxen	7	75	65-75	65-80	7	90	85-90	85-95
male	4	27.5	20-30	15-30	4	22.5	12.5-33	10-36
females	4	47.5	42.5-50	40-50	4	65	57-75	54-80
Juvenile muskoxen	7	25	25-35	20-35	7	10	10-15	5-15
yearling	7	15	12.5-25	10-30	7	6.5	4-10	4-10
calves	7	10	5-12.5	5-12.5	7	5	2-6	1-6
Adult caribou	7	65	65-70	50-75	7	80	70-85	70-88
male	4	22.5	20-25.5	20-26	3	20	20-25	20-25
females	4	42	34.5-45	30-45	3	50	50-55	50-55
Juvenile caribou	7	35	30-35	25-50	7	20	15-30	12-30
yearling	7	17.5	12.5-25	5-25	7	10	5-20	5-20
calves	7	15	12.5-25	10-30	7	10	5-12.5	3-15

APPENDIX L

Group interviews: participants' perceptions of the relative proportion (%) of adults (males and females) and juveniles (yearling and calves) in the dead muskoxen (acute mortality) observed in the Iqaluktutiaq area (Victoria Island, Nunavut, Canada) during the decline period

	Muskox acute mortality			
	N	Median	IQR	Range
Adults	5	95	85-95	60-95
male	5	48	45-51	24-81
females	5	34	15-46	14-71
Juveniles	5	5	5-15	5-40
yearling	5	5	4-5	2-25
calves	5	3	1-10	0-15

APPENDIX M

Manuscript based thesis - copyright disclosure statement

July 23, 2018

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Chapter 2 - Tomaselli M, Gerlach C, Kutz S, Checkley S, and the community of Iqaluktutiaq. 2018. Iqaluktutiaq voices: local perspectives about the importance of muskoxen, contemporary and traditional use and practices. *Arctic, 71(1):1-14.* http://dx.doi.org/10.14430/arctic4697

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