2010 Muskox Health Survey: Victoria Island

A report prepared for Kitikmeot Food Ltd

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EXECUTIVE SUMMARY

Muskoxen are important animals in northern Canada, both as a key wildlife species but also for cultural and economic importance as animals hunted for meat, leather, qiviut and sport. Therefore, careful health monitoring of these animals is important for sustainable populations, and also for the health and safety of the people who use the products. Currently only a limited amount of data are available on the health of the muskoxen on Victoria Island, Nunavut.

To determine the general health status of these muskoxen, we evaluated 216 free-ranging hunter killed muskoxen (*Ovibos moschatus*) for selected veterinary and zoonotic pathogens . They were harvested between December 2009 to March 2010 from three regions of Victoria Island. Researchers and hunters collected samples of feces, blood, skin, lymph nodes, and other organs. Pathogen selection for testing was based on previous reports of infection in muskoxen and pathogens known to cause problems in the production of domestic livestock. As no test methods have been validated for muskoxen, selection of test method was based on using the best available option (gold standard) for ruminants and the method most likely to detect exposure to the pathogen.

General post-mortem examination of 67 muskoxen revealed only minor pathological changes in 16 animals. The most significant finding was the difference in distribution of lungworm *Umingmakstrongylus pallikuukensis* cysts, present in all lungs examined in animals from the southwest of the island (n=26), but not detected in commercial harvested animals near Ikaluktutiak that (n=62). This lung parasite is well established in muskoxen on the mainland. We also found the newly described *Varestrongylus* spp. lungworm larvae in 3.8% (6/151) of the commercially harvested muskoxen. This is the first time it has been detected on Victoria island.

Neospora caninum, a protozoan parasite that causes abortion and serious illness in livestock was found in serum samples from 3/49 (6.1%) commercially harvested muskoxen with titres of 1:25, 1:100, and 1:3200. This is a marked contrast to previous findings of only one positive (titre 1:40) of 224 muskoxen from Alaska in 2005. The significance of this finding is currently unknown. The detection of antibodies to *Toxoplasma gondii* in 2.0% (1/49) serum samples is comparable to previous reports of animals around Ikaluktutiak .

Enteric parasites detected in fecal samples included *Marshallagia spp., Nematodirus spp.,* trichostrongylids, *Monezia spp.* and *Eimeria spp*. (n= 182) similar to other reports of parasites in muskoxen. Samples were all negative for *Mycobacterium avium* subspecies *paratuberculosis* (n=67), *Chlamydophila* spp. (n=49), *Yersinia* spp. (n=67), *Giardia* spp. (n=202), *Crytposporidium* spp. (n=202), and *Besnoitia spp.* (n=199).

Overall, a low prevalence of pathogens significant to animals and humans was found in these animals and no gross signs of major clinical diseases were evident. A key limitation was the lack of sera available from animals harvested in the southwest portion of the island. Monitoring the health of these muskoxen

is significant for surveillance of changing pathogen distribution, which has previously been demonstrated based on differences in *U. pallikuukensis* and *T. gondii* in muskoxen on the mainland compared to Victoria Island. While this provides key baseline data, ongoing sampling and testing is required to better understand the implications for human health, sustainable harvesting, and disease ecology in the Arctic in the muskoxen of Victoria Island.

INTRODUCTION

Muskoxen are hunted as part of community hunts, in commercial harvests, and for sport. They are a source of meat for local people, but also provide leather and qiviut. For an ongoing harvest, a healthy sustainable wildlife population is necessary. Infectious diseases are known to alter the survival and reproductive success in both domestic and wild animals and this can have significant consequences for population size and cycles. Additionally, zoonotic diseases, those that can be transmitted from animals to people, may influence the safety of harvested animals for human consumption. Therefore, understanding what potential risks are present is important.

Very little is known about the viruses, bacteria, and parasites (collectively known as 'pathogens'), capable of causing disease in muskoxen on Victoria Island. The recent documentation of the muskox lungworm, *Umingmakstrongylus pallikuukensis,* in muskoxen on the southwest region of the island raised concerns about the spread of this parasite and other pathogens of muskoxen. The transmission patterns and impacts of many pathogens are also highly sensitive to environmental conditions, and this becomes a particular concern in the Arctic where significant and rapid climate change is already altering ecosystem dynamics. A better understanding of the influence of pathogens and periodic monitoring of their prevalence will provide key information for the management of the herd and the design of a business plan for commercial ventures using this muskoxen population.

The objective of this study was to establish the baseline prevalence of pathogens of concern in muskoxen, those of potential concern for human health, and pathogens known to cause production losses in domestic ruminants. This data will provide the foundation for ongoing monitoring to ensure a sustainable muskoxen population on Victoria Island and to indirectly monitor ecological changes in the area.

MATERIALS AND METHODS

Muskoxen from three distinct regions on Victoria Island, Nunavut were sampled in 2009-2010. This included the commercial hunt at Ikaluktutiak and two community harvests. Samples from the commercial hunt (A) were collected at the Kitikmeot Foods abattoir facilities in Ikaluktutiak from February 23, 2010 to March 11, 2010. Animals were harvested by local hunters near Ikaluktutiak (Back Point, Lady Pelly). Hunters collected whole blood in the field before transport of carcasses to the abattoir. Intensive sample collection was carried out by researchers at the abattoir for the first 7 days of the harvest. Samples collected included metatarsal skin, lymph nodes (submandibular, retropharyngeal, mesenteric), tonsils, tongue, lungs, heart, diaphragm, abomasum, ileum, and feces. Abattoir staff continued to collect samples of skin and feces from each animal for the remainder of the harvest.

Samples from the community hunts were collected by local hunters from the southwest corner of Victoria Island from December 13-20, 2010 (B) and April 13-14, 2010 (C) and included lower jaw, spleen, skin, and feces (for B) and tongue, spleen, skin, feces, lymph node, and lungs (for C).

All samples were initially stored in an outdoor shed in conditions between -10°C and -45°C before shipping as frozen specimens to the University of Calgary, Calgary, Alberta, Canada. Samples were then stored at -20°C until testing, with the exception of serum which was kept at -80°C.

Samples were processed in Calgary or sent to external laboratories (details below). Pathogens were selected based on previous studies of muskoxen disease, those with zoonotic potential, and pathogens known to be detrimental to production in domestic ruminants (see discussion for further details about pathogens). Test method selection was based on the gold standard method for pathogen detection in domestic ruminants, or the best available option.

Specific Test Methods

Viruses

Serum samples were sent to the Norwegian School of Veterinary Science, Tromsø, Norway for alphaherpes testing using a commercial BoHV-1 blocking ELISA (LSI, Lissieu, France) and pestivirus testing using SERELISA^{TM} BVD p80 Antibody Mono blocking (Synbiotics, Europe SAS France). Both tests detect antibodies to the viruses in the blood which indicates that the animal has been previously exposed to the virus, but the animal does not necessarily currently have an infection or the disease.

Bacteria

We tested samples for three different bacteria. Serum samples for the detection antibodies to *Chlamydophila* spp. (direct complement fixation) were sent to Texas Veterinary Medical Diagnostic Laboratory, College Station, Texas. Mesenteric lymph nodes and ileal tissue were tested for evidence of *Mycobacterium avium* subspecies *paratuberculosis* by polymerase chain reaction (PCR) and culture, respectively (Prairie Diagnostic Services, Saskatoon, Saskatchewan). These techniques detect the actual presence of the bacteria; PCR detects the DNA of the bacteria, while culture is used to grow the bacteria if it is present. Culture was also used for detection of *Yersinia spp*. using ileal scrapings, cold enrichment and cefsulodin-Irgasan-novobiocin agar plates (Bow Valley Research Inc., Calgary, Alberta).

Parasites

Lung

A modified beaker Baermann technique was used for recovery of first stage parasitic larvae (Forrester and Lankester, 1997) from feces. Between 2-5g of feces were placed in a cheesecloth envelope and placed in water for 16-24 hours at room temperature. After removal of the envelope and supernatant, the sediment was concentrated by centrifugation at 1500 rpm for 10 minutes and supernatant discarded for a total of 2-3 mL in total. Three 50 mL aliquots were examined microscopically for larvae, and if no larvae were detected in the aliquots, the entire sediment was examined. For intact lung lobes, the parenchyma was examined grossly and all airways dissected completely to locate lungworm cysts.

Airways were also examined for adult worms. Cysts were enumerated, location noted (lung lobe), and measured for size.

Gastrointestinal tract

Fecal samples were examined using a quantitative fecal flotation –Wisconsin double centrifuge technique for detection of enteric parasites (Egwang and Slocombe, 1982). Between 2-4g of feces from each sample was analyzed depending on the total amount of feces available.

For detection of *Giardia* spp. and *Cryptosporidum* spp., an immunofluorescence assay (IFA) method used by Kutz et al. (2008) was modified as follows: 1-2g of feces were suspended in 8 mL of PBS; for each sample a 20 µl aliquot from each 1 mL of re-suspended pellet was placed on Fluorescent Antibody microscope slide (Fisherbrand, Ottawa, Ontario). Slides were stained using AquaGlo G/C Direct Comprehensive Kit (Waterborne Inc., New Orleans, Louisiana). Enumeration of *Giarda* cysts and *Cryptosporidium* oocysts was done based on direct visualization using fluorescence microscopy.

Tissue

A modified agglutination test (MAT) was used for detection of antibodies to *Toxoplasma gondii* (Dubey, 1997) (USDA, Beltsville, Maryland), using dilutions of 1:25, 1:50, 1:100, and 1:200, with a titre of 1:25 or higher considered an indication of *T. gondii* exposure (Kutz, Elkin, Gunn, Dubey, 2000). Detection of antibodies to *Neospora caninum* used the *Neospora* agglutination test (NAT) (Romand, Thulliez, Dubey, 1997) (USDA, Beltsville, Maryland) at a titre of 1:25 for initial testing due to limited amounts of antigen available, followed by confirmatory testing at 8 dilutions up to 1:3200. A presumptive cut-off value of less than 1:25 was considered positive.

Metatarsal skin sections (1 cm x 1 cm) were fixed in 10% buffered formalin for conventional histology and identification of *Besnoitia* cysts; paraffin-embedded sections were stained with hematoxylin and eosin (H&E) and examined microscopically for presence of cysts (Faculty of Veterinary Medicine, University of Calgary).

Statistical analysis

Results were summarized in a spreadsheet and proportions calculated using MIcrosoft®Office Excel®2007 (Microsoft Corporation, Albuquerque , USA). Mean larvae intensity per gram feces was calculated as the mean number of larvae of a particular parasite species per infected host (Margolis, Esch, Holmes, Kuris, Schad, 1982). Mean cyst/egg/oocyst intensity per gram feces was calculated using the same formula.

RESULTS

Samples were collected from a total of 216 muskoxen. For samples collected from the commercial harvest A, 67 (41%) were collected by researchers.

Table 1. Distribution of samples of collected by sex and age.

Collection	Sample Size	Male # (%)	Female # (%)	Unrecorded Sex, # (%)	Calf # (%)	Yearling # (%)	Adult # (%)	Unrecorded Age, # (%)
A	162	58 (36)	104 (64)	0	13 (8)	17 (11)	132(81)	0
B	27	8 (30)	13 (48)	6 (22)	0	13 (48)	8 (30)	6 (22)
C	27	5 (19)	21 (78)	1 (4)	0	5 (19)	22 (82)	0

Of 67 animals examined by researchers at the commercial harvest, all were found to be free of debilitating disease. Minor pathological abnormalities were found in 15 animals. Five animals had taenia (tapeworm) cysts on the liver or diaphragm. Three animals had one to four necrotic areas in the liver ranging from approximately 0.4 to 1 cm in diameter, one animal had necrotic lesions in the mesenteric lymph node approximately 0.3 cm diameter, and one animal had a similar necrotic lesion in the mesenteric lymph node and a taenia cyst on the liver. One animal had these necrotic lesions in both the liver and mesenteric lymph node. One animal had inflammation of the tongue (wooden tongue) as well as caseous (pus-filled) abscesses on the diagphragm, and necrotic lesions in the liver (like those described above). One other animal had a jaw infection (lump jaw). There was one animal with a wound tract along the ventral midline and one animal with evidence of *Hypoderma spp*. infestation of the skin (warbles).

A total of twelve tests were used to detect 18 different pathogens. For some animals a complete set of samples was not successfully collected (e.g. blood) and thus certain tests could not be done. Blood was difficult to collect and transport in the field due to freezing of samples and breaking of tubes. For samples of feces with small volumes, priority was placed on testing for *Giardia spp*., *Cryptosporidium spp*., and lungworms.

Table 2. Summary of results from viral pathogen testing.

Pathogen	**Test Result**		
	A	**B**	**C**
	Proportion Positive		
Alphaherpesvirus	0/44	N/A	N/A
Pestivirus	1/44	N/A	N/A

Table 3. Summary of results from bacterial pathogen testing.

Pathogen	**Test Result**		
	A	**B**	**C**

	Proportion Positive		
Chlamydophila abortus	0/48	N/A	N/A
Mycobacterium avium subspecies *paratuberculosis*	0/67	N/A	N/A
Yersinia pseudotuberculosis	0/67	N/A	N/A

Table 4. Summary of results from lung parasite testing. PP = proportion positive, Lpg = mean larvae per gram feces, CI = mean cyst intensity.

Pathogen	**Test Result**					
	A		**B**		**C**	
Baermann Test	**PP**	**Lpg**	**PP**	**Lpg**	**PP**	**Lpg**
Umingmakstrongylus pallikuukensis	0/159	N/A	19/19	82.3	25/25	75.3
Varestrongylus spp.	6/159	2.5	N/A*	N/A	N/A*	N/A
Gross Examination	**PP**		**PP**		**PP**	**CI**
Dictyocaulus spp.	0/62		N/A		1/26	1
Umingmakstrongylus pallikuukensis	0/62		N/A		26/26	23.5
Varestrongylus spp.	0/62		N/A		0/26	N/A

*may be present but larvae morphologically similar to *U. pallikuukensis*

Table 5. Summary of results from gastrointestinal parasite pathogen testing. Prev = prevalence (%), I = mean egg/oocyst intensity per gram feces. Sample size for helminths (parasitic worms): n= (A) 157, (B) 19, (C) 7.

Pathogen	**Test Result**					
	A		**B**		**C**	
Protozoan	**Proportion Positive**					
Cryptosporidium spp.	0/158		0/19		0/25	
Giardia spp.	0/158		0/19		0/25	
Helminths	**Prev**	**I**	**Prev**	**I**	**Prev**	**I**

Nematodirus spp.	52.2	1.7	63.2	1.6	14.3	1.5
Eimeria spp.	82.8	23.5	100	19.0	85.7	49.0
Marshallagia spp.	76.4	2.5	26.2	0.3	42.9	0.9
Teladorsagia/Ostertagia	3.2	0.25	0	N/A	0	N/A
Moniezia spp,	3.2	30.3	5.2	1.4	0	N/A

Table 6. Summary of results from tissue parasite testing.

Pathogen	**Test Result**		
	A	**B**	**C**
Tissue	**Proportion Positive**		
Besnoitia spp.	0/153	0/23	0/23
Toxoplasma gondii	1/49 (titre 1:200)	N/A	N/A
Neospora caninum	3/ 49 (titre 1:25, 1:100, 1:3200)	N/A	N/A

DISCUSSION

This was the first effort for a broad scale survey of muskoxen health on Victoria Island. Results indicate there are geographical differences in the distribution of pathogens and that overall, there is evidence of a low prevalence of exposure or infection with most pathogens. Our findings are relatively comparable to previous research of muskoxen, except for the gross post-mortem findings. The number of necrotic lesions found in these animals was higher than noted in post-mortem findings from this commercial harvest in the mid to late 1990s (Kutz, personal communication).

One of the most interesting findings was the geographical difference in distribution of animals infected with *U. pallikuukensis.* This lungworm is specific to muskoxen and causes exercise intolerance and difficulties breathing due to space occupying cysts in the lungs that contain adult worms and larvae (Kutz, Hoberg, Polley, 2001). Population level impacts of this parasite may also be possible and may be a factor in some decreasing muskoxen populations (Kutz, Hoberg, Nagy, Polley, Elkin, 2004). While *U. pallikuukensis* is common in muskoxen on the mainland west of the Coppermine River (Kutz, Hoberg, Nagy, Polley, Elkin, 2004), our study corroborates previous findings of the parasite in animals on the southwest portion of Victoria Island (Kutz et al., unpublished).

Our results suggest that the parasite is well established in this geographical region, while the animals near Ikaluktutiak are currently free from infection. Previous studies of muskoxen on the island have not shown evidence of the parasite before 2009 (Gunn, Leighton, Wobeser, 1991; Kutz et al., unpublished). When dissected, *U. pallikuukensis* cysts in lungs from animals on Victoria Island were not calcified and this suggests more recent infections. This is in contrast to the high proportion of calcified cysts in muskoxen from the mainland. We do not know how long the parasite has been present on the southwest part of Victoria Island.

The exact cause of the range expansion of the parasite onto Victoria Island is unclear. Island muskoxen have a small home range with only seasonal migrations, thought to be influenced by forage availability, snow conditions, animal density, and predation (Gunn and Fournier, 2000). This movement of animals may contribute to the spread of the parasite, however, the migratory activity of other animals and a changing climate need to be considered as well (Brook, Kutz, Veitch, Popko, Elkin, Guthrie, 2009; Kutz, Polley, Elkin, Lair, Jenkins, Veitch, Ducrocq, 2009). If this parasite is spreading, the implications for the spread of other pathogens must be carefully monitored and studied.

A new finding was the detection of a newly described lungworm larvae *Varestrongylus* spp. in 3.8% of fecal samples from the commercial harvest (Verocai, Kutz, Simard and Hoberg, in prep.). This parasite also infects caribou and moose and this is the first documentation on an Arctic Island (Kutz et al., 2007). The parasite may also be present in muskoxen from the southwest portion of the island, however, the presence of morphologically similar *U. pallikuukensis* larvae in fecal samples make it difficult to identify *Varestrongylus spp*. without additional molecular verification. The implication of this parasite on the health of muskoxen is currently unknown. This parasite does not infect humans.

Our study shows comparable seroprevalence (exposure to the pathogen at some point in their life causing the formation of antibodies) of *Toxoplasma gondii* as previous reports for animals near Ikaluktutiak (Kutz, Elkin, Gunn, Dubey, 2000). This protozoan parasite has been documented as a cause of abortion in a captive muskox (Crawford, Dunker, Dubey, 2000). An outbreak of toxoplasmosis in pregnant women in northern Quebec was previously recorded, and risk factors included skinning of animals and frequent consumption of caribou meat (McDonald, Gyorkos, Alberton, MacLean, Richer, Juranek, 1990), however, recent evidence suggests a different route of exposure. While seroprevalence of animals in this study was low, this parasite is a serious concern as it can cause abortion in humans, and therefore ongoing monitoring is important for human safety.

Neospora caninum was previously reported in one muskox out of 224 in Alaska compared with the 6.1% in this study (Dubey and Thulliez*, 2005). The high titre of one animal, 1:3,200, indicates this animal had a strong immune reaction to *Neospora* or an unidentified related parasite. *Neospora* is known to cause spontaneous abortion in livestock, however, the implications for reproduction in muskoxen are unknown. In addition, the transmission cycle of this parasite in the Arctic ecosystem remains unknown. There currently is no evidence of transmission of *Neospora* to humans.

Pestiviruses causes a disease in cattle called Bovine Viral Diarrhea (BVD) that is a serious concern in cattle production. Signs in ruminants include ulcers of the mouth and between the hooves, as well as diarrhea. A BVD-like virus specific to reindeer has been identified previously (Avalos-Ramirez, Orlich, Thiel, Becher, 2001), as well as positive titres detected for a BVD-like virus in caribou (Elazhary, Frechette, Silim, Roy, 1981). This is the first reported serological evidence of BVD-like virus in muskoxen. This animal had a strong positive result. Its role in wildlife (disease and transmission) is unclear and further study is required to understand the full implications of this finding. The test method used has been validated for cattle and not for muskoxen and therefore it is unclear if the antibodies detected are to the pestivirus that infects cattle, or to a different pestivirus such as the reindeer specific pestivirus. This virus does not infect humans.

The lungworm *Dictyocaulus* spp*.* is common in young muskoxen and caribou. This parasite does not infect humans. The low prevalence in this study may reflect the season and/or the low proportion of yearlings, which are more vulnerable to infection (Gunn, Shank, McLean, 1991) . Detection of this parasite in frozen fecal samples is not possible as the larvae cannot survive the freezing process.

Gastrointestinal parasites are very commonly found in wildlife and include roundworms, tapeworms and coccidia. They can cause poor hair coats and weight loss in muskoxen but do not affect people. The type of gastrointestinal parasites observed was typical of previous reports from muskoxen on Banks Island and the mainland. It is interesting to note that the prevalence of trichostrongylids (presumably *Teladorsagia boreoarcticus* and *Marshallagia marshalli*) based on fecal floatation was lower than previously recorded, and likely only reflects low levels of shedding in the winter compared to the summer, rather than low levels of infection (Samuel and Gray, 1974; Hughes, Albon, Irvine, Woodin, 2008).

A number of pathogens previously detected in other muskoxen were not detected in our samples. Kutz et al. (2008) documented *Giardia* assemblage A, a zoonotic genotype, in muskoxen from Banks Island, Northwest Territories however no *Giardia spp*. were detected in our samples. To date, *Cryptosporidium* has not been documented in muskoxen. Both of these protozoan parasites can cause diarrhea in animals and humans and some animals may be carriers of the parasite without signs of disease. Humans can be infected with some strains of these parasites through contact with animal waste or contaminated water. As potential contributors to environmental contamination, regular monitoring of muskoxen for these parasites is particularly important for human health and to inform those who use the land.

Chlamydophila spp**.** has previously been reported in muskoxen in Alaska but not in Canada (K Beckmen, pers. comm). We used serological methods in this study, however, with the collection of additional samples in the future (i.e. vaginal swabs) we will be able to use test methods that are more sensitive. *Chlamydophila* spp. is a bacteria that causes abortion in animals and some species can be transmitted to humans but only when in close contact with infected animals. It causes flu-like symptoms in humans.

Mycobacterium avium subsp*. paratuberculosis* has been documented once in muskoxen in a captive setting (Garde, Kutz, Schwantje, Veitch, Jenkins, Elkin, 2005) and is a cause of serious production loss in domestic cattle. It causes significant weight loss and diarrhea in ruminants and the human health implications of this pathogen are unclear at this time. It is well documented in cattle, sheep and goats but the occurrence and impact is not known in muskoxen.

Sudden death caused by *Yersinia pseudotuberculosis* has been reported periodically in muskoxen on nearby Banks Island starting in 1986 (Blake, McLean, Gunn, 1991).Some animals are believed to be carriers of this bacteria and become sick when stressed (Williams and Barker, 2001). Humans may become infected through contaminated water and feces, but it generally only affects children, the elderly, and immunosuppressed individuals. Culture results were all negative in these samples, however, it is important to note that this bacteria is difficult to detect. In the future, serological testing may be a better option to determine if an animal has been exposed to the bacteria in the past without developing clinical signs.

Besnoitia spp. Is a common parasite of caribou and was first noted in muskoxen in the late 1980s and was not detected in these animals (Gunn, Shank, McLean, 1991). While not zoonotic, it is a concern for animal health. It causes thickened skin, deformed hooves, and hair loss in muskoxen. There is no known risk to humans and meat is safe to eat.

Alphaherpesvirus has not previously been documented in muskoxen and no samples were positive in this study. This virus causes a disease in cattle called Infectious Bovine Rhinotracheitis. Signs in cattle include upper respiratory problems (nasal and ocular discharge), eye lesions, genital disease, and abortion. Its role in muskox is unclear. There is no risk to humans. Additional testing for this might suggest the existence of a similar virus in muskoxen.

The Canadian Food Inspection Agency (CFIA) routinely tests animals from the commercial harvest for an important pathogen for muskoxen and humans, *Brucella* spp. Humans may become infected by eating raw meat, bone marrow, and raw milk and cheese. It causes flu-like symptoms in people, and may also cause long-term damage to the nervous system and heart. There were no positives from samples during this commercial harvest (personal communication, CFIA).

Overall Impact

The impact of these pathogens in muskoxen, both clinically and subclinically, is unknown at this time indicating the importance of regular surveillance to understand the effect on the population over time. Monitoring those pathogens that are zoonotic is also important for human health. Long-term monitoring for changes in distribution of pathogens will provide important information not only for changing muskox health, but also for monitoring overall ecosystem health and ecosystem changes, including climate change (Kutz, Hoberg, Nagy, Polley, Elkin, 2004).

Muskoxen are not the only mammals that inhabit Victoria Island and there is also the possibility of interspecies transmission of pathogens, specifically with caribou. The Dolphin-Union caribou herd migrates between the mainland and the southern part of Victoria Island seasonally, overlapping similar geographical areas as muskoxen and this is a potential route for pathogen introduction to the island (Hughes, Albon, Irvine, Woodin, 2008).

There were a number of challenges and limitations in this study which included sample size, sample types available, sample handling, and validation of tests for muskoxen. The quantity of samples from the community harvests was limited and therefore future results are critically dependent on additional samples, and sample types (such as serum) from local hunters who harvest further west on the island. For example, without sera from the community harvests, we were unable to test for *Toxoplasma gondii*, *Neospora caninum*, alphaherpesvirus, pestivirus, and *Chlamydophila* spp. Testing for these pathogens would provide important information in monitoring changes in pathogen and disease ecology of muskoxen between the southwest and southeast parts of the island. This has implications for muskox populations, food safety but also in monitoring changes in the ecosystem.

The primary limitation of this study was the lack of validated tests for muskoxen. This is a common problem in wildlife studies, as diagnostic tests are often validated for domestic species only. Our selection of tests was based on using techniques that have been used previously on muskox samples, methods that would be most likely to detect the pathogens of interest, or tests that have been validated for cattle. Further research in validation of tests would be beneficial. The difficulties in collecting blood samples indicates a need for other validated sampling methods for pathogen testing, such as the use of filter papers (Curry, 2009).

This was the largest general health study of muskoxen to date and provides important foundational data for ongoing sampling. The geographical difference of infection with *U. pallikuukensis* points to the potential difference in distribution of other pathogens, which warrants deeper investigation through ongoing larger scale sampling. Based on these results it is anticipated that more intensive and comprehensive sampling of muskoxen on Victoria Island and the mainland, will increase our understanding of the differences in pathogens, transmission of diseases, and therefore the overall impacts on muskox health and population sustainability on Victoria Island and contribute to an ongoing successful commercial harvest in Ikaluktutiak .

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