Yukon North Slope and Richardson Mountains Muskox Research Plan

Prepared by the Wildlife Management Advisory Council (North Slope)

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Photo: Jay Frandsen / Parks Canada

Production Note

Although this Research Plan has been produced by the Wildlife Management Advisory Council (North Slope), it is the result of many years of collaboration with our partners, especially the Aklavik Hunters and Trappers Committee. Other partners involved include: the community of Aklavik, the Ehdiitat Renewable Resources Council, Wildlife Management Advisory Council (NWT), Inuvialuit Game Council, Parks Canada, the Gwich'in Renewable Resources Board (GRRB), Yukon Government, Government of Northwest Territories, and McGill University. The Wildlife Management Advisory Council thanks Laurence Carter for drafting this research plan.

Purpose

This research plan is designed to accompany the *Framework for the Co-management of Yukon North Slope Muskox*, a document also produced by WMAC NS. While the framework provides directions to the management of muskox, this document aims to provide direction to research, occurring from 2018-2022, that will inform decision-making related to the management of Yukon North Slope muskox. The research detailed in this plan is expected to be carried out in part by the WMAC NS and Yukon Government, but also through collaborations with academic partners and other interested researchers.

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Summary

The Yukon North Slope is home to a population of approximately 300 muskoxen. The management objective for this population is conservation as it is defined in the *Inuvialuit Final Agreement* – "The management of the wildlife populations and habitat to ensure the maintenance of the quality, including the long term optimum productivity, of these resources and to ensure the efficient utilization of the available harvest". The research described in this plan is intended to complement this management direction and provide information that will assist the relevant management organizations in their decision-making regarding Yukon North Slope muskox. The primary research themes are: population dynamics, habitat use and movement, and muskox-caribou interactions. Health and genetics is a secondary theme. This research plan describes objectives and recommended programs of study under each theme. The integration of Inuvialuit knowledge into all aspects of research is highly encouraged and examples are provided for how this can occur. The outcomes of the research described in this plan are expected to assist the relevant management organizations in achieving the management objective for Yukon North Slope muskox.

Introduction

The muskoxen of the Yukon North Slope are found on the coastal plains of the Yukon and Northwest Territories west of the Mackenzie River, in the northern Richardson and Barn mountains as well as Ivvavik National Park and portions of Vuntut National Park (Figure 1). In 2016, this range was home to approximately 300 muskoxen.

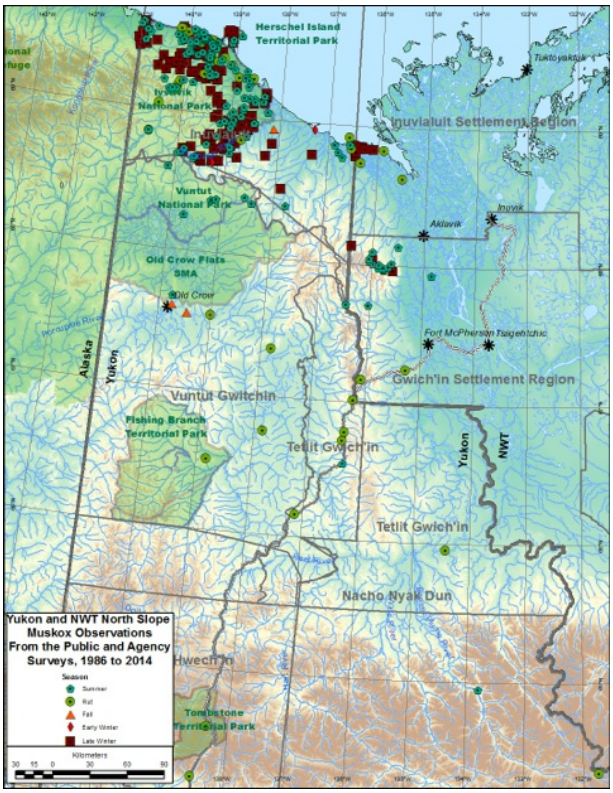

Figure 1. Distribution and group size of muskoxen, 1986 to 2014, in northern Yukon and Mackenzie Delta Region of the Northwest Territories.

These muskoxen are found within the Inuvialuit Settlement Region, Gwich'in Settlement Region, and the Gwitch'in Traditional Territory in the Yukon. They overlap Yukon and Northwest Territories and two national parks. Organizations with direct management responsibility for Yukon North Slope muskoxen include: Environment Yukon, Parks Canada, the Wildlife Management Advisory Council (North Slope) and the Aklavik Hunters and Trappers Committee.

The management objective for Yukon North Slope muskox, as described in the *Framework for the Co-management of Yukon North Slope Muskox,* is conservation as defined in the *Inuvialuit Final Agreement* – "The management of the wildlife populations and habitat to ensure the maintenance of the quality, including the long-term optimum productivity, of these resources

and to ensure the efficient utilization of the available harvest." The research described in this plan is intended to complement this management direction and provide information that will assist the aforementioned organizations in their decision-making regarding Yukon North Slope muskox.

The development of this research plan and the accompanying *Framework* has been community driven and collaborative. Partners involved in muskox management and research in the Yukon North Slope/Richardson Mountains (NS/RM) region were interviewed for their views on muskox research priorities. Years of meetings with the community of Aklavik culminated with a workshop on November 28th, 2017 with the Aklavik Hunters and Trappers Committee. The workshop was led by WMAC NS, with Council representatives from the Inuvialuit Game Council, Parks Canada and the Yukon Government present, and was attended by GNWT, GRRB, WMAC NWT, Ehdiitat Renewable Resource Council, and McGill University. Research themes and questions were defined during the expert interviews, and objectives were built, based on the themes and questions, at the workshop. A gap analysis was completed to determine what research had already been undertaken for NS/RM muskox and if any of the identified objective had been researched outside the NS/RM region (Table/Appendix). See Appendix 1 for detailed methods.

Research Themes and Objectives

Three research themes were identified as top priorities during the interviews and workshop:

- Population dynamics
- Habitat use and movement
- Muskox-caribou interactions

A secondary priority research theme is muskox health and genetics. Though health and genetics did not receive unanimous support, it was decided during the prioritization process that if research could be held at a low cost, genetics and health research should be included as a priority. The priority research themes are explored in detail. Muskox health and genetics is also discussed in this section but with less detail. Table 1 provides an overview of the research themes, objectives, and actions to be taken.

In developing this research plan, there was a strong desire expressed for muskox research that responds to community concerns and includes basic monitoring that can contribute to management decisions. Communication, education and outreach emerged as an overarching theme that should guide all research being undertaken on Yukon North Slope muskox. Taking this one step further, collaboratively developing research projects with the community of Aklavik,

from conception to completion, would be beneficial. This would include community driven priority identification (as was the case with the workshop), collaborative development of methods, participation in research, and sharing of results. Communication and education efforts are already underway. A document comparing muskox and caribou features is now available on WMAC's website; fact sheets concerning muskox are also available.

The Aklavik Hunters and Trappers Committee was a key player in starting the research program concerning muskox. To ensure that community involvement is a priority, budgets and action plans should emphasize community involvement (e.g.: working with community members on project design, hiring field technicians from the community and ensuring there are community members present during aerial surveys) and time should be set aside to visit Aklavik to present research results and leave room for discussion and interpretation. Other avenues to be kept in mind are outreach programs in schools or community gathering areas and production of infographics or other pieces of communication material that the WMAC NS and AHTC and partners can use to communicate and disseminate research results.

Using Inuvialuit Knowledge

The *Inuvialuit Final Agreement* states that:

> The relevant knowledge and experience of both the Inuvialuit and the scientific communities should be employed in order to achieve conservation.
> *IFA Section 14.(5)*

> It is recognized that one of the means of protecting and preserving the Arctic wildlife, environment and biological productivity is to ensure the effective integration of the Inuvialuit into all bodies, functions and decisions pertaining to wildlife management and land management in the Inuvialuit Settlement Region.
> *IFA Section 14.(4)*

Although this research plan does not specifically identify Inuvialuit knowledge projects, WMAC NS and partners encourage researchers to explore how knowledge co-production, integration of Inuvialuit knowledge, and Inuvialuit participation can be built into each aspect of their project. There are some instances where a question can be entirely answered using Inuvialuit knowledge. Some research programs can be designed by combining Inuvialuit and non-Inuvialuit input. Greater Inuvialuit involvement throughout all aspects of a research program will result in stronger relationships, better communication from start to finish, improved research results, and more effective research-based management.

Theme 1. Population Dynamics

The aim of this theme is to generate an understanding of muskox population dynamics, explore the best methods for monitoring the muskox population, and to assess the impact of harvest on population trajectories.

Objective 1. Assess temporal trends in muskox population size, age structure, sex structure, and demographic parameters (survival, reproduction).

During the development of this research plan, there was a desire expressed for regular muskox population monitoring, a necessary action to accomplish this objective. In addition to monitoring, this objective requires that past, present and future trends in muskox be analysed to answer questions such as:

- How did the muskox population fluctuate since its reintroduction?
- How did age and sex structure vary throughout the years?
- Can we quantify survival and reproduction of muskox?
- Can we use this information to predict future population trend for muskox?

All partners will be better equipped when it comes to making management decisions with these numbers compiled in one place. Inuvialuit knowledge can be utilized in assessing historic trends; Inuvialuit have been spending time out on the land of the Yukon North Slope for many generations. Their knowledge of the ecosystem and how it has changed over time can contribute to understanding muskox temporal trends.

Objective 2. To assess the best way to monitor the muskox population that includes confidence intervals on population estimates.

Past muskox population counts in the NS/RM region have been conducted by surveying the entire region with fixed-wing aircraft. This method is costly and time consuming and produces a minimum count, rather than the preferred population estimate with confidence intervals. Researchers should consider improving upon this existing method, with the aim of producing a robust population estimate with confidence intervals. This could be achieved by performing high intensity counts on a smaller portion of the range. One example where Inuvialuit knowledge can be employed for this type of objective is in survey design, including identifying locations where high intensity counts could be performed.

Objective 3. To assess muskox population trajectories, including determining potential for muskox population increase, the impact of harvest on muskox population trajectories, and the impact of grizzly bear predation as a population limiting factor.

Muskox breeding groups have been established in the Yukon North Slope since the mid-1980s. Since then, the population has slowly grown to include approximately 350 individuals, as of 2017. It is unclear at this point in time what population trajectories can be expected for this population, or what variables (predation, harvest, weather, etc.) are may have the greatest impact on muskox populations. It should be noted that the interest in this objective is driven in part by the large increase in muskox abundance on Banks Island during the 20th century. Though that population has since decreased, the possibility for large increases in muskox growth rate in the North Slope should be evaluated. One component of this work is to assess the impact of grizzly bear predation on muskox population trajectories.

Theme 2. Habitat Use and Movement

The aim of this theme is to assess past, present and future muskox habitat use and movement.

Objective 1. To quantify muskox resource selection including variation among seasons and years.

Resource selection functions allow researchers to assess which characteristics in a habitat are important to species. This analysis can be used to compare habitat selection within years and at different times during a single year. Quantifying resource selection is also an essential for objective 2, determining if there is potential for muskox range expansion. Inuvialuit knowledge can be employed in this type of research objective in variable selection, ground truthing, and other aspects of study design and verification.

Objective 2. To determine if there is potential for muskox range expansion in the region.

Because the NS/RM muskox population is recently re-introduced, it is unclear if the current range is at its maximum. The data that currently exist are not at a high enough resolution to assess the potential for range expansion in the NS/RM region. A recommended preliminary analysis is to use the high-resolution data that exist for part of the range and assess habitat availability within the current range. Inuvialuit knowledge of past muskox movement patterns and range can assist in study design.

Theme 3. Muskox-caribou interactions

The aim of this theme is to assess the impact of muskox on caribou in the NS/RM region.

Objective 1. To determine seasonal spatial co-occurrence patterns of muskox and caribou.

Aklavik community members have expressed concerns about caribou avoidance of muskox groups. Some have suggested caribou may avoid muskox because of their smell or because muskox resemble caribou predators from afar. Caribou, as well as being of cultural importance to the community, are an important source of food. Harvesters are worried that avoidance behaviour may change caribou migration routes, making them harder to hunt. Caribou have not been coming as close to the community in recent years. For this objective, an Inuvialuit knowledge study could formally document observations of muskox-caribou interactions and could be used to feed into further investigations.

Objective 2. To determine seasonal dietary overlap and potential for competition for food between caribou and muskox.

The possibility that caribou and muskox might be competing for food has been mentioned by members of the Aklavik community, though this issue seems to be of lesser concern.

Objective 3. To determine potential for habitat overlap and competition between muskox and caribou.

Aklavik community members have expressed concerns about the possibility of competition for habitat between muskox and caribou. If these two species use the same, limited land resources, there may be potential for competition.

Objective 4. To determine the effects of grazing and trampling of vegetation by muskox on caribou forage availability.

Another way in which caribou may be affected by muskox that has been hypothesised by members of the Aklavik Hunters and Trappers Committee is muskox overgrazing. Members have said muskox tear out the roots of plants they graze, rather than nibbling the top like caribou. This objective should include investigating if caribou use habitat subsequent to muskox grazing as well as the percent of high quality caribou habitat overlapping with the muskox grazing footprint.

Theme 4. Health and Genetics

Genetics and population health were not present in the top three research themes identified by all researchers during interviews. However, during subsequent meetings and talks, many stakeholders voiced their interest in health and genetics research, especially if samples can be collected and analysed at low cost. The general goal would be to monitor muskox population health and analyse the genetics of the population through a sample collection program.

The impact of genetic mixing between the reintroduced muskox population living west of the Mackenzie River and the indigenous muskox population living east of the Mackenzie is one research topic that has come up frequently. Certain stakeholders have mentioned they believe genetic mixing has already occurred. However, most participants are confident that genetic mixing will be a positive outcome to both muskox populations who have gone through numerous bottlenecks and have low genetic diversity.

Research conducted on muskox populations elsewhere in Canada and in the Arctic have revealed the importance of bacteria, parasites and other health issues in the decline of muskox. Little work has been done on the NS/RM population, but could be of interest, especially given the potential for disease transmission when mixing between the introduced and indigenous muskox population occurs.

Table 1. Summary of North Slope/Richardson Mountains muskox research objectives and gap analysis

Theme	Objective	Available information	Missing information	Actions to be taken
Muskox population dynamics	To assess temporal trends in muskox population size, age structure, sex structure, and demographic parameters (survival, reproduction)	- Aerial surveys ('93, '95, '96, '99-'06, '11, '16) - Composition counts ('86, '93, '95, '96, '98-06, '16, '17)	- Demographic parameters (survival, reproduction) - Analysis of composition counts and aerial surveys	- Calculate demographic parameters (survival, reproduction) using composition counts and aerial surveys - Analyse temporal trends in population size, age and sex structure, demographic parameters - Periodic muskox population surveys and composition counts
	To assess the most efficient way to monitor the muskox population that includes confidence intervals on population estimates.	N/A	- Information on different methods of conducting population surveys - Information on determining confidence intervals	- Evaluate the feasibility of different remote population surveys - Determine how to include confidence intervals in population estimates
	To assess muskox population trajectories	- Muskox longevity (not specific to NS/RM region) - Aerial surveys ('93, '95, '96, '99-'06, '11, '16) - Composition counts ('86, '93, '95, '96, '98-06, '16, '17)	- Demographic parameters (survival and reproduction) - Population growth rate - Demographic stochasticity (variation in population growth)	- Determine the potential for muskox population increases - Additional muskox monitoring to determine demographic parameters - Assess impact of harvest on muskox population trajectories - Assess impact of grizzly bear predation as a population limiting factor

Theme	Objective	Available information	Missing information	Actions to be taken
			- Environmental variation (weather, vegetation) - Genetic risks - Information on impact of grizzly bear predation as a population limiting factor	
Muskox habitat use and movement	To quantify muskox resource selection including variation among seasons and years	- Muskox collar data (11 years, 35 collars, 93-present) - Use of watersheds, elevation (1999-2005) - Land cover use (1993-1994) - Updated land cover classification for Vuntut and Ivvavik National Parks and North Slope	- Updated muskox habitat selection (1999-present) - Relevance of other factors (distance to water, slope) - Land cover classification for Richardson Mountains and Herschel Island	- Adapt ecological land classification so it is compatible with existing ecological classification for Ivvavik and Eastern Yukon North Slope - Extend ecological land classification to Richardson Mountains - Analyse habitat selection from 1999-present - Fine scale habitat use/behavioural study - Generate seasonal resource selection functions - Determine if seasonal habitat selection has shifted over time
	To determine if there is potential for muskox range expansion	- Muskox collar data (11 years, 35 collars, 93-present) - Use of watersheds, elevation (1999-2005)	- Updated muskox habitat selection (1999-present)	- Extend land cover classification - Analyse habitat selection from 1999-present - Fine scale habitat use study

Theme	Objective	Available information	Missing information	Actions to be taken
		- Land cover use (1993-1994) - Updated land cover classification for Vuntut and Ivvavik National Parks and North Slope	- Relevance of other factors (distance to water, slope) - Land cover classification bigger than actual muskox range	- Analysis of opportunities for spatial expansion
Muskox-caribou interactions	To determine seasonal spatial co-occurrence patterns of muskox and caribou	- Muskox collar data (11 years, 35 collars, 93-present) - Caribou collar data - Pilot behavioural study	- Analysis of collar data - Extensive behavioural data - Additional muskox collar data	- Spatial co-occurrence analysis - Caribou-muskox behavioural study - Collect additional collar data
	To determine seasonal dietary overlap and potential for competition for food between caribou and muskox	- Muskox diet from Dehn (1996) - Muskox diet outside NS/RM region - Seasonal porcupine caribou diet	- Statistically valid seasonal diet for muskox in NS/RM	- Collect fecal samples from muskox and caribou in NS/RM in different seasons and send for analyses - Statistical analysis of fecal sample data
	To determine potential for habitat overlap and competition between muskox and caribou.	- Muskox collar data (11 years, 35 collars, 93-present) - Caribou collar data - Pilot behavioural study - Updated land cover classification for Vuntut National Park and North Slope	- Analysis of collar data - Extensive behavioural data - Land cover classification for Richardson Mountains and Herschel Island	- Extend land cover classification - Analyse collar data for habitat use - Collect additional collar data - Fine scale habitat use study - Determine potential for muskox over-grazing

Theme	Objective	Available information	Missing information	Actions to be taken
	To determine the effects of grazing and trampling of vegetation by muskox on caribou.	- Muskox collar data (11 years, 35 collars, 93-present) - Caribou collar data	- Locations of grazed and ungrazed sites - Sampling of vegetation - Spatial overlap of muskox grazed sites compared to caribou habitat use	- Analysis of collar data to detect sites that have been grazed by muskox - Sampling of vegetation on grazed and ungrazed sites - Analysis of impact to caribou

Gap Analysis

A gap analysis was performed to detail previous research conducted on muskox in the NS/RM region and around the globe to determine if research objectives identified in the first section have already been fulfilled, or if data exists that would allow us to fulfill those objectives (Appendix 2). This information was used to complete the 'missing information', 'available information' and 'actions to be taken' columns in Table 1. The gap analysis covered: available data for the NS/RM region (population counts, composition counts, muskox collar data), muskox studies completed in the NS/RM region (home range, movement rates, use of watersheds, elevation, land cover selection, temperature data, diet, behaviour, genetics), studies outside the NS/RM range (muskox diet, muskox and caribou diets, muskox and caribou habitat use, grazing, health and genetics).

Recommended programs of study to meet objectives

Below is a description of the efforts that can be put in place to meet the research objectives. These recommended programs are not grouped by theme, but rather by actions that could be put in place. The section is divided by field work and analyses. Appendix three contains a table detailing the recommended programs of study, priority and timeframe.

Field work

Composition counts and collection of fecal samples: The composition counts and collection of fecal samples can be combined because both actions require teams to be on the ground. The composition counts would allow for objectives 1 (assessing temporal trends) and 2 (assessing muskox population trajectories) of theme 1, muskox population dynamics, to be met. The fecal samples would provide information for objective 2 (determining seasonal dietary overlap between muskox and caribou) of theme 3, muskox caribou interactions, and for health and genetics research.

Population surveys: Population surveys would allow for objectives 1 (assessing temporal trends) and 2 (assessing muskox population trajectories) of theme 1 to be met. Ideally, population surveys should be conducted every five years.

Muskox collaring: A collar is present on most muskox groups in the Yukon North Slope and Richardson Mountains region at this time. Currently, collaring is done discretely, for a specific project. Additional collars may be put out depending on the outcome of further investigation into

research methods. Further collaring work will also be based on community engagement; collaring will only be done if Aklavik community members are comfortable with further collaring of muskox. Collared muskoxen allow researchers to gather data on both objectives (range expansion and habitat selection) of theme two, provide information to answer objective 1 (assessing temporal trends) in theme 1, muskox population dynamics, and allow us to analyse muskox-caribou interactions. Collars have also proven be valuable when conducting population counts.

Muskox grazing study: A field study on the impact of muskox grazing on the landscape would provide data to inform objective 4 in theme 3 (Muskox-caribou interactions).

Behavioural and habitat use study and collection of fecal samples: A habitat use and behavioural study would consist of going on the land near groups of muskoxen to record their behaviour. Preferably, the location and timing of this study would allow for observations of interactions with caribou. This study would provide information for objective 1 in theme 2, habitat use. It would also provide information for objective 3 in theme 3 concerning muskox-caribou interactions and potential for habitat competition. This study would require field crew to be on the land. As such, muskox feces should be collected for future analysis. Fecal analysis would provide information for health and genetics research and would also be used to characterize muskox diet.

Sample collection from harvested animals: Though this is not a formal objective, a few stakeholders have expressed a desire to collect tissue samples from muskox to gather information on health and genetics. When hunters bring back carcasses to the community, sample kits and a payment would be provided to the hunters for this purpose. Samples would have to be stored in a freezer before their analysis in a laboratory.

Social science fieldwork: Interviews, workshops, surveys and meetings can all be employed to achieve the aforementioned research themes and objectives. Communication and education in the community of Aklavik pre- and post-project are expected but knowledge co-production methods are also encouraged. Interviews aimed at gathering Inuvialuit traditional and local knowledge of muskox could contribute to research questions but should only be undertaken if the community indicates that they are a priority. Avoidance of community 'interview fatigue' is important.

Analyses

Population dynamics

Analyse past temporal trends in muskox population size, age structure, sex structure, and demographic parameters (survival, reproduction): Composition counts and aerial surveys should be analysed to calculate the above-mentioned parameters. The location and the size of the surface covered for the composition counts and surveys should be taken into account as to render the parameters comparable. The use of a population model may be helpful in combining these variables to better understand the importance of specific monitoring metrics.

Determine the potential for muskox population increase: After having analysed population growth and demographic parameters, an analysis of the potential for muskox population increase should be completed. This analysis should include case studies and comparisons with other muskox populations.

Determine the best way to conduct population counts: Because of expensive flight time, large survey areas, limited number of animals and limited resources, attention should be put on conducting the most efficient population counts. An investigation of methods for muskox population counts should consider the ability to generate population estimates with confidence intervals – a measure currently lacking.

Habitat Use

Expand the ecological land classification to the Northwest Territories side of the Richardson Mountains and ensure data is compatible on Hershel Island, too: Ensuring the entire range of NS/MR muskoxen has available land cover classification will allow habitat and spatial analyses to be completed. Currently, most of the Yukon North Slope is covered by an ecological land classification that could be extended to the NWT side of the Richardson Mountains.

Generate seasonal resource selection functions and determine if seasonal habitat selection has shifted over time: Analysing satellite data to generate seasonal resource selection functions for muskox would provide information on where muskox can be expected to be found.

Analyse opportunities for spatial expansion: Once seasonal resource selection functions have been generated, they can be used to determine if satisfying habitat for muskox occurs outside their current range and estimate the possibility for muskox range to expand.

Analyse spatial co-occurrence (muskox-caribou): Using muskox and Porcupine caribou satellite data, an analysis looking at the patterns of co-occurrence between these species should be performed.

Compare muskox-caribou habitat selection: Resource selection functions would have to be generated for the Porcupine caribou herd and compared with that of muskox. Overlap and differences in habitat selection should be quantified and described.

Analyse muskox grazing impact: Once the field work for muskox grazing impact on vegetation is completed, the data should be analysed and put into context as to its impact on caribou.

Other

Analyse muskox samples for parasites: Muskox samples (e.g., fecal samples) collected from hunters and during research (e.g., composition counts, habitat work) should be sent to laboratories with the expertise to identify parasites (e.g., Dr. Susan Kutz at the University of Calgary).

Analyse muskox samples for genetics to assess ingression of NWT mainland muskox into the population: Samples collected by hunters and researchers should be sent to a genetic lab to examine whether mixing of mainland NWT muskox and YNS muskox has occurred. Baseline data assessing this relationship is available (Paetkau 2010).

Analyse muskox fecal samples for diet: Muskox fecal samples collected during composition counts or other field work should be sent to laboratories for analysis. Past diet analyses were completed using a microhistological technique. The Wildlife Habitat and Nutrition Lab at Washington State University offers the microhistological analyses of fecal samples however this lab may no longer analyse samples after this 2018. Other techniques, such a DNA metabarcoding could also be envisioned.

Compare muskox-caribou diet: Once muskox fecal samples have been analysed for diet content, they can then be compared with existing data on the Porcupine caribou herd. Ideally, new diet data for Porcupine caribou would be available for comparison.

Conclusion

The work outlined in this Research Plan identifies the research activities that WMAC NS envisions being undertaken for muskox on the Yukon North Slope from 2019-2022. The outcomes of this research will help the Council fulfill its obligations under the Inuvialuit Final Agreement. This Research Plan is intended as a companion document to the *Framework for the Co-management of Yukon North Slope Muskox*, a document also produced by WMAC NS. By 2022, WMAC NS will work with partners to review the state of knowledge of muskox on the Yukon North Slope and provide a summary as it relates to the recommendations in this Research Plan. At that time, WMAC NS or other may consider updating the Research Plan to meet evolving information needs.

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Appendices

Appendix 1. Methods

A1.1 Interviews

This research plan was drafted with the objectives and priorities of the many partners involved with muskox in the Yukon North Slope/Richardson Mountains region (NS/RM). The following personnel were contacted for their views on muskox research priorities:

- Édouard Bélanger, Wildlife Biologist, Gwich'in Renewable Resources Board
- Tracy Davison, Regional Biologist, Government of the Northwest Territories
- Ian McDonald, Ecological Team Leader, Vuntut National Park, Parks Canada
- Jennifer Smith, Executive Director, Wildlife Management Advisory Council North Slope
- Lindsay Staples, Chair, Wildlife Management Advisory Council North Slope
- Mike Suitor, North Yukon Regional Biologist, Yukon Government
- David Tavares, Resource Conservation Manager for WAFU, Parks Canada

Interviews conducted with the individuals above sought to define their views on muskox research. The following questions were asked to each:

- In your view, why is it important to study muskox on the North Slope?
- Describe previous involvement and experience with muskox management and research. Please mention any individuals in your organization of importance and/or documentation including reports, presentations, or data you or someone in your organization may hold that is relevant.
- Please rank the following nine research themes in order of importance (1 being the most important and 8 being the least important).
    - Genetics (e.g., mixing with NWT mainland herds)
    - Health (e.g., disease, parasites)
    - Habitat Use (e.g., diet, seasonal habitat selection, habitat impacts)
    - Movement and distribution (e.g., range dynamics, migration, density)
    - Predation
    - Population dynamics (e.g., population size, survival, productivity, recruitment)
    - Muskox-caribou interactions (e.g., behavioural, direct competition)
    - Other
- Describe relevant research questions that could apply to the top 2-3 themes identified in question 3.
- How do the top research themes identified in question 3 relate with current or projected muskox management objectives?

A1.2 Workshop

On November 28th 2017, a workshop was held in Aklavik with the Aklavik Hunters and Trappers Committee to define their priorities concerning muskox research. The workshop was led by WMAC NS including most of that Council (includes Inuvialuit, Parks Canada, Yukon Government), GNWT, GRRB, WMAC NWT, Ehdiitat Renewable Resource Council, and McGill University. During this workshop, previous research completed on muskox as well as available data was presented to the members of the committee. Most of the workshop took the form of an informal conversation between participants along with pertinent presentations to provide background information.

A1.3 Defining objectives

Research themes and questions defined during the interviews and the workshop were then transformed into research objectives. The top 4 themes identified by respondents during the interviews were generally the same. These were:

- Muskox-caribou interactions
- Population dynamics
- Movement and distribution
- Habitat use

During the workshop in Aklavik, the major concern from the Hunters Trappers Committee was about muskox interactions with caribou. When formulating research objectives, muskox habitat use and movement and distribution themes were merged into one category (habitat use and movement) because of their similarities. Though health and genetics did not receive unanimous support, it was decided that if research could be undertaken at a low cost there was no reason why these themes should not be included. Other themes were excluded for lack of widespread support. Objectives for each theme were determined by matching the research questions the stakeholders thought were appropriate to each of their top themes. Research themes and objectives are summarised in Table 1.

Stakeholders globally expressed their desire for muskox research that responds to community concerns and includes basic monitoring that can contribute to management decisions. The following research themes and objectives were written within this context. In addition to the specific research priorities identified within the three themes, sections on health, genetics and communication were added.

A1.4 Gap analysis

Reports, presentations, and management tools relating to muskox were analysed to determine what research had already taken place in the NS/RM region that answered research objectives identified by stakeholders. Scientific literature was also consulted to determine if any objectives had been researched elsewhere. Once this was completed, a list of missing information and actions to be taken was compiled. The gap analysis is summarised in Table 1.

A1.5 Recommended programs of study and budget

Following the gap analysis, a list of recommended programs of study was drafted. A draft budget was developed for certain anticipated projects. This document can be obtained from WMAC NS upon request.

Appendix 2. Gap Analysis

A2.1 Available muskox data in the North Slope/Richardson Mountains region

A2.1.1 Population counts

Pre-calving population counts were conducted in late March or early April before muskox calves were born. These counts were intended to be total counts, and were used to assess the size of the muskox population (see Figure A1). However, not all these counts were conducted in the same region nor with the same surface area. Population counts were conducted in the following years:

- 1993, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2011, 2016

Summer aerial surveys were conducted in 1986, 1993 and 1999 to 2005, mostly to assist crews in finding muskox groups for composition counts. They were not intended to be complete population surveys.

Survey	C	Y	2 year (uncl)	M 2	M 3	M 4	M 5+	AM (uncl)	F 2	F 3	F 4+	AF (uncl)	Uncl	Total
June, 1986	0	5	0	0	0	0	0	5	0	0	0	7	6	23
March, 1993	0	0	0	0	0	0	0	0	0	0	0	0	157	157
July, 1993	38	10	0	0	0	0	0	50	0	0	0	54	0	152
March, 1995	0	15	22	0	0	0	0	42	0	0	0	53	14	146
March, 1996	0	4	0	5	4	5	34	0	2	2	19	0	46	121
April, 1998	0	8	0	5	3	3	36	0	5	7	26	0	3	96
March, 1999	0	6	0	8	3	4	29	0	4	8	40	0	37	139
July, 1999	18	2	0	1	6	2	25	0	0	4	21	0	40	119
April, 2000	0	10	0	6	6	6	25	0	7	11	12	0	4	87
July, 2000	20	15	0	5	5	7	29	0	2	7	29	0	2	121
April, 2001	0	14	0	8	7	6	28	0	6	21	25	0	9	124
July, 2001	19	22	0	17	16	6	36	0	2	6	58	0	10	192
April, 2002	0	19	0	13	10	19	26	0	13	18	36	0	32	186
July, 2002	17	12	0	8	8	5	23	1	3	13	26	0	30	146
April, 2003	0	6	0	4	5	2	27	0	5	10	28	0	8	95
July, 2003	20	4	0	7	2	1	18	0	2	8	29	0	7	98
April, 2004	0	16	0	9	4	1	35	0	3	13	40	0	23	144
July, 2004	5	8	0	5	3	0	12	0	0	2	28	0	3	66
April, 2005	0	15	0	5	4	1	14	0	2	4	30	0	11	86
July, 2005	12	10	0	1	5	0	25	0	3	5	37	0	12	110
April, 2006	0	4	0	0	0	0	0	8	0	0	0	7	60	79

C=calf, Y=yearling, 2 year (uncl)=unclassified 2 year old, M2=2 year old male, M3=3 year old male, M4=4 year old male, M5+=5 year old, or older, male, AM (uncl)=unclassified adult male, F2=2 year old female, F3=3 year old female, F4+=4 year old, or older, female, AF (uncl)=unclassified adult female, Uncl=unclassified.

Figure A1. Sex and age class composition of muskoxen counted on the Yukon North Slope during pre-calving and summer aerial surveys, 1986-2006. (Cooley & McDonald, 2010)

A2.1.2 Composition counts

Composition counts were conducted in association with summer survey areas and pre-calving population counts. Late winter counts allowed the estimation of percent of yearlings in the population as a measure of survival. Summer counts allowed the estimation of the ratio of calves to cows as a measure of birth rate. Composition counts were conducted in the following years:

- 1986, 1993 (March and July), 1995 (March), 1996 (March), 1998 (April), 1999 -2005, 2006 (April), 2011 (small survey), 2016 (summer), 2017 (summer)

A2.1.3 Muskox collar data

Muskox were collared in the NS/RM regions in the following years:

- 1993-1994 (3 females)
- 1999-2002 (10 collars: 8 female and 2 male)
- 2002-2005 (8 collars: 4 re-collars and 4 new collars)
- 2015-present (14 collars: 14 females)

From 1999 to 2005, a total of 14 muskox (9 females, 5 males) were collared for 11,793 muskox/days. 12 additional collars were deployed in late winter 2018.

A2.2 Muskox studies in the North Slope/Richardson Mountains region

A2.2.1 Home Range sizes

Home range sizes were calculated for each individual for every year from 1999 to 2005. Due to collar failures and muskox mortalities, home range calculations for males were possible for only 7 of 38 seasons (Cooley & McDonald, 2009).

A2.2.2 Movement rates

Movement rates were calculated for muskox from 1999 to 2005. On average, females moved more than males in all seasons except during the fall. In fall, males moved 3 times the number of kilometers as recorded for females. Mean daily distance moved by season for males and females, and daily movement rates by sex were calculated (Cooley & McDonald, 2009).

A2.2.3 Use of watersheds

The use of 11 river watersheds was calculated to see if usage was higher or lower than what would be expected with random movement across the territory. Muskoxen use the areas between the Alaska border to the Babbage River more than would be expected if locations were random ($p < 0.0001$) (Cooley & McDonald, 2009).

A2.2.4 Elevation

Muskox distribution over 5 different elevation classes was studied. The percent of muskox locations found at low elevation was higher than if those locations had been randomly generated (Cooley & McDonald, 2009).

A2.2.5 Land cover selection

Land cover selection was analyzed for the 1993-1994 collar data, and varied by season. In late winter, muskox used moist vegetation classes preferentially. In spring, muskoxen used wet graminoid/low shrub and low shrub tundra preferentially but avoided moist cottongrass tussock. In summer, muskoxen were highly selective for moist non-tussock sedge communities with other land cover classes not differing significantly. In fall, muskox preferentially used shrub thicket, wet barrens, dry or partially vegetation wet barrens communities (Cooley, 2004).

A2.2.6 Temperature data

Temperature was recorded on muskox collars in the 1999-2002 collaring set (Cooley & McDonald, 2009).

A2.2.7 Diet

In a 1996 habitat use and diet study conducted by the Department of Renewable Resources of the Yukon Government, fresh fecal samples were collected from a few groups of muskoxen and analyzed. The primary vegetation found in the fecal samples were willow (Salix spp.), cottongrass (Eriophorum spp.), sedges (Carex spp.), and horsetail (Equisetum spp.). The authors mention that because the fecal samples were not collected systematically, they only provide anecdotal information on muskox diet. This information is summarized below.

Month	Season	Carex	Eriophorum	Horsetails	Other	Willows
Feb	Late winter	6	8	2	6	78
Mar	Late winter	20	34	0	18	28
Jul	Summer	3	15	1	12	69
Oct	Fall	11	11	52	7	19

Muskox diet on the North Slope in percentage (Dehn, 1996).

A2.2.8 Behaviour

A pilot behavioural study, led by Mike Suitor, was conducted on muskox and caribou interactions in the summer of 2016. Observations of behaviour were recorded for a few days.

A2.2.8 Genetics

Samples of muskox tissue and fecal samples from the North Slope, Banks Island and the Canadian Archipelago were analysed and compared. There is sufficient genetic variability between these populations to allow the identification of mixing between the populations, should this ever occur.

A2.3 Studies outside the North Slope/Richardson Mountains range

A2.3.1 Muskox diet

In 1989 and 1991, muskox summer fecal samples were collected in the Queen Maud Gulf Area (Gunn, 1997). Analysis of these samples revealed that summer diet consisted mainly of sedges (Carex spp. and Eriophorum spp.) and willows (Salix spp.). In 1989, sedges made up the greatest proportion of the diet and in 1991 proportions reversed and willows made up the greatest proportion. Klein and Bay's 'Foraging dynamics of muskoxen in Peary Land, northern Greenland' (1990) provides a detailed analysis of muskox diet in the summer months. Sedges were the major food item for muskox who foraged in fens while willows were the major dietary component for muskox foraging in areas where willow was the dominant species. 'In Resource Partitioning by Mammalian Herbivores in the High Arctic (Klein & Bay, 1994) summer and winter muskox fecal samples were analysed to reveal that sedges and willows were the most common vegetation types used by muskox year-round. Willow intake increased in the early summer months. Foraging Strategies and Seasonal Diet Optimization of Muskoxen in West Greenland (Forchhammer & Boomsma, 1995) examined how diet changed during the summer months to maximize energetic intake.

These studies were for the most part conducted in latitudes north of the range habited by the population of interest, but the diet data collected in the North Slope in 1996, where willows composed most of the diet, seems to comply with these studies.

A2.3.2 Muskox and caribou diets

In Western Alaska, percent cover for all vegetation classes did not differ between muskox and reindeer habitat, but diet did. Muskox diet was composed of significantly more sedge and moss, and less lichen than caribou. Muskox and caribou did not select differently from each other for snow depth or hardness (Ihl & Klein, 2001). Diets of muskox and reindeer were analyzed on Wrangel Island, Russia (Kazmin & Abaturov, 2011). They found that the two species had similar diet composition, forage intake rate and digestibility. On Banks Island (Larter & Nagy, 1995), muskox and Peary caribou had monthly diet similarities ranging from 17.8-73.3%. Diet similarities were more pronounced when muskox densities were high. Studies conducted on the Porcupine Caribou Herd, whose range overlaps with North Slope muskox, revealed that caribou diet varied little from September to May, where it was composed mainly of fructitose lichen (64%) evergreen shrubs (11%) and lichen (8%). During pre-calving and calving periods, diet was composed mainly

of evergreen shrub, graminoids and moss, while post-calving fecal samples reveal a diet mostly composed of deciduous shrubs. Later in the summer, caribou diet was mainly composed of deciduous shrubs and forbs (Russell, Martell, & Nixon, 1993).

A2.3.3 Muskox and caribou habitat use

Summer habitat use was studied in muskox and Peary caribou living in the High Arctic in the 1970s. This study showed that caribou used broader habitat and moved more than muskox. Muskox selected for a sedge-producing hydric meadow whereas caribou preferred polar-desert and mesic-meadows (Parker & Ross, 1975). Muskox foraged opportunistically to maximize intake and spent over 50% of their days foraging during the summer (David R. Klein & Bay, 1990). A team mapped Banks' Island arctic habitat into seven classes using LANDSAT images. Muskox were most likely to be found in wet sedge meadow, graminoid tundra and graminoid/dwarf shrub tundra cover types during the summer (Ferguson, 1991). In Northern Alaska, satellite-based vegetation maps, digital elevation models and terrain data were used with muskox locations to produce muskox habitat models. Summer habitat was ideal in low, wet areas and winter habitat in higher, drier areas (Danks & Klein, 2002).

A few studies have looked at muskox winter habitat use. On Victoria Island, muskox selected for habitat containing water sedge, *Carex aquatilis*. This study also found that the scale at which habitat selection was observed and analyzed had little impact on the data collected (Schaefer, & Messier, 1995). In Norway, it was found that muskox preferred *Dryas* (an evergreen shrub) located on steep slopes with little snow accumulation (Nellemann, 1998).

A2.3.4 Grazing

A study done on Unalakleet Muskox Farm in Alaska showed that following grazing, the most noticeable response was an increase in annual sedge productivity, except in cases where the soil had been destroyed. Lichen and shrubs decreased with grazing pressure (McKendrick, 1981). A group of researchers observed population structure of three sedges (*Carex aquatilis* ssp *stans, Carex membranacea, Eriophorum angustifolium* ssp *triste)* in grazed and ungrazed sites. In grazed vegetation, *C. stans* had greater biomass than in ungrazed, (Tolvanen & Henry, 2000). Biomass in grazed areas was higher for all three species. In 2010, researchers put up exclosure fences to keep muskox from grazing in plots in the Greenland arctic. Three years later, the total density of vascular plants in the exclosures (not subject to grazing) was lower than in the control areas, even though total biomass had increased.

A2.3.5 Health and genetics

A few muskox populations have been in decline in recent years, and studies have looked at the causes of these declines. On Banks Island and Victoria Island, the declines coincided with the

emergence of disease. Amongst these diseases are two species of lungworm (*Umingmakstrongylus pallikuukensis* and *Varestrongylus eleguneniensis*) that were first detected on Victoria Island in 2008. A bacteria strain, *Erysipelothrix rhusiopathiae*, was also found to be the cause of death of muskoxen. Both the lungworm and the bacteria were north of their habitual range (Kutz et al., 2016). In Alaska, the reintroduced population of muskox living on the eastern North Slope declined from 1999-2006. Researchers looked at blood serum, carcasses, trace minerals and gastrointestinal parasites to determine causes of death. No single pathogen or disease could be pinpointed to have been the cause of population decline. Rather, a host of causes including predation, polyarthritis caused by or consistent with *Chlamydophila* spp. infection, hoof lesions, copper deficiency, pneumonia, and bacterial bronchopneumonia due to *Trueperella pyogenes* and *Bibersteinia trehalosi* were found to have caused or been involved in the death of muskox (Afema, Beckmen, Arthur, Huntington, & Mazet, 2017).

Appendix 3

This appendix details the specific actions to be completed under each them, along with the priority, timeframe, lead and expected cost. Many of the details are not yet completed but it is expected that this table can be revisited by the management organizations and partners and filled in as need be.

Topic	Action	Priority	Timeframe	Lead	Expected Cost
Population Dynamics	Analyse past temporal trends in muskox population size, age structure, sex structure, and demographic parameters (survival, reproduction)	Medium		YG-DoE, GNWT-ENR	
	Determine the potential for muskox population increase	Medium			

	Determine the best way to conduct population counts	Medium			
Habitat Use	Expand ecological land classification to the NWT side of Richardson Mountains	Medium	2018-19	McGill	None
	Generate seasonal resource selection functions and determine if seasonal habitat selection has shifted over time	Medium	2018-19	McGill	None
	Analyse opportunities for spatial expansion	Medium	2018-19	McGill	None
	Analyse spatial co-occurrence (muskox-caribou)	High	2018-19	McGill	None
	Compare muskox-caribou habitat selection	High	2018-19	McGill	None
	Analyse muskox grazing impact	High	2018-19	McGill	None
Other	Analyse muskox tissue and fecal samples for parasites	Low	2018-19	GNWT-ENR, YG-DoE	

	Analyse muskox tissue and fecal samples for genetics	Low	2018-19	GNWT-ENR, YG-DoE	
	Analyse muskox fecal samples for diet	Low			
	Compare muskox-caribou diet	Low			
	Social science fieldwork	Medium			

YG-DoE – Yukon Government – Department of Environment
GNWT-ENR – Government of the Northwest Territories – Environment and Natural Resources