MUSKOX HEALTH ECOLOGY SYMPOSIUM

ABSTRACTS
Contents

Oral Presentations

Tuesday 08 Nov. 2016

I.  **Keynote Talk:** Between splendor and reality in the world’s highest latitudes and elevations ........................................... 5

Session 1: Value of Muskoxen

II.  Exploring the Importance of Muskoxen: Perspectives from Ikaluktutiak, Victoria Island, Nunavut ..................... 6
III.  Examining the impact of muskox wool industry on Native Alaskan villagers ................................................................. 7
IV.  Qiviut, a treasure of the Arctic .................................................................................................................................................. 7
V.  Outfitted muskox hunting in the Canadian Arctic: cultural, conservation and socio-economic importance .............. 7

Session 2: Status and Trends

VI.  Muskox status and trends of muskox in Alaska .............................................................................................................................. 8
VII.  Status and trend of Yukon North Slope muskoxen ..................................................................................................................... 8
VIII.  Population status and trends of muskoxen in the Northwest Territories ............................................................... 9
IX.   Population status and trends of muskoxen in Nunavut ......................................................................................................... 9
X.    Population status and trends of muskoxen in Quebec ........................................................................................................... 10
XI.   Population status and trends of muskoxen in West Greenland ......................................................................................... 10
XII.  Status and trends of muskoxen in Northeast Greenland .................................................................................................... 11
XIII. Development and management of an introduced population of Muskoxen in Norway ........................................ 11
XIV.  Population status and trends of muskoxen in Russia ........................................................................................................... 12

Session 3: Declining Populations

XV.  Demography of a muskox decline in northwest Alaska, 2009-2013 ......................................................................................... 13
XVI. Disease complexity in a declining Alaskan Muskox (*Ovibos moschatus*) population ...................................................... 13
XVII. No Smoking Guns: Emerging diseases and general ill-health coincide with rapid declines of muskox populations on Banks and Victoria Islands, NWT and Nunavut, Canada ................................................... 14
XVIII. Muskox health and disease in a rapidly changing outpost – Dovrefjell in Norway ...................................................... 15
Wednesday 09 Nov. 2016

XIX. **Keynote Talk: Hindsight, insight, and foresight - The Yin, Yang, and Yung for advancing perspectives in muskox ecology and management** ................................................................. 16

**Session 4: Advances in Knowledge, Threats and Vulnerabilities**

XX. **A sedentary nomad: Year-round movements of muskoxen in high arctic Greenland** .................................................. 17

XXI. **Genetic assessment of local adaptation in *Ovibos Moschatus*** .................................................................................. 18

XXII. **Climate trends and severe winter and summer weather coincident with nutritional stress and disease outbreaks recorded for muskoxen on Banks and Victoria Islands, Arctic Canada** .................................................. 18

XXIII. **Local thermal adaptation of parasites and its implications in a global climate change context** ......................... 19

XXIV. **Range expansion of protostrongylid nematodes infecting muskoxen and caribou in the Canadian Arctic** .............. 20

XXV. **Infections of muskoxen (*Ovibos moschatus*) from Nunavik by the giant liver fluke (*Fascioloides magna*)** ............... 20

XXVI. **Serological survey for exposure to *Erysipelothrix rhusiopathiae* in muskoxen across the Arctic** ....................... 21

Thursday 10 Nov. 2016

**Session 5: Tools for Muskox Monitoring and Management**

XXVII. **Community-based participatory methods: a tool to enhance muskox research and co-management** ................. 22

XXVIII. **Show me your rump hair and I will tell you what you ate** .................................................................................. 23

XXIX. **Muskox vulnerability to a warming climate: implications for monitoring** ......................................................... 23

XXX. **Androgens, feces and Muskox machismo** .................................................................................................. 23

XXXI. **Developing tools for monitoring health: an innovative method of qiviut cortisol quantification in muskoxen (*Ovibos moschatus*) using liquid chromatography coupled to tandem mass spectrometry** ........... 24

XXXII. **Exploring herpesvirus and parapoxvirus diversity in muskoxen from the Canadian arctic** ............................ 25
Poster Presentations

I. Gastrointestinal parasites and fitness in arctic ungulates: the example of *M. marshalli* in Dall’s sheep .......... 26

II. Distribution and abundance of Muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) on Prince of Wales, Somerset, and Russell Islands, March 2016 ........................................................................................................ 27

III. Distribution and abundance of Muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) on Prince of Wales, Somerset, and Russell Islands, August 2016 ......................................................................................................................... 27

IV. Absence of association between stress and parasitism in muskoxen (*Ovibos moschatus*): a tolerance of these hosts to their parasites? .......................................................................................................................... 28

V. Investigating the dental health of muskox and caribou populations in the Canadian Arctic ............................... 28

VI. Systematic Health Monitoring of the Norwegian Muskox Population: 12 years of surveillance and interventions ........................................................................................................................................... 29

VII. The Canadian Wildlife Health Cooperatives role in wildlife health monitoring: 26 years of insight into the health of Muskoxen ........................................................................................................................................ 30

VIII. Lungworms of Victoria Island Muskox: Climate change and disease dynamics .................................................. 30

IX. Testing the Caprine 50K SNP chip for its utility in the management and monitoring of Musk Ox .............................. 31

X. Addressing caribou-muskox interaction concerns in the mainland Western Arctic ................................................. 31

LIST OF REGISTERED DELEGATES ....................................................................................................................................... 32
The world’s landscapes have amazing diversity – hot and tropical, cold and non-peopled, temperate and increasingly peopled. Some 95% of the world’s humans live below 1000 meters and 99% beyond the Arctic. The clan of snow oxen – species of goat-antelope ancestry – is reflective of species of the remote and cold, untrammeled and wild zones. My talk will offer a sense of the magnificence and challenge confronting species persisting at the extreme edges of the world. I’ll feature three vignettes: 1) The importance of peri-glacial zones to wild yak, a species surviving only above 4500 meters, 2) How a changing climate is affecting the Arctic’s largest land mammal, muskoxen, and 3) Clues to what ecological connectedness mean for global conservation. It is only when we re-think how to do better by moving beyond modern technology alone and coalescing groundwork with insights from people on the land, that we will improve upon our successes.
Session 1:

Value of Muskoxen

II. Exploring the Importance of Muskoxen: Perspectives from Ikaluktutiak, Victoria Island, Nunavut

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Understanding the human-wildlife relationship, including how humans value wildlife, is critical to consider when implementing wildlife oriented activities, being these management, conservation and/or monitoring. As part of a study focused on the development of a participatory muskox health surveillance system in the Arctic community of Ikaluktutiak (Cambridge Bay) on Victoria Island, Nunavut, Canada, we explored community perspectives on the importance of muskoxen. This study was also focused on understanding the impact at the individual and community level of local decline of muskoxen in the Ikaluktutiak area.

We interviewed individually 30 community members, using semi-structured interviews. We recruited participants through the purposeful sampling and snowball techniques, and we defined the sample size by the thematic saturation approach. The interviews were recorded and information transcribed to allow thorough thematic content analysis. Once information was interpreted, we validated the findings by presenting back the results to participants in feedback sessions, in which 26 of the 30 interviewees participated.

Participants identified 4 major themes to describe muskox importance both at the individual and community level, and defined it as nutritional, socio-cultural, economic and environmental importance. Additional sub-themes emerged when exploring each domain, providing a richer description of participants’ values and attitudes toward muskoxen. Local decline of muskoxen was perceived by participants to have significant and multiple impacts on the local economy, food security, as well as socio-cultural dimensions. This work provides valuable insights about the Ikaluktutiak community point of view. It also further justifies the importance of implementing a surveillance system to monitor muskox population health and trends for sound management and conservation actions. Finally, it provides information on participatory bottom-up methods and approaches useful to foster dialogue with community members and resource users in a co-management fashion.
III. Examining the impact of muskox wool industry on Native Alaskan villagers

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From the inception of the Co-op in 1969, the Musk Ox project has grown. The Co-operative’s headquarters is located in downtown Anchorage, Alaska. Starting off we went out and conducted workshops in several villages that produced 25 starting knitters. We now have 250 knitters in 25 different villages of Alaska, which has put nearly $150,000 back into the economy in a very poor areas of Alaska on a yearly basis. Over the course of the inception of the Co-operative, the members have earned an estimated $6,000,000 which they have used for their individual needs. This income has helped to defray the continued increasing costs of fuel, food and other things that need a cash income and have been introduced to the villages over the past 45 years. The Co-operative gives the members a way to earn money for the necessities that can not be found in the tundra and use the creative skills that are a major part of their culture.

IV. Qiviut, a treasure of the Arctic

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V. Outfitted muskox hunting in the Canadian Arctic: cultural, conservation and socio-economic importance

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VI. Muskox status and trends of muskox in Alaska

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Muskoxen (Ovibos moschatus) disappeared from Alaska and Yukon, Canada, by the late 1800’s and remaining populations in other areas of Canada and in Greenland were in decline. Concerns that the species may become extinct were raised, and the United States government provided money to obtain animals and restore muskoxen to Alaska. In 1931, 34 young muskoxen, captured in Greenland, were transported to Fairbanks, Alaska, where they remained in captivity for 5 years. In 1935-1936, 31 surviving animals and offspring born in captivity were moved to Nunivak Island in the Bering Sea off the western coast of Alaska. By the late 1960’s, this population had grown to > 700. For the next 14 years, muskoxen were translocated from Nunivak Island to 4 other areas in Alaska. The objective of this poster is to report changes in abundance and current distribution in these 5 populations of muskoxen in Alaska.

VII. Status and trend of Yukon North Slope muskoxen

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VIII. Population status and trends of muskoxen in the Northwest Territories

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The muskox population on Banks Island grew in the 1980s and early 1990s to nearly 70,000, but has declined since 2001 and declined more rapidly from about 37,000 in 2010 to just 14,000 in 2014. On northwest Victoria Island, estimates were 18,000-19,000 in 1998-2001 and 12,000-13,000 2005-2015. On the mainland, infrequent surveys and changing survey areas make it difficult to document trend. Based on regional reports, trend in the Inuvik region is roughly stable densities with some shifts in distribution, trend in the Sahtú region is increasing densities and expanding range, trend in the North Slave region is expanding range with uncertain trend in densities, and trend in the South Slave region is expanding range with uncertain trend in densities. In the Thelon Game Sanctuary, wilderness tourism operator Alex Hall noted peak muskox numbers in the early 1990s, then a large decline and very low abundance in recent years.

Understanding drivers of change in muskox abundance in the NWT is difficult in most areas due to limited information on densities and trend. On Banks Island, the nearly 2/3 decline 2010-2014 may be due in part to reduced calf productivity and survival, but a decline of this magnitude could only have occurred if adult mortality rates were exceptionally high. Harvest rates have been relatively low.

Key themes for muskoxen in the NWT:
1. In the NWT since 2000 a strong emphasis on monitoring declining barren-ground caribou herds has meant limited monitoring of other wildlife like muskoxen.
2. In some areas, muskoxen are viewed negatively, particularly where muskoxen have increased and caribou have declined.
3. In general, muskox harvest rates have been consistently low across the territory.
4. Grizzly bear predation on young calves may be a key limiting factor in some regions.
5. The rapid decline on Banks Island is a reminder that muskoxen have at times historically been very low in abundance in Canada.
6. Health issues – lungworms, Erysipelothrix, low genetic diversity, and a warming climate – are likely to be significant for muskoxen in northern Canada.
7. There is a need for regular surveys in the NWT to monitor distribution and abundance, and a better knowledge of muskox demographics, predator-prey relations, health issues and the effects of climate change.
IX. Population status and trends of muskoxen in Nunavut

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Muskoxen are distributed on the mainland and arctic islands of Nunavut. After their populations were decimated and their ranges contracted in the late 1800s and early 1900s, harvest bans were implemented and the Thelon Game Sanctuary established to promote their recovery. Their populations have increased and they now reoccupy much of their historic range. Declines and recovery on the arctic islands has been largely due to sporadic weather-related die-offs, although depredations by polar explorers likely took a toll on populations of some island groups. In western Nunavut and Victoria Island, parasitism and disease have reduced muskox populations and are currently the primary concern for maintaining healthy populations and sustainable harvests.

X. Population status and trends of muskoxen in Quebec

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XI. Population status and trends of muskoxen in West Greenland

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Muskoxen are currently distributed over much of Greenland, excepting southeast coast. They are indigenous in northwest, north and northeast Greenland. Present populations in the west are result of translocations. Despite low founding numbers and assumed poor genetic variation, all but one established successful self-sustaining populations. One additional population was founded by natural emigration. Today there are nine muskox populations in Greenland. Expanding into unexploited habitats most translocations resulted in rapidly growing populations owing to high calf production, cows birthing annually and birthing among 2-year old cows. Now muskox are both an important food resource and the foundation under economic opportunity, job creation and imported capital. However, as muskox density increased calf recruitment declined. Although population growth has been the norm for several decades, forage resources can be a limiting factor. Populations are dependent on the ‘islands’ of land along the coastal edge of the central Ice Cap. Poor calf production has recently been observed in two monitored populations. Since in Greenland large predators are absent (except in the northeast) and industrial development minimal or non-existent, fluctuations in Greenland muskox populations may be primarily affected by density-dependent factors, range quality quantity and availability, and harvest. Other important factors would include health, latitude, weather events, climate change, and for some, predation. Expected low genetic variation may affect their resilience to adverse conditions. Government regulated sport and commercial harvesting is permitted on seven of the nine populations. Harvest is poorly documented. Meanwhile commercial harvests can be substantial and entailing slaughter houses with veterinary inspection. Many populations support guided trophy hunting. Poaching is known to occur. The use (illegal) of skidoo/ATV/drones to hunt is on the rise. Meanwhile funding for monitoring is insufficient. Only two populations have been monitored somewhat regularly, the largest was last done in 2010. Harvest season extensions have eroded possible census windows. Most populations received a one-time effort or none at all. Latter includes the indigenous population in Northeast Greenland. Regular monitoring combined with relevant harvest documentation and regulation would assist wildlife managers in planning the future for sustainable use of muskoxen and all the subsequent economic rewards entailed.
II. Status and trends of muskoxen in Northeast Greenland

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Only limited knowledge on the status and trends of the muskox population(s) in Northeast Greenland is currently available. The only long-term monitoring of muskoxen in the region is the monitoring conducted at Zackenberg. Here the continuous monitoring has revealed interesting patterns: During the past two decades, the muskox population there has exhibited a gradual build up to a distinct peak in 2007, after which then population has declined. A concomitant change in muskox demographics has been observed. The major driver in the system is inter-annual variation in snow precipitation, which negatively affects the recruitment of both calves and yearlings. However, additional drivers, such as pathogens, may also be at play, particularly at high population densities. Whilst the detailed monitoring at Zackenberg has yielded important insight into the population dynamics and its likely drivers in Northeast Greenland, the lack of reliable information outside this locality precludes the general evaluation of the status and trends of muskoxen in this high arctic region.

III. Development and management of an introduced population of Muskoxen in Norway

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Muskoxen from East-Greenland were introduced in an alpine area in Mid-Norway at several occasions from 1932 to 1953. The population increased slowly the first decades, mainly due to deaths caused by train and killing of stray animals. Significant mortality caused by diseases were not detected until 2004. Since 2004, ORF and pneumonia have caused increased mortality, balancing recruitment and mortality so that the winter population varies between 200 and 300 animals on an annual basis.

According to the management plan, the population has a designated living area limited to 340 km\textsuperscript{2}. Shorter seasonal migrations outside this area are allowed. Stray animals are shot if they come to close to inhabited areas. Annual population development is surveyed by a team with representatives from the norwegian nature inspectorate (SNO) and local rangers.

Field surveillance includes counting of the whole population once in late winter, counting calfs/cows 3yr+ in June/July, registration of dead animals and handling of stray animals. Since 2004, standardized health monitoring of the population by the Norwegian Veterinary Institute has included field examination and tissue sampling from dead animals and registration and follow up/handling of sick animals.
Historically, muskoxen inhabited most of Russia. The latest discoveries indicate that the species was present in the country until 2'000-3'000 years ago, distributed on the Polar Urals, Taymyr Peninsula and further east. Reintroduction began in 1974, with 10 animals from Banks Island (Canada) followed by 40 animals from Nunivak Island (United States) in 1975. Breeding of muskoxen and their adaptation to the new conditions took place on Wrangel Island and in the Taymyr Peninsula. The next phase of resettlement began in 1996 when 238 free-ranging animals were translocated to become the founders of eight new populations along the coast. At the present time, the total number of animals exceeds 15'000 heads and muskoxen are now harvested for commercial purpose in some regions. In the Taymyr Peninsula, muskoxen populations have reached the western part of the peninsula. Additionally, populations from different origins have joined in the area between the Anabar and Lena Rivers. The next steps include further resettlements of muskoxen in the Verkhoyansk mountain system and introduction of the species on arctic islands. Altogether monitoring and demographic analysis indicate that muskoxen populations in Russia are still growing and expanding their range. This is supported by the development of a sustainable commercial harvest in the Taymyr Peninsula. Possible issues due to competition between muskox and caribou for food, in particular on island ecosystems, have yet to be investigated.
Session 3:

Declining Populations

XV.  Demography of a muskox decline in northwest Alaska, 2009-2013

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During 2009-2013, my colleagues and I conducted a radiotelemetry study to investigate muskox demography on the northern Seward Peninsula, Alaska. Our study population arose from muskox reintroductions to the Seward Peninsula in 1970 and 1981. Our research involved capturing female muskoxen ≥ 22 months-old in late March via helicopter darting; weighing and blood sampling them while sedated; radiocollaring most individuals ≥ 34 months-old; and locating radioed muskoxen throughout the year to determine their survival. To determine age-specific productivity, we assayed blood serum for PSPB from 22 month-old, 34 month-old, and older females. The Alaska Department of Fish and Game, in collaboration with federal land management agencies, conducted regular surveys to determine population size and late-winter age/sex composition of our study population. Prior to our research, muskoxen numbers on the northern Seward Peninsula exhibited a prolonged increasing trend of about 11%/year during 1992-2007. However, population estimates plateaued at around 910 muskoxen during 2007-2010, then declined abruptly to 290 by 2015, or 16%/year. Our research provides evidence of the demographic processes at play during the population decline. I will provide information on body mass/condition of females, productivity, calf survival, and adult female survival during this period of decline and speculate on possible causes.

XVI.  Disease complexity in a declining Alaskan Muskox (\textit{Ovibos moschatus}) population

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The muskox population inhabiting the eastern North Slope (ENS) of Alaska declined dramatically during 1999-2006, a period when populations in western Alaska (WA) were stable or increasing. To understand morbidity and mortality factors contributing to the decline, Alaska Department of Fish and Game initiated pathological investigations of carcasses in 2005 and continued investigations until 2008. In addition, archived sera from both ENS and WA muskoxen collected during 1984-1992, before the documented beginning of the ENS decline; sera collected during 2000, near the beginning of the decline; and contemporary sera (from live-capture-released adult females) collected during 2006, 2007, and 2008 were analyzed to determine if sero-prevalence of potential pathogens differed in the two areas or changed over time. The pathogens selected for investigation were those that were believed to be able to cause lameness or poor reproduction or to adversely impact general health. Furthermore, trace mineral levels, hemograms, and gastrointestinal parasites were evaluated in live adult females captured 2006-2008. Since 2008, available carcasses and enhanced sampling of live-capture release as well
has hunter harvested muskox has continued. Pathological investigations identified several comorbid conditions including predation, polyarthritis caused by or consistent with *Chlamyphila* spp. infection, hoof lesions, copper deficiency, contagious eczema, verminous pneumonia, hepatic lipodis suggestive of negative energy balance, and bacterial bronchopneumonia due to *Arcanobacterium pyogenes* and *Pasteurella trehalosi*. Pathogens suspected to be newly introduced in the ENS muskox population, based on serological detection, included bovine viral diarrhea, respiratory syncytial virus, *Chlamyphila* spp., *Brucella* spp., *Coxiella burnetti*, and *Leptospira* spp., while parainfluenza virus-3 antibody prevalence has increased in the WA population. While multiple disease syndromes were identified that contributed to mortality and, in combination, likely limited the ENS muskox population, further more holistic investigations of disease agents, trace minerals status, and nutritional factors in conjunction with intensive demographic and environmental analyses would provide a better understanding of factors that influence Alaskan muskox populations.

XVII. No Smoking Guns: Emerging diseases and general ill-health coincide with rapid declines of muskox populations on Banks and Victoria Islands, NWT and Nunavut, Canada

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Muskox populations have fluctuated substantially in ecological and evolutionary time. On Banks and Victoria Islands in the western Canadian Arctic archipelago, there is archeological evidence of large numbers of muskoxen prior to the 1900s; however, by the early 1900s muskoxen had disappeared from Banks Island and only a few remained on Victoria Island. Following this severe bottleneck, populations began to recover and recolonize the islands and by the mid 1970s numbers on both islands were rapidly increasing. Populations likely peaked sometime around/shortly after the turn of the 21st century, at which point these two islands were home to the majority of the global population of muskoxen. Health assessments at commercial harvests suggested animals were in good health, but infection intensities with abomasal nematodes on Banks Island were very high. By 2014, however, both islands had experienced substantial population declines (>50%). These declines coincided with the occurrence of several newly detected diseases and health issues. The lungworms Umingmakstrongylus pallikuukensis and Varestrongylus eleguneniensis were detected in muskoxen on Victoria Island for the first time in 2008, indicating a range expansion likely linked with changing ecological conditions. Between 2009-2011, unusual summer mortality events of muskoxen were reported on Victoria Island, and similar events were observed on Banks Island in 2012-13. Erysipelothrix rhusiopathiae, a bacterium most commonly known from pigs and poultry, previously unknown in the Arctic, was determined as the cause of acute death in the sampled animals. A single strain was isolated from all carcasses tested on both islands. Concomitantly, there were increased reports from both islands of ‘orf’ like lesions, a disease associated with parapox virus and often seen in immunosuppressed animals. Finally, ongoing health sampling of muskoxen from southeast Victoria Island is indicating poor body condition, unusually high occurrence of severe incisor breakage, hoof abnormalities, and possibly increased stress levels. These findings, together with local and traditional knowledge collected in the community of Ikaluktutiak (Cambridge Bay), Nunavut, and set in the context of a rapidly changing regional climate, indicate substantial complexity with respect to factors driving the population declines, and no ‘smoking guns’.
XVIII. Muskox health and disease in a rapidly changing outpost – Dovrefjell in Norway

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The muskoxen were introduced to Dovrefjell in Norway from North-East Greenland about 60 years ago. The population has increased slowly but steadily, and has now reached about 300 animals. The animals seem to be thriving, but while mortality in the first 50 years was caused by shooting of stray animals or accidents, several disease outbreaks with high mortality rates have been observed the last decade. In the summer of 2004 an outbreak of orf, in the late summer of 2006 a pneumonia, in the winter of 2011 another outbreak of orf and in the late summer of 2012 another pneumonia epizootic.

We do not know why these disease outbreaks occur, or if there at all is any common causal factor that predisposes the animals to disease. In this presentation we try to present what we think we know about the interaction between stress, health and environmental stressors for this muskox population. We will discuss different causal or predisposing factors as climate warming and variability, increased human encroachment or disturbance, increased contact with domestic species and other wildlife species, increased population density, changes in plant society and how these factor possibly may be related to disease outbreaks, and we will try to outline which approach we will choose to elucidate how muskoxen respond to environmental changes.
**Keynote Talk**

**XIX. Hindsight, insight, and foresight - The Yin, Yang, and Yung for advancing perspectives in muskox ecology and management**

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In Chinese philosophy, Yin and Yang are concepts used to “describe how seemingly opposite or contrary forces may actually be complementary, interconnected, and interdependent in the natural world and how they may give rise to each other as they interrelate to one another”. By extending this concept beyond dualism, we may consider a third ‘opposite’ and interdependent force. Correspondingly, I think the perspectives we apply to gaining knowledge and decision-making in wildlife management are triadic and interrelated. In this context the perspectives applied may be based on hindsight (looking to the past to understand the present), insight (looking deeply within and across disciplines and cultures), and/or foresight (anticipating and preparing for unknown future conditions). With respect to muskoxen, I suggest that advancements in our collective understanding of their ecology and improvements in our practice of managing wild populations will require a more deliberate integration and application of these three perspectives. I discuss examples from other northern ungulates to illustrate this thesis.
A sedentary nomad: Year-round movements of muskoxen in high arctic Greenland

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Detailed knowledge on movement behaviour of free-ranging muskoxen (Ovibos moschatus) is currently very scant. It is therefore crucial to quantify the variation in individual movement patterns and the variables driving it, not just to understand how muskoxen meet their basic requirements, but also to inform proper management. Here we present high-resolution location data from 14 adult female muskoxen roaming around Zackenberg in Northeast Greenland (74°28' N, 20°34' W), and report on their year-round temporal and spatial movement patterns. Generally, the movement patterns of this high arctic species reflected the extreme variability and seasonality of the nutrient-poor tundra high arctic tundra ecosystem in which they live. Hence, we found that throughout the year the fine-scale movement and activity patterns of muskoxen varied with time of day, ambient temperature, and land cover types. In areas with denser vegetation, muskox speed of movement was consistently lower than in areas with sparse vegetation. Also, speed of movement was increased with ambient temperature when the days were long, and decreased with temperature in periods with few or no hours of daylight. Diurnal peaks in movement and activity patterns were observed most of the year (including the period with complete darkness), except continuous day light, where individual movement and activity remained continuously high. Habitat suitability analyses indicate large intra-annual variation in the amount of available habitat. Hence, in summer muskoxen roam over most lowland areas, while in winter muskoxen mainly utilise areas along the coast line. Analyses of displacement patterns revealed a mixture of movement behaviours, and we conclude that muskoxen in high arctic Greenland adopt a largely nomadic movement behaviour, but do so within a rather small geographical area (app. 5000 km\textsuperscript{2}), and may thus be best described as sedentary nomads.
XXI. Genetic assessment of local adaptation in *Ovibos Moschatus*

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Muskoxen are an iconic Arctic species that have experienced multiple bottlenecks leaving them genetically impoverished with low genetic variability. As a result, muskox populations may be poorly equipped to deal with rapid changes in climate conditions, changing disease and pathogen dynamics, and increasing environmental stress. Essentially, muskoxen may not have the genetic variation necessary to adapt to rapid changes to the suite of selective pressure to which they are being exposed. We have taken a multipronged approach to better understand the levels and geographic distribution of genetic variation in muskox populations, pathogens to which they are exposed, and unique genetic characteristics that have allowed muskoxen to adapt to Arctic landscapes relative to their closest relatives.

1. Neutral genetic markers were used to determine the genetic variation and genetic structure of the muskox populations. Thus far, low genetic variation has been found in all loci tested and no genetic structure could be identified between populations.
2. To track the dispersal and abundance of two muskox parasites thought to be increasing in distribution and quantity, we established a species-specific quantitative PCR protocol to accurately identify two lungworm species thought to present an increasing threat to island muskox populations.
3. We are assembling a de novo muskox genome to both identify unique genetic attributes that have allowed muskoxen to exploit the harsh Arctic environment relative to their closest relatives and to also set the stage to perform population genomics to identify patterns of local adaptation in muskox populations in response to local and changing selective pressures. We intend to focus on genetic variation associated with immune response to identify potential variants associated with pathogen resistance that could provide insight into the capacity of muskox populations to adapt to the warming climate.

Overall, these data will inform work being performed by our collaborators on muskox health and physiology, and hopefully help direct management actions aimed at conserving this iconic species.

XXII. Climate trends and severe winter and summer weather coincident with nutritional stress and disease outbreaks recorded for muskoxen on Banks and Victoria Islands, Arctic Canada

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Climate change has had widespread impacts on a variety of biological systems and the extent of its influence will increase in the near future. The effect of climate change on parasite distribution has increasingly received attention particularly because parasites represent at least half of the species diversity of the world, and changes in their distribution have direct implications for public health, the food industry and conservation biology. The amplitude of temperature variations across environments is thought to be one of the principal abiotic factors driving the development of thermal tolerance in organisms. For instance, in areas where temperature variations are minimal, the breadth of an organism’s thermal tolerance is predicted to be narrower than in areas where extreme daily and seasonal temperature variations are more variable. While several studies have examined this hypothesis and shown correlations between thermal tolerance and geographic distribution for free living organisms, research on parasites is limited. In this presentation we summarize the theoretical concepts of local thermal adaptation applied to parasitic systems, using *M. marshalli*, an abomasal nematode of...
muskoxen, wild sheep, and caribou as study species. We discuss concepts related to local thermal adaptation (e.g. acclimation, thermal curve, thermal norm, phenotypic traits) and their implication for parasite dynamics in a climate change context. We then present preliminary results on local thermal adaptation of M. marshalli across different geographic regions. To do this we first have to define the morphology, morphometric, and development of M. marshalli eggs and larval stages when incubated at 21 °C. We then compare the morphology of eggs and larvae sourced from different latitudinal locations to determine and measure phenotypic differences among them. Finally, we determine the minimum, maximum and optimal temperature of development for M. marshalli by incubating it at a range of temperatures. These data form the basis for understanding local adaptation in this parasitic species and will allow us to refine current predictions regarding climate change impact on host-parasite interactions and geographic changes to the fundamental niche of parasites.

XXIII. Local thermal adaptation of parasites and its implications in a global climate change context


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Climate change has had widespread impacts on a variety of biological systems and the extent of its influence will increase in the near future. The effect of climate change on parasite distribution has increasingly received attention particularly because parasites represent at least half of the species diversity of the world, and changes in their distribution have direct implications for public health, the food industry and conservation biology. The amplitude of temperature variations across environments is thought to be one of the principal abiotic factors driving the development of thermal tolerance in organisms. For instance, in areas where temperature variations are minimal, the breadth of an organism’s thermal tolerance is predicted to be narrower than in areas where extreme daily and seasonal temperature variations are more variable. While several studies have examined this hypothesis and shown correlations between thermal tolerance and geographic distribution for free living organisms, research on parasites is limited. In this presentation we summarize the theoretical concepts of local thermal adaptation applied to parasitic systems, using M. marshalli, an abomasal nematode of muskoxen, wild sheep, and caribou as study species. We discuss concepts related to local thermal adaptation (e.g. acclimation, thermal curve, thermal norm, phenotypic traits) and their implication for parasite dynamics in a climate change context. We then present preliminary results on local thermal adaptation of M. marshalli across different geographic regions. To do this we first have to define the morphology, morphometric, and development of M. marshalli eggs and larval stages when incubated at 21 °C. We then compare the morphology of eggs and larvae sourced from different latitudinal locations to determine and measure phenotypic differences among them. Finally, we determine the minimum, maximum and optimal temperature of development for M. marshalli by incubating it at a range of temperatures. These data form the basis for understanding local adaptation in this parasitic species and will allow us to refine current predictions regarding climate change impact on host-parasite interactions and geographic changes to the fundamental niche of parasites.
XXIV. Range expansion of protostrongylid nematodes infecting muskoxen and caribou in the Canadian Arctic


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Unprecedented climate warming has affected various physical and biological processes in the Arctic. One probable consequence of this is the recent emergence of parasites in muskoxen on the Canadian arctic archipelago. The recent invasion and establishment of two protostrongylid nematodes, the muskox lungworm, *Umingmakstrongylus pallikuukensis* (UP), and the recently described muskox and caribou lungworm, *Varestrongylus eleguneniensis* (VE), on southern Victoria Island, has been attributed at least in part to climate warming and has led to a broader surveillance for these parasites across the Canadian Arctic. We examined over 1000 muskox and caribou fecal samples and 40 muskox lungs collected from various areas of the Canadian Arctic from 2013 to present for protostrongylids. Concurrently we have run a series of laboratory experiments to investigate life history characteristics of *V. eleguneniensis*. Results from fecal analyses demonstrate a substantial range expansion of UP to Victoria Island, with abundance following the latitudinal gradient: 455 ± 452 larvae per gram (lpg) at the southernmost (near Norman Wells, NT) and 7.14 ± 9.09 at the northernmost (near Ulukhaktok, NT) extent of its range. *Umingmakstrongylus pallikuukensis* has colonized most part of Victoria Island (VI) with an overall prevalence of 67.8% and mean lpg = 38.27 ± 215, whereas VE is limited to southcentral – southeast Victoria Island and is less abundant (prevalence 20%, mean lpg = 4.86 ± 25.25). We detected a third protostrongylid, the muscle worm *Parelaphostrongylus andersoni*, in Dolphin and Union Caribou that were collared on the mainland and subsequently migrated to northwest Victoria Island, suggesting the potential introduction of the parasite to Victoria Island. In preliminary lab experiments, VE has a higher threshold temperature for development from first to third stage larvae (9.1 versus 8.5 in UP) and requires more heating degree days (178.5 vs 167 in UP). This, combined with the lower fecundity of VE may explain the slower colonization of the island despite the fact that VE is a multi-host parasite. Finally, habitat modelling based on thermal requirements (degree days) of *U. pallikuukensis* suggests that the range expansion of the parasite follows the expansion of suitable habitat as a result of the climate warming. Our model further suggests that *U. pallikuukensis* could potentially colonize muskoxen of other arctic islands in the future.

XXV. Infections of muskoxen (*Ovibos moschatus*) from Nunavik by the giant liver fluke (*Fascioloides magna*)

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Following the introduction of 55 muskoxen in the mid nineteen-seventies, the free-ranging population of muskoxen of Nunavik is now estimated to be over 1400 animals. An experimental harvesting of this population occurred between 2006 and 2011, which provided an opportunity for a population health assessment. Hepatic lesions associated with the presence of the giant liver fluke (*Fascioloides magna*) were reported in the harvested muskoxen. To better characterize these parasitic infections, livers from 52 harvested muskoxen (15 females, 37 males; averaging 4-rys of age) were examined. Evidences of *F. magna* infections were found in 49 of the 52 livers (94%), with infection intensities reaching up to 40 adult trematodes. These parasites were usually associated with extensive lesions including hepatic necrosis, cholangiocellular hyperplasia, cavities with adult trematodes and eggs, and multifocal to confluent areas of hepatic inflammation and fibrosis. The estimated percentage of hepatic parenchyma affected by parasite-induced structural changes ranged from 0.1% to 86% (average = 35%), and was positively associated with the number of parasites present. The number of parasites was higher in females than males. Older animals seem to carry smaller numbers of parasites, but this trend was not
statistically significant. This is the first report of *F. magna* in muskoxen. The intensity of the parasitic loads and the percentages of lesioned liver were not associated with variations in different body condition indicators. This finding, as well as the steady growth of this population, does not suggest a significant impact of this parasite at the individual or population level.

XXVI. **Serological survey for exposure to *Erysipelothrix rhusiopathiae* in muskoxen across the Arctic**

F. Mavrot\(^1,8\), A. McIntyre\(^1\), K. Orsel\(^1\), L. Adams\(^3\), K. Beckmen\(^3\), M. Branigan\(^1\), S. Checkley\(^1\), C. Cuyler\(^5\), T. Davison\(^4\), M. Dumond\(^6\), B. Elkin\(^4\), W. Hutchins\(^7\), L.-M. Leclerc\(^6\), N. Navarro-Gonzalez\(^1\), A. Schneider\(^1\), M. Tomaselli\(^1\), S.J. Kutz\(^1\)

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*Erysipelothrix rhusiopathiae*, a bacterium frequently observed in pigs and poultry, was isolated from muskoxen (*Ovibos moschatus*) for the first time on Banks and Victoria Island (Canadian Arctic) during a series of acute mortality events between 2010 and 2012. In addition to being a conservation concern, the zoonotic potential of the pathogen raises the issue about food safety for community members handling and consuming muskoxen. In order to better understand the epidemiology of the bacterium and to document its historical and current occurrence, we initiated a serological survey using archived and newly collected samples from several muskox populations ranging from Greenland to Alaska.

We obtained serum from over 900 muskoxen sampled during monitoring or research projects between 1976 and 2015. Animals originated from Alaska (n>500), Canada (n>350) and Greenland (n=20). Blood was collected in blood tubes or filter-paper strips, and serum was obtained through centrifugation or elution and tested for anti-*E. rhusiopathiae* antibodies using an indirect Enzyme-linked Immunoassay (ELISA) developed in our lab.

Preliminary data (n=330) indicate exposure in various Alaskan herds from 1976 to present with a seroprevalence around 20%. In contrast, data from Banks Island in Canada (n=161), where we have a time series from 1991/92, 2001, 2008 and 2012 demonstrate low to no seropositivity in 1991/92, but increasing seropositivity from 2001 and all sampling time periods thereafter. High seroprevalence in fall 2012 aligns with a large mortality event observed in the previous summer in this region. Results across all sampled herds, regions and time periods as well as spatial and temporal patterns will be presented in detail. Further insights into the dynamics and impact of *E. rhusiopathiae* infection on muskox populations and potential public health significance will be discussed.
Thursday 10 Nov. 2016:

Session 5:

Tools for Muskox Monitoring and Management

XXVII. Community-based participatory methods: a tool to enhance muskox research and co-management

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In a rapidly changing Arctic, monitoring wildlife population health, including status and trends, is a matter of urgency. However, in such a vast and remote environment, undertaking long term and regular wildlife monitoring activities is a difficult endeavor. This often results in the inability to detect changes in the status of wildlife populations in the early stages, and consequently being incapable of acting promptly with suitable management actions. However, people who live year round in the Arctic and make extensive use of local resources have a vast and holistic knowledge about the natural environment and its wildlife. They can, therefore, significantly contribute to understand wildlife population health status and early detect its changes.

As part of a broader study focused on the development of a participatory muskox health surveillance system in the community of Ikaluktutiak, on Victoria island, Nunavut (Canada), we gathered Inuit and local knowledge to understand trends and status of local muskoxen. We implemented this research in three phases, which aimed at collecting qualitative and quantitative data on the local muskox population. Semi-structured individual interviews (phase 1), followed by group interviews (phase 2), were implemented with a total of 38 participants. To increase data accuracy and reliability, we implemented purposeful sampling, thematic saturation, and triangulation techniques. Finally, we presented the results back to participants to validate data analysis and interpretation (phase 3; n=31).

Novel epidemiological observations on muskoxen were elucidated through the interviews. These included information on historic and contemporary population trends, morbidity and mortality data, relative prevalence of endemic and emergent diseases, and spatiotemporal patterns of mortality outbreaks. In addition, this work provides a methodological framework for the collection of data on wildlife populations relevant for management and conservation decisions. The flexibility and ease of implementation render these methods portable to other settings and species. We envision that such a study, if applied in a community network fashion, could largely help understanding the status of muskox populations across their range and inform future research priorities. Finally, and equally importantly, these methods largely promote the inclusion of Indigenous people in the research process, contributing to its democratization and facilitating the co-management process.
XXVIII. Show me your rump hair and I will tell you what you ate

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The nutritional state of animals is tightly linked to the ambient environment, and for northern ungulates the state strongly influences vital population demographics, such as pregnancy rates. Using sequential data on nitrogen stable isotopes ($\delta^{15}$N) in muskox guard hairs from ten individuals in high arctic Northeast Greenland, we were able to reconstruct the dietary history of muskoxen over approximately 2.5 years with a high temporal resolution of app. 9 days. The dietary chronology included almost three full summer and winter periods. The diet showed strong intra- and inter-annual seasonality, and was significantly linked to changes in local environmental conditions (temperature and snow depth). Winter diets were markedly different between years, a pattern apparently linked to snow conditions. Snow-rich winters had markedly higher $\delta^{15}$N values than snow-poor winters, indicating muskoxen had limited access to forage, and relied more heavily on their body stores. Due to the close link between body stores and calf production in northern ungulates, the dietary winter signals could eventually serve as an indicator of calf production the following spring, and thereby constitutes a promising candidate for population-level monitoring of animals in remote, arctic areas.

XXIX. Muskox vulnerability to a warming climate: implications for monitoring

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Climate change is rapid in the Arctic and recent declines in muskox abundance reveal complex and inter-related causes which raise the question of how vulnerable are muskoxen to a warmer climate. Understanding vulnerability depends on increased monitoring to help arctic communities adapt to changes in muskox abundance. In the context of climate change, vulnerability is the outcome of exposure, sensitivity and adaptability. However, as shown here, a circum-arctic vulnerability assessment is impeded by the spatially and temporally fragmentary monitoring data. An additional incentive to collate and coordinate muskox monitoring data is the Arctic Council’s Circumpolar Biodiversity Monitoring Program which is setting up species monitoring networks. The recent MOXNET is meeting during this symposium which is an opportunity to update indicators and methods to collaboratively monitor muskoxen especially in face of a warming climate.

XXX. Androgens, feces and Muskox machismo

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The courtship and aggressive behaviour of muskoxen has been well described from a distance. This paper will begin with a brief account of events that can only be fully appreciated at close quarters. These include the uses and structure of the large preorbital glands and the capacious prepuce of the bull. Both of these are lined with hair and appear to contribute the semiochemical environment of the rutting display. The prepuce certainly contributes to the rutting odour and thus to the name given to muskoxen by early European explorers. The rigors of the arctic climate ensured that they mainly encountered muskoxen during the rut.
Rutting behaviour is mediated by testosterone but measuring this is difficult. Testosterone secretion is highly pulsatile so single blood samples are of limited value, and taking blood from a rutting male muskox may require a degree of restraint that could suppress testosterone secretion. Measuring androgens in feces offers a possible alternative.

Preliminary work showed that fecal samples from rutting muskox bulls contain a substance or substances that cross-react with an anti-testosterone antibody. Further, when testosterone was added to a slurry of muskox feces it could be recovered roughly in proportion to the amount added, and testosterone given intramuscularly to castrated muskoxen could be found in their serum almost immediately and in their feces about a day later.

To complicate matters some immunoreactive material was present in the feces of castrates. This was probably of adrenal origin because its concentration was greatly increased by administration of ACTH.

When androgen concentration was measured in the feces of intact bulls throughout the year a distinct annual cycle was evident in the dominant animals and there was initial evidence that losing a fight led to a sharp decline in testosterone concentration.

This was mainly the work of summer students. They were: Jay Thrush, Gordon Clark, Gillian Muir, Noreen Carrigan, Sylvia Checkley, Gordon Krebs, Susan Kutz, Wendy Sanford, Chris Schenk and Chris Walther. Others who played a vital role were: Janice Rowell, Jan Adamczewski, Susan Tedesco, Susan Cook, Ewald Lammerding, Norman Rawlings and Susanne Abrams.

XXXI. Developing tools for monitoring health: an innovative method of qiviut cortisol quantification in muskoxen (Ovibos moschatus) using liquid chromatography coupled to tandem mass spectrometry


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Introduction: Muskoxen (Ovibos moschatus) in some parts of the Canadian North are currently undergoing substantial population declines that may be linked to a variety of factors including environmental changes, infectious diseases, and other stressors. Our goal is to develop a set of integrative tools to monitor the health and resilience of muskoxen. Hair, fecal, and blood corticosteroids, haptoglobin, serum amyloid A, dental enamel hypoplasia, and other physiological indicators have been suggested as tools for wildlife health monitoring. Here we focus on evaluating qiviut cortisol across a several muskox populations and time periods.

Material and methods: A piece of hide from the rump was collected from harvested muskoxen by subsistence and sport hunters near several communities of the Canadian Arctic from 2012 to 2016. Qiviut samples (whole hairs cut from the hide) were washed, cold-extracted in methanol, and then quantified using liquid-chromatography coupled to tandem mass spectrometry (LC/MS). The effect of sex, season, and year on qiviut cortisol was assessed using mixed-effects models with location as a random effect.

Results: Qiviut was sampled in four decreasing populations and three stable populations from a total of 150 adult muskoxen. Qiviut cortisol concentrations followed a right-skewed distribution and levels ranged from 3.51 to 48.92 pg/mg with a median of 11.73 pg/mg. Sex, year, and season all had a significant effect on qiviut cortisol levels and there was a trend towards higher cortisol in the declining populations.

Discussion: Using LC/MS successfully to quantify cortisol in the hair of a wild mammal species has not previously been reported in the literature. Results showed that sex, season and year had an effect on qiviut cortisol levels, with also a possible effect of the sampling location. However, they should be taken with caution as we had very small sample sizes and a poor representation across groups.

Conclusion: We have developed a reliable method to quantify cortisol in qiviut and have demonstrated considerable variability within and between populations. Future research will assess the use of qiviut cortisol as a retro- and prospective indicator of health in individual and populations of muskoxen.
Exploring herpesvirus and parapoxvirus diversity in muskoxen from the Canadian arctic

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Muskoxen have recently been found dead on Banks and Victoria Island in the Canadian arctic. Some of these animals show clear evidence of infection; lesions on limbs, skin, and/or muzzle suggestive of disease. As part of an ongoing project designed to characterize the diversity of wildlife viruses, our research explores the role of parapoxvirus and herpesvirus in muskox health. Herpesviruses and parapoxviruses can cause painful lesions upon viral replication and shedding which may result in weight loss due to reduced suckling and feeding. These lesions may also reduce animal fitness and facilitate opportunistic infection from other pathogens. We screened opportunistically derived tissue biopsies from apparently healthy and diseased muskoxen for genetic evidence of herpesvirus and parapoxvirus infection. Using molecular approaches, we amplified and sequenced signature viral genes, and included these sequences in alignments and phylogenetic analyses. Our preliminary findings indicate that our muskox samples were infected with parapoxvirus and herpesvirus strains. These strains were closely related within our population compared to previous strains deposited in GenBank. Examining the relatedness of virus strains within our muskoxen population will improve our understanding of virus transmission within Banks and Victoria Islands. Phylogenetic relatedness to strains from cohabiting animals and introduced populations may help us discover potential wildlife viral reservoirs. Further, understanding how these viruses are related to muskoxen from other regions in the Canadian arctic can directly influence potential biosecurity measures to manage the spread of parapoxvirus infection. Additionally, we touch on the importance of screening wildlife animals for endemic and transmitted viruses, and challenges of virus detection in wildlife samples.
Gastrointestinal parasites and fitness in arctic ungulates: the example of *M. marshalli* in Dall’s sheep

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Gastrointestinal parasites (GIP) are important selective forces in wildlife populations and can influence the fitness of adults and their offspring. The abomasal nematode *Marshallagia marshalli* is a major component of the parasitic fauna infecting wild ungulates in the Arctic. This species has been documented in muskoxen across a broad geographic range in the Holarctic, is one of the most common parasite species in Dall’s sheep, and is also found in caribou. Despite the prominence of *M. marshalli* among Arctic parasitic fauna, little is know about the impact that these nematodes can have on wild ungulate populations. We investigated the relationship between infection intensity of *M. marshalli* and fitness in the host (e.g. body condition, fetus development) using a unique historical dataset for 105 Dall’s sheep (*Ovis dalli dalli*) collected from the Mackenzie Mountains, Northwest Territories, Canada in 1971 and 1972. This dataset included individual information on the number and species of gastrointestinal parasites, sex, age, reproductive status, and several body measurements including body weight, body length, horn length from each Dall’s sheep. In the case of pregnant females, information on the fetuses was also available including sex and detailed body measurements. The parasite diversity included 9 helminth species. The most common species was the nematode *Marshallagia marshalli* with a prevalence of 100% and the highest infection intensity (median=223.5, range=42-2457). The infection intensity of *M. marshalli* was negatively associated with adult ewe body condition (ANOVA, \(F_{3,37} = 6.965, p>0.001\)) and pregnancy status (t-test, \(t_{25.03} = 2.49, p\)-value = 0.0194). In pregnant sheep, infection intensity of *M. marshalli* was negatively associated with body condition (Permutation test, \(p=0.0295\)) but had no association with fetus condition (Permutation test, \(p=0.3819\)). Counter-intuitively for a sexually dimorphic species, male fetuses, which are expected to be more costly to produce, were associated with ewes that had a higher infection intensity of GIP and *M. marshalli* compared to those ewes with female fetuses (Permutation test, \(p=0.0328\)). Mechanisms that might explain these associations are further discussed. These results suggest that infection intensity of GIP and specifically *M. marshalli* could play an important role influencing Dall’s sheep population dynamics; similar impacts may be expected on other host species such as muskoxen.
II. Distribution and abundance of Muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) on Prince of Wales, Somerset, and Russell Islands, March 2016

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We flew a survey of Devon Island (Muskox Management Unit MX-04) in March 2016, and saw update the population estimate for caribou and muskoxen in the study area. The previous survey, in 2008, reported a minimum count of 17 Peary caribou and population estimate of 513 muskoxen (302-864, 95%CI). The 2016 survey found the highest reported abundance estimate for muskoxen (1,963 ±343 SE). A minimum count of 14 Peary caribou suggests that they continue to persist at low densities on the island. Muskoxen were abundant in the coastal lowlands where they have been found historically, at Baring bay, Croker Bay, Dundas Harbour, and the Truelove Lowlands. They were also abundant on the north coast of the Grinnell Peninsula, and particularly abundant on Philpots Island, where we observed 310 muskoxen. This population trend is mirrored on neighboring Bathurst Island to the west, surveyed in 2013, and southern Ellesmere Island to the north, surveyed in 2015. The population could support increased harvest.

III. Distribution and abundance of Muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) on Prince of Wales, Somerset, and Russell Islands, August 2016

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We flew a survey of Prince of Wales, Somerset, Russell, Pandora, and Prescott islands (Muskox Management Zone MX-06), by Turbine Otter and Twin Otter between August 5 and 23, 2016, to update the population estimate for Peary caribou and muskoxen in the study area. The previous survey, in 2004, did not detect any Peary caribou, although ground surveys the following year found two groups of four caribou on Somerset Island. The 2016 survey provided a population estimate of 3052± SE 440 muskoxen on the Peel Islands, with 1569 ± SE 267 on Prince of Wales, Pandora, Prescott, and Russell islands, and 1483 ± SE 349 muskoxen on Somerset Island. The results suggest there has been a decline from the population densities of muskoxen recorded in the mid-1990s, but no clear decline from the 2004 estimates of 2086 muskoxen on Prince of Wales/Russell islands (1582-2746, 95% CI) and 1910 muskoxen on Somerset Island (962-3792 95% CI; Jenkins et al. 2011). Only two Peary caribou were seen while the survey was underway, by hunters searching rugged terrain along the west coast of Somerset Island south of Aston Bay. The lack of observations of Peary caribou suggest that the population has not recovered from the precipitous decline in the late 1980s and early 1990s.
IV. Absence of association between stress and parasitism in muskoxen (Ovibos moschatus): a tolerance of these hosts to their parasites?

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Introduction: Muskoxen (Ovibos moschatus) can be infected by a wide range of pulmonary and gastrointestinal parasites. Individuals usually appear healthy, but heavy parasitic infections can have significant impacts on health and fitness. Parasites may, therefore, potentially act as stressors. Glucocorticoids (GCs) are produced in response to stress and are incorporated in feces in the form of metabolites. Chronically elevated levels of these hormones have been associated with detrimental effects such as reduced health, fitness, and survival in free-ranging wildlife. Several studies have already assessed the relationship between fecal GC metabolite (FGM) levels and parasitism but their results are inconsistent. However, very few wildlife studies have looked at this relationship, especially in large mammals. The goal of our study was to determine if there is an association between FGM levels and parasite infection intensity and diversity in muskoxen.

Material and methods: 53 fecal samples were collected opportunistically in April 2016 next to the community of Norman Wells, Sahtu Region, Northwest Territories. Larvae were extracted using the Beaker Baermann method, before being identified and quantified. The Wisconsin double centrifugation flotation technique was used to collect and subsequently count parasite eggs and oocysts. GC metabolites were extracted from the feces and quantified using an enzyme immunoassay.

Results: FGM levels were significantly higher in "dry" samples compared with "fresh" samples (p<0.001), with median fecal corticosterone and cortisol levels of 55.01 ng/g (range: 32.47-321.6) and 15.94 ng/g (range: 8.37-32.82) in "fresh" samples (n=33) versus 179.6 ng/g (range: 37.67-774.4) and 32.9 ng/g (range: 6.04-58.15) in "dry" samples. No significant association was found between FGM levels and parasite infection intensity and diversity.

Discussion: Our study had several limitations due to the opportunistic collection of samples. Significantly higher FGM levels in "dry" samples could result from a desiccation phenomenon that may have led to the concentration of FGMs. This result emphasizes the importance of collecting fresh fecal samples and freezing them as quickly as possible upon collection. The absence of relationship between stress levels in feces and parasitism supports the hypothesis that during chronic infections, hosts may develop a tolerance for their parasites even if they use their resources and negatively affect their fitness and health.

V. Investigating the dental health of muskox and caribou populations in the Canadian Arctic

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Dental health is crucial for wild ruminants as it is directly associated with food intake and is thus a determining factor for the survival of an individual. Recent anecdotal observations of dental abnormalities in muskoxen (Ovibos moschatus) on Victoria Island, Nunavut, in the Canadian Arctic led us to initiate a study on muskox dental health. In this pilot-study, we aimed to: 1) establish a standard examination protocol for monitoring of dental health, 2) examine and compare dental health of hunted muskoxen and caribou (Rangifer tarandus caribou), 3) compare our findings in muskoxen to previous data collected during the 90's.

Incisor breakage, molar wear pattern and enamel defects were identified as key features of dental health and were included in our examination protocol. We also recorded incisor length and jaw width, tooth cracks and misalignment as well
as soft tissue and bone abnormalities. We examined the dentition of nine mandibles and eight incisors bars for muskoxen and eleven mandibles for caribou collected during 2015-16 in Northern Canada. We compared our findings from these to a study done in the same area in 1989-91 by Ann Gunn.

The most common finding in both species was incisor breakage (present in 13/17 muskoxen and 5/11 caribou). In muskoxen, the number of broken incisors in each jaw was also higher than in caribou and breakage occurred more often on the central incisors whereas no pattern was found in caribou. Preliminary analyses also suggest an increased incidence of incisor breakage in muskoxen of Victoria Island in 2015-16 (100% animals had at least one broken incisor, n=8, compared to the same region in 1989-91 (30%, n=190), however, samples sizes from 2015-16 were small and age and sex were not controlled for. Causes of incisor breakage are still unclear but may be associated with vitamin or mineral deficiencies, genetic predisposition or mechanical wear due to changes in diet or in the environment. This pilot study will establish a basis for a continued long-term monitoring of jaw health in muskoxen of the Canadian Arctic.

VI. Systematic Health Monitoring of the Norwegian Muskox Population: 12 years of surveillance and interventions

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Systematic health monitoring of the Norwegian muskox population at Dovrefjell has been run at the Norwegian Veterinary Institute (NVI) since 2004, in close cooperation with the Norwegian Nature Inspectorate (SNO) as part of a health surveillance program managed by the Norwegian Environmental Agency. SNO has submitted to NVI samples from more than 350 dead or killed animals and several large disease outbreaks have occurred during the monitoring period. In summer 2004 a major outbreak of contagious ectyma (orf; parapoxvirus) appeared, primarily affecting calves. Echtyma outbreaks were also seen in the winters of 2012 and 2016. In summer 2006 and 2012 large outbreaks of pneumonia with a high mortality (25-30%) occurred. The primary cause of the 2012 outbreak was the sheep associated bacterium Mycoplasma ovipneumoniae and retrospective studies on archived lung tissues revealed that this bacterium was also involved in the 2006 epidemic. The two outbreaks seemed to occur after separate introductions of the virus, presumably from co-grazing sheep, and salt lick sites for sheep were suspected contact points for infection. Since 2012, an endemic situation seems to have been established for M. ovipneumoniae in the muskox population, leading to annual losses of calves. In summer 2014 a large outbreak of ocular inflammation was observed, affecting the great majority of animals in several controlled flocks. The outbreak had a benign course and the bacterium Moraxella ovis, a common cause of eye inflammation of sheep, was isolated. The presence of several viruses has also been reported between 2004-2016 with variable prevalences. These include: muskox gammaherpesvirus, respiratory syncytial virus, ruminant pestivirus, coronavirus and parainfluenza type 3. Lung worms (Dictyocaulus sp., Muellerius sp.) and various gastro-intestinal parasites are found, but heavy infections are not common. 42 animals sampled between 2004-2010 have been tested for prion disease and found to be negative. The health status of the Norwegian muskox population in general seems to be satisfactory, but there are challenges associated with sharing pasture with other animal species (especially domestic sheep), with climate change and several anthropogenic drivers.
The Canadian Wildlife Health Cooperative role in wildlife health monitoring: 26 years of insight into the health of Muskoxen

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The Canadian Wildlife Health Cooperative (CWHC), Alberta region, queried the CWHC national wildlife disease database to compile a muskox (Ovibos moschatus) specific diagnostic dataset. The search resulted in a total of 237 different diagnostic cases spanning over 26 years (1990-2016) in 229 known different incident locations across seven provinces and territories. Caseload was differentiated between wild submissions (n=209) and captive muskoxen primarily housed in outdoor pens under research conditions (n=28). Cause of death in wild muskoxen was sorted into four categories; those being emaciation, traumatic injury, infectious/inflammatory processes and other/unknown classification. The most consistent cause of death in wild muskoxen was infectious/inflammatory processes (57%) followed by trauma (22%), other/unknown (18%), and emaciation (4%). Mortality in captive muskoxen was similarly caused primarily by infectious/inflammatory disease (61%) followed by other/unknown (29%), nutritional deficiencies (7%), and toxicity (4%). Muskoxen in captive and wild environments are still poorly understood. This is often attributed to their habitat being sparsely populated by humans and relatively inaccessible to those who study the species in their native ranges. These circumstances, like many other wildlife health issues of similar nature, represent exemplary models for which the CWHC plays a critical role. We provide a cross-Canada infrastructure of expertise to fulfill the needs of national based wildlife disease surveillance.

Lungworms of Victoria Island Muskox: Climate change and disease dynamics

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Two parasitic lungworms, \textit{Umingmakstrongylus pallikuukensis} and \textit{Varestrongylus eleguneniensis}, have recently established year-round in muskoxen populations on Victoria Island in the Canadian Arctic. What effect these parasites are having at the host population level is unknown, and generating testable hypotheses that consider the complex interactions between host ecology, parasite life-history, and environmental variables is difficult. Given recent population declines on the island, and troubling local accounts of muskox health, the need to understand how these parasites influence muskox population health has taken on a greater urgency. A wealth of experimental data are becoming available on the life-cycle and life-history parameters of both \textit{U. pallikuukensis} and \textit{V. eleguneniensis}, and important field observations of muskox ecology, population structure, and movement patterns continue to accumulate. I will construct mechanistic models with the aim of synthesizing these data to provide a dynamic picture of the interactions between host populations, parasite populations, and climatic variables through time. Ongoing work will focus on analyzing the sensitivity of model predictions to different biological parameters in order to identify critical data gaps and inform empirical research programs, which in turn will be used to refine model structure. Understanding the dynamic nature of muskox-lungworm interactions will help us to evaluate and address the risks facing Victoria Island muskox now and under future climate scenarios.
IX. Testing the Caprine 50K SNP chip for its utility in the management and monitoring of Musk Ox

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Muskox, like many wildlife species, do not have reference genomes sequenced and publically available. To date, most genetic research in Muskox have used microsatellites which are quickly being replaced by SNPs (Single Nucleotide Polymorphisms) in the livestock genetics community. We genotyped 53 samples from two Muskox farms in Alaska on the commercially available caprine (goat) 50K SNP chip to test its utility for management in Muskox. The SNPs located on the chip are known to be polymorphic across the goat species. Before quality control was applied, there were 27,111 SNPs with two or more alleles out of the 50,454 markers that were genotyped in two or more individuals. The average sample call rate was 0.79 (range 0.52 – 0.88) before filtering out poorly called markers. After filtering SNPs for a call rate less than 0.8 and a minor allele frequency greater than 0.01, 803 polymorphic SNPs remained. Forty individuals had a genotyping call rate greater than 80%. Genomic inbreeding coefficients relative to the tested population were calculated on the filtered dataset, with an average FIS of 0.110 (range -0.727 – 0.836). This confirms previous genetics research showing high levels of homozygosity seen in the Muskox.

These results indicate there are some polymorphic SNPs that could be used for parentage testing or population management on a low density SNP chip. However given the relatively small sample set and no knowledge of where these SNPs are located in genes or on the Muskox genome, these results are not as beneficial as they could be. The sequencing and creation of a reference genome will make any future Muskox genetic studies far more useful than is currently possible.

X. Addressing caribou-muskox interaction concerns in the mainland Western Arctic

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