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Arctic Climate Change Research and Monitoring

A Review for Use on the Yukon North Slope

Prepared for Wildlife Management Advisory Council (North Slope)

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Contents

Chapter 1: Introduction

Overview

The Yukon North Slope (YNS; Figure 1) is an ecologically and culturally significant landscape in the Western Canadian Arctic. The YNS is home to a wide range of arctic fish and wildlife species and is integral to Inuvialuit subsistence harvesting and cultural practices. The Inuvialuit Final Agreement (IFA) was legislated in 1984 and establishes the management priority of the YNS as the conservation of the land, waters, wildlife and Inuvialuit traditional use. To assist in meeting this priority, the IFA established the Wildlife Management Advisory Council (North Slope) – WMAC(NS) - as a co-management body comprised of federal, territorial and Inuvialuit representatives and an independent chair. The mandate of WMAC(NS) is to provide advice on all matters related to wildlife management on the YNS, including to prepare a Wildlife Conservation and Management Plan.

WMAC(NS) is currently in the process of updating the existing Wildlife Conservation and Management Plan (WCMP) and this updated Plan will recognize the critical influence that climate change will have on the ecological and cultural values of the YNS. Implementation of the Plan and on-going management and conservation will require better information and on-going research on the potential and realized climate effects on these values. Climate change research and monitoring will also inform the development and implementation of a proposed Indigenous Protected and Conserved Area (IPCA) for Aullaviat/Auguniarvik (eastern North Slope; Figure 1) which is part of the WCMP recommendations. WMAC(NS) has worked closely with the Aklavik Hunters and Trappers Committee (AHTC) in facilitating necessary research to support the new plan. Round River Conservation Studies (RRCS) is part of this team and has contributed to the development of ecological and cultural data to support the updating of the Wildlife Conservation and Management Plan.

This report is an assessment of the climate change research and adaptation efforts that currently exist on the Yukon North Slope (YNS) and a review of other relevant efforts, particularly in the Western Canadian Arctic and Alaska. Given the extensive research that exists on climate change impacts to arctic ecosystems, it is not possible to cover all existing research that is relevant to the YNS. We focused on research and monitoring initiatives that may provide feasible and effective approaches to increase understanding of climate change effects in the YNS. This includes current efforts that take place in select locations along the YNS but could be expanded for a more systematic understanding across the region.

We have also prioritized our review to focus on climate change effects that directly impact the values of highest concern for WMAC NS and the AHTC, as we understand them. Therefore, while we refer to the international significance of climate change in the study area (e.g., contributions of coastal erosion to global carbon emissions or relevance of local environmental change to pan-arctic discussions of shrub proliferation), the primary focus of this review is understanding the extent of work that has been done to understand changes that affect the land, wildlife, and traditional use of the YNS and identify information gaps that may be suitable topics for future research and monitoring efforts; particularly those efforts that can be developed through community-based study designs. Therefore, we have focused our efforts on values of importance to the Aklavik HTC, not an exhaustive review of climate change vulnerabilities.

To tailor this report to issues of relevance to the Aklavik HTC, we have chosen broad themes based on their relevance to Inuvialuit traditional use of the YNS and cultural values across the landscape. These themes reflect the guidance of Aklavik HTC and are the topics of the following chapters: Chapter 2: Traditional Use, Traditional Knowledge, and Climate Change adaptation, Chapter 3: Vegetation Change, Chapter 4: Fish and Wildlife Vulnerability, and Chapter 5: Erosion, Permafrost Thaw, and Aquatic and Marine Impacts. Each chapter focuses on the issues of most relevance to Inuvialuit land-users and is shaped by the guidance of the Akalvik HTC. For example, our review of climate change impacts to fish and wildlife focuses largely on focal species, such as caribou, moose, and polar bear, that have been selected by Aklavik HTC to represent ecological values across the landscape. This excludes a large body of research that describes other climate change impacts, such as changes to artic lake systems, marine mammals, insect populations, etc., and focuses on measures that can be taken to better understand and respond to changes that are occurring on the YNS that are of most relevance to Inuvialuit land-users.

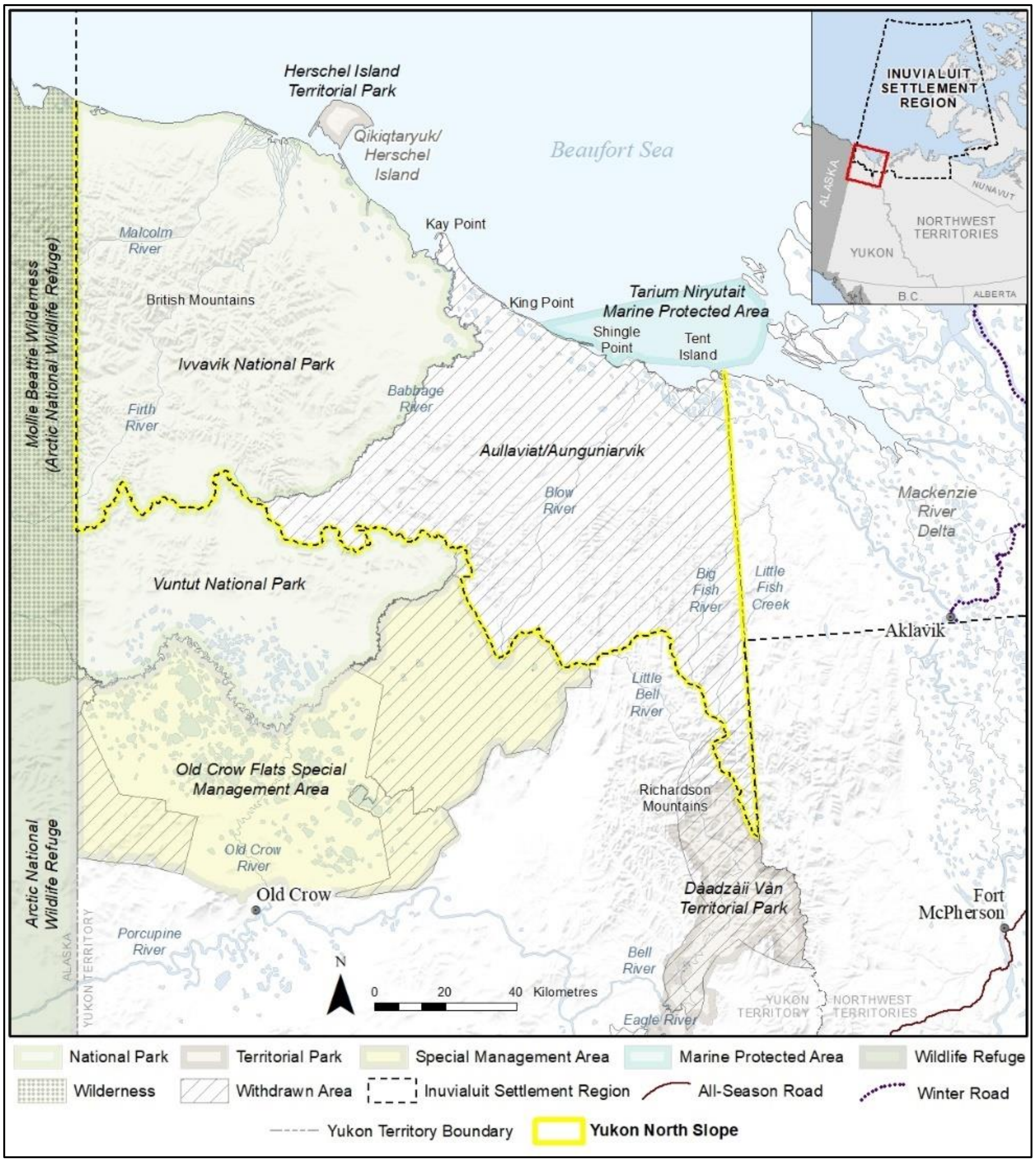

Figure 1. Yukon North Slope and surrounding management areas.

Chapter 2: Traditional Use, Traditional Knowledge, and Climate Change Adaptation on the YNS

Overview and Definition of Terms

Traditional knowledge, traditional use, and climate change adaptation are separate but related topics, whose relation to one another can often lead to a misuse of terms. Because this document refers to all three terms throughout, it is important to provide clarity of meaning.

The commonly used definition of **traditional Knowledge** is the "*cumulative body of knowledge, practice, and belief, evolving by adaptive process and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and their environment"* (Berkes 1999). In the context of this report, we use the terms "traditional knowledge," "indigenous knowledge," and "Inuvialuit Knowledge" interchangeably. We refer to many traditional knowledge research projects, in which Inuvialuit land-users describe wildlife, habitat, changes on the landscape, or cultural practices. This knowledge is detailed, nuanced, and informative for an array of management directives across the ISR, however it is also important to remember this knowledge is formed and communicated in specific contexts and locations. It is not easily generalized or applied to other study areas or scenarios.

In this report, **traditional use** refers to the physical interaction between Inuvialuit community members and the landscape that supports their traditional economy as well as their cultural and spiritual relationship with the YNS. This means the harvest of fish, wildlife, and plants, but it also refers to non-consumptive values, such as burial sites, travel routes, historic places and other culturally important sites. Traditional use is *informed* by traditional knowledge - for example, harvesting a caribou requires knowledge of wildlife, habitat, weather, and harvesting traditions that have been handed down from elder to youth. Similarly, traditional knowledge may be *obtained* through a history of traditional use. For example, observations of historical shoreline change on the YNS are traditional knowledge which may have been obtained through frequent trips along the coast to summer hunting and fishing grounds.

Climate change adaptation is a response to the impacts of a changing climate to allow the continuation of a specific activity or the protection of a specific value. In the context of this report, we refer to climate change adaptation regarding Inuvialuit traditional use and a response to the impacts of climate change on the land, water, and traditional resources of the YNS. Adaptation can occur at a variety of temporal, spatial, and institutional scales. Examples of climate change adaptation related to traditional use in the ISR include building emergency shelters and caches for survival in the case of unpredictable weather, building bridges in areas where landscape change has made water crossing unsafe, harvesting alternative species when preferred species availability shift, and organizing workshops and harvesting camps to promote greater knowledge transfer and safety training (Pearce et al. 2011, 2012). It is important to note that climate change adaptation covers a broader range of topics than just traditional use. For example, in addition to subsistence harvesting, ISR-wide adaptation planning considers topics such as infrastructure stability, energy production, and commercial shipping (IRC 2016).

Part of the potential for confusion between these terms comes from the fact that they are often discussed together. For example, discussions of climate change impacts on traditional use in the ISR also report traditional knowledge of ecological change (Nickels et al. 2005, Pearce et al. 2012). In many cases, traditional knowledge and traditional use are inextricably linked, and their relationship should be acknowledged. For example, Inuvialuit observations of moose habitat on the YNS are particularly detailed because moose in certain parts of the study area are preferably harvested over others (WMAC NS and AHTC 2018a). The relationship between traditional knowledge and traditional use makes for a rich body of information that provides perspective that is not addressed through western science. However, the terms themselves should not be conflated. As this report frequently refers to all three topics, it is important to keep these distinctions in mind.

Traditional Knowledge of Climate Change Impacts

There has been extensive community-based research on climate change observations throughout the ISR for over twenty years (Berkes and Jolly 2001, Riedlinger 2001, Kruse et al. 2004, Nickels et al. 2005, Ford and Pearce 2010, Armitage et al. 2011). Climate change has been incorporated into many of the WMAC traditional knowledge studies that describe specific species, wildlife habitat, or traditional use across the YNS (WMAC NS and AHTC 2008, 2009, 2018a, 2018b). This report refers to the wealth of existing traditional knowledge research that has occurred in the ISR as it relates to the specific topics discussed in the proceeding chapters, however Table 1 provides an initial overview of the climate change impacts that have been observed by Inuvialuit land-users, including land-users of the YNS.

Traditional Use and Climate Change on the YNS

Traditional use has been documented across the YNS on a variety of levels (recently reviewed in WMAC(NS) and AHTC 2018b). Oral history projects in the early 1990s documented the rich history of Inuvialuit cultural and subsistence use of the YNS from pre-contact through the multitude of cultural transitions that took place across the ISR (Nagy 1994). Quantitative research has documented the level of reliance on subsistence harvesting across the ISR, including the Beaufort Sea and the YNS (Usher 2002, Joint Secretariat 2003). Early traditional use interviews broadly mapped extensive use across the YNS in two time periods: prior to 1955 and from 1955 to 1974 (Figure 2; Freeman 1976, Usher 1976). Most recently, a thorough interview series documented traditional use of the YNS, including mapping of harvesting areas, travel routes, cultural sites, and indigenous infrastructure (Figure 2; WMAC NS and AHTC 2018b).

Climate change impacts to traditional use have been documented throughout the ISR. Land-users have described impacts to travel due to ground subsidence, erosion, changes in weather, and decreasing sea ice (Nickels et al. 2005, Pearce et al. 2011, 2012, IRC 2016); impacts to the health and availability of harvested wildlife due to changes in weather, species distribution, or habitat (Nickels et al. 2005, WMAC NS and AHTC 2009, 2018a, Pearce et al. 2012); and loss of cultural sites and infrastructure due to erosion and increasingly strong storms (Nickels et al. 2005, WMAC NS and AHTC 2018b). While many of these observations are reported in ISR-wide studies, they have also been documented on the YNS either anecdotally (WMAC, Pers. comms.) or in published research (Nickels et al. 2005, WMAC NS and AHTC 2009, 2018b, IRC 2016). These impacts should form the basis for vulnerability assessments and adaptation planning for traditional use.

Table 1. Climate change impacts observed by Inuvialuit traditional knowledge holders and selected references. Only research and observations that occurred entirely or partially in the community of Aklavik are referenced. Several other studies from the ISR that describe similar impacts are not cited, as they do not make explicit reference to the community of Aklavik.

Theme	Observation	Selected Sources
Climate Change Impacts to Wildlife and Habitat	Changing migration routes and timing	(Nickels et al. 2005, Furgal and Seguin 2006, WMAC NS and AHTC 2009, 2018a, Bartzen 2014)
	Changes in species abundance, range, or frequency of observation	(WMAC NS and AHTC 2009, 2018a, Bartzen 2014)
	Changes to denning timing or behavior	(WMAC NS and AHTC 2008, 2018a)
	Changing quality of harvested fish and wildlife	(IRC 2016)
	Changes to wildlife habitat	(WMAC NS and AHTC 2009, 2018a, Joint Secretariat 2015)
	New or invasive species	(IRC 2016)
Changes to weather and ice	Stronger storms	(Nickels et al. 2005, IRC 2016)
	Greater frequency of freezing rain events	(Nickels et al. 2005, WMAC NS and AHTC 2009, 2018a)
	Later freeze up, earlier breakup	(Nickels et al. 2005)
	Changing near shore ice conditions	(Nickels et al. 2005, Joint Secretariat 2015, IRC 2016, WMAC NS and AHTC 2018b)
Landscape and Vegetation Changes	Lower water levels, less fresh drinking water	(Nickels et al. 2005, Furgal and Seguin 2006)
	Increased sedimentation due to erosion or runoff	(Papik et al. 2003, Nickels et al. 2005, WMAC NS and AHTC 2018b)
	Permafrost thaw and ground subsidence	(Nickels et al. 2005)
	Increased shrub proliferation	(Nickels et al. 2005, WMAC NS and AHTC 2018a)
	Increased rate of landscape greening	(IRC 2016)

Climate Change Adaptation

Increasingly, community-based research has broadened from primarily documenting observed climate change impacts to generating vulnerability assessments and adaptation plans. These assessments are often broad in scope and include many topics that are beyond WMAC's mandate on the YNS (e.g., road maintenance, shipping of commercial goods, and energy production). However, central to many adaptation plans is an effort to ensure continued traditional land-use for current and future generations. These plans emphasize increased traditional knowledge transmission between elders and youth (Pearce et al. 2012, 2015, Johnson et al. 2016, Kettle. et al. 2017, Ford et al. 2017), development of infrastructure to facilitate safe travel over a changing landscape (Pearce et al. 2012, Kettle. et al. 2017, Ford et al. 2017), and a better integration western science, traditional knowledge, and community observation (Johnson et al. 2016, Kettle. et al. 2017, Ford et al. 2017).

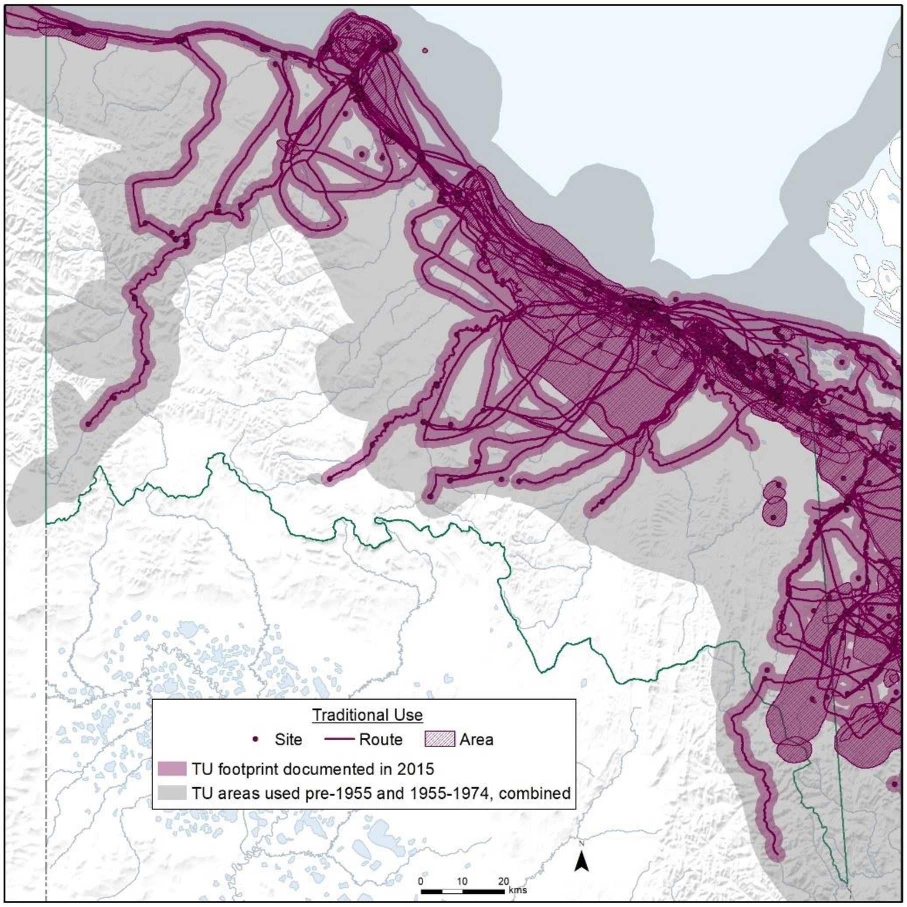

Figure 2. Traditional use on the Yukon North Slope has been documented through at least three different interview-based studies documenting use from pre-1955 to present.

The ISR is engaged in vulnerability and adaptation planning at multiple levels. Regionally, an ISR-wide climate change adaptation plan places a large emphasis on traditional use and the necessity for greater community-based monitoring, adaptation, and increased knowledge transmission between elders and youth (IRC 2016). At a national level, the ISR has contributed to an Inuit adaptation strategy and Government of Canada discussions of climate change adaptation, both of which highlight the need for scientific data and traditional knowledge to inform decision making and adaptation efforts, as well as the desire for more involvement of indigenous land-users in the research and monitoring of climate change (Environment and Climate Change Canada 2018, ITK 2019). These regional and national efforts can directly inform the future work that occurs on the YNS.

Information Gaps and Future Research

Inuvialuit observations of climate change have been, and continue to be, well-documented. Given this strong foundation of work, and the clear mandate to integrate scientific and traditional knowledge in adaptation efforts (IRC 2016, Environment and Climate Change Canada 2018, ITK 2019), there is an opportunity to use traditional knowledge to address research and monitoring needs throughout the YNS. Specific opportunities for traditional knowledge application are described in relation to the topics discussed in following chapters (e.g., application in wildlife research). The focus of this section is to describe the opportunity for building an overarching framework for mobilizing indigenous knowledge and supporting continued traditional use through adaptation planning.

Continued efforts to support traditional use of the YNS are necessary for adapting to the myriad of changes facing landscapes and land-users in the region. The challenges posed by climate change to travel and harvest have been documented in a general sense, but there is a lack of documentation of challenges and unique requirements for continued access and use along specific travel routes, at specific sites, and related to specific activities. For example, shoreline erosion, decreasing near-shore ice, and more unpredictable weather create specific challenges for travel on the coast, while shrub proliferation, changing wildlife migration patterns, and altered river flow likely pose very different challenges for inland hunting camps and cabins. There is a need for research efforts focused on a place-based needs assessment and identification of the adaptation measures necessary to support continued traditional use at specific sites across the YNS.

The 2018 Traditional Use study (WMAC NS and AHTC 2018b) provides excellent documentation of these places. To advance climate change adaptation planning for traditional use, workshops or outreach sessions with land-users could identify the specific challenges, needs and opportunities for continued traditional use on the YNS. Land-users can identify the appropriate adaption strategies that can most effectively support traditional use on the YNS in the face of climate impacts. This could also serve as a tool to channel scientific research proposals towards topics and locations of highest priority for Inuvialuit land-users, while also providing scientists with the necessary context and local knowledge to make their research most relevant.

Additional outreach should also incorporate previously documented traditional use on the YNS. In instances where certain areas or resources are no longer in use, adaptation efforts should seek to understand why. The cultural and social shifts that have occurred throughout the ISR are responsible for major changes in Inuvialuit use of the YNS (WMAC NS and AHTC 2018b), however in instances where environmental change is responsible for less frequent traditional use, adaptation workshops may identify community supported approaches towards sustaining or revitalizing Inuvialuit travel across the region.

There is also a need to make relevant research and monitoring data accessible to land-users. Inuvialuit adaptation planning emphasizes the importance of all citizens being able to access relevant information to inform decision making processes, such as when or where to harvest (IRC 2016, Environment and Climate Change Canada 2018, ITK 2019). While land-users can currently access a variety of disparate data sources (e.g., https://nsidc.org/arcticseaicenews/, https://inuvialuit.knowledgekeeper.ca/, https://www.arcticborderlands.org/), future work should coordinate with greater ISR-wide efforts to make relevant data more accessible to Inuvialuit community members. This will ensure that more land-users benefit from the wealth of climate change information that is produced along the YNS.

Summary

Climate change research and monitoring along YNS is well-positioned to benefit from the extensive knowledge of Inuvialuit land-users. Much of this knowledge is well documented in existing research and is described in the following chapters. The gaps in indigenous knowledge research largely apply to the framework that exists for integrating it alongside scientific studies of climate change. Development of a more formalized program for gathering and applying indigenous knowledge within the existing management framework would benefit both community members and scientific research. Land-users would have greater access to relevant data, and scientists and management bodies could prioritize future based on documented concerns, expressed needs, and land-user observation.

Similarly, traditional use of the YNS has been well-documented and provides a strong foundation for community-based research focused on understanding the challenges, needs, and opportunities land-users currently experience. This supports the development of place-based vulnerability assessments and adaption strategies that can most effectively sustain traditional use on the YNS in the face of climate change. Pursuing this work alongside the development of an accessible database for scientific research and indigenous knowledge will ensure that the current and future research and adaptation efforts on the YNS are of direct relevance to Inuvialuit land-users. These initiatives are summarized in Table 2.

Table 2. Suggested traditional knowledge, traditional use, and climate change adaptation initiatives for use on the YNS

Value	Initiative	Description
Traditional Knowledge	Continued co-application of western science and traditional knowledge	Specific opportunities for traditional knowledge, indigenous monitoring, and western scientific research are described as they relate to specific climate change impacts in the following chapters
	Development of accessible database for Inuvialuit land-users	Create a centralized hub for relevant scientific information and indigenous observation of the YNS, so land-users can make informed travel and harvest decisions
Traditional Use Vulnerability and Adaption	Place-based vulnerability assessment	Community-based description of the threats and opportunities that face travel routes, harvesting areas, infrastructure, and cultural sites throughout the YNS
	Comparison of traditional use studies and assessment of change	Review the broader documentation of Inuvialuit use across the YNS and assess climate change impacts to areas or uses not described in the 2018 Traditional Use study
	Site-specific and use-specific adaptation plans	Building upon the vulnerability assessments, development of community-supported adaption strategies that can be implemented to support on-going access and use of YNS for traditional activities

Chapter 3: Vegetation Change

Overview

Vegetation response to climate change is well-studied across the circumpolar arctic. Indigenous knowledge and observation has documented changing vegetation patterns throughout the arctic (Riedlinger 2001, Huntington et al. 2004, Bennett and Lantz 2014, WMAC NS and AHTC 2018a) and scientific research ranges from using landscape-scale measurements of vegetation change (Tape et al. 2006, van der Kolk et al. 2016, Druel et al. 2019) to site-specific studies that identify changes at an ecosystem or species level (Lantz et al. 2013, Myers-Smith et al. 2019). Regionally, extensive research has been conducted across the Western Canadian Arctic and Alaska, which can be used to guide future studies, particularly in Aullaviat/Auguniarvik. This research can be predictive, retrospective or long-term monitoring, and consists of both broadscale spatial analyses and site-specific field research (SNAP 2012, Zorn et al. 2017, Beamish et al. 2018, Myers-Smith et al. 2019). For the purposes of this review, we have primarily focused on research that is occurring in nearby study areas (Alaska and the Western Canadian Arctic) that has direct relevance for the YNS. We have broadly grouped this research into indigenous knowledge and observation, landscape-level spatial analyses, and site-specific field research.

Indigenous observation of climate change impacts has contributed significantly to understandings of vegetation change in the arctic. In the ISR, indigenous knowledge and observation has identified changes in vegetation growing season, quality, abundance, and distribution (Riedlinger 2001, Nickels et al. 2005, IRC 2016, WMAC NS and AHTC 2018a). On the YNS, the significance of some of these changes on wildlife habitat was recently documented in an interview series of focal species habitat requirements (WMAC NS and AHTC 2018a), and both Herschel Island-Qikiqtaruk Territorial Park and Ivvavik National Park incorporate indigenous observation of vegetation change into ongoing research and monitoring (Parks Canada 2008, 2018, Yukon Parks 2019).

In order to understand patterns of vegetation change at a landscape level, spatial analyses have proven useful in documenting historic change as well as monitoring current trends. The use of LANDSAT data has allowed for a retrospective analysis of vegetation change in Tuktut Nogait National Park and correlating these data with more recent SPOT imagery has produced an estimate of shrub proliferation over a 28-year period (Zorn et al. 2017). In Ivvavik National Park, vegetation change monitoring uses MODIS data to derive NDVI values for the Park and track changes in plant productivity and growing season (Government of Canada 2020a). These approaches are effective in tracking the pace and scale of vegetation change across large areas.

Mapping predicted shifts in vegetation communities provides insight to the future of arctic landscapes. Across the circumpolar arctic, modeling efforts at multiple scales suggest changes to arctic vegetation as temperatures and precipitations patterns shift and landscape dynamics are altered (Pearson et al. 2013, van der Kolk et al. 2016, Druel et al. 2019). In regions with a longer history of field monitoring and weather station data, spatial analyses combined with site-specific research have been used to estimate change probabilities of specific ecotypes that occur across a landscape (DeGange et al. 2014, Marcot et al. 2015). Predictive analyses as they exist along the YNS occur at a broader scale. Anticipated changes in precipitation, temperature and related climate variations have been associated with existing broad vegetative communities to define and map ‘cliomes” and predict shifts in the distribution of these into the future, including for the YNS (SNAP 2012, Rowland et al. 2016). This information is available to inform planning for the YNS.

While landscape-level spatial analyses provide an understanding of broad shifts in vegetation patterns, site-specific field research is integral in understanding species-specific responses and the influence of local environmental conditions on vegetation change. Regionally, long-term monitoring on Qikiqtaruk has documented patterns in shrub proliferation (Myers-Smith et al. 2011b, Myers-Smith et al. 2019), while research in Alaska and the Mackenzie Delta also document increasing shrub proliferation (Sturm et al. 2001, Tape et al. 2006, Lantz et al. 2013). Studies such as these are important for the potential to correct remotely sensed data that may mischaracterize local landscapes. These studies also provide a more detailed understanding of the influence of site characteristics (topography, water availability, etc.) on vegetation change (Walker et al. 2016, Myers-Smith et al. 2019).

Gaps, Future Research, and Monitoring

Indigenous observation of vegetation change exists for traditional use areas in the YNS but potentially not for the most remote areas. Additionally, scientific monitoring and research exists at disparate levels, with significantly less investment in monitoring or research in the eastern YNS than in Ivvavik National Park or on Herschel Island-Qikiqtaruk Territorial Park. Landscape-scale research is needed to better understand change occurring within the region, but this research is often limited by data availability. Thus, prioritizing modeling that relies on readily available datasets may be one way to structure future research efforts (Table 3).

Research and Modelling.

Expanding the coverage of remote vegetation change monitoring that occurs in Ivvavik National Park to the rest of the YNS is one opportunity for advancing understanding of the region. This monitoring uses readily and freely available remote sensing data to derive timing and patterns for green up, brown down and productivity using repeatable and straightforward analyses (Government of Canada 2020a). Extending this across the YNS would provide consistent monitoring of important indexes of change.

Specific ecosystem vulnerability to climate change could be assessed using methods similar to those in Tuktut Nogait National Park (Zorn et al. 2017) that combined ecological conditions assessed as part of the development of an ecosystem classification and downscaled global climate models. This approach may be relatively straightforward if the appropriate ecological data exists (e.g., grids of soil nutrient and moisture regimes characterizing PEM ecosystem classes) and could provide a first prioritization of ecological communities for site-based monitoring.

Tuktut Nogait National Park (Zorn et al. 2017) also completed a much more intensive retrospective analysis of vegetation change using a combination of remote satellite data, which allowed the mapping of shrub and sedge changes over the last 30 years. While this is not a straightforward analysis, it may be considered, particularly to support other potential retrospective analyses of long-term data sets (e.g., Porcupine caribou herd) that could inform current status and potential trends moving forward.

Long-term efforts in Alaska seek to understand the probability of ecosystem transitions at a fine scale (DeGange et al. 2014, Marcot et al. 2015). This research relies on inputs that have been generated from extensive field data, as well as spatial data, and is not currently feasible on the YNS. However, it may be worth monitoring for outputs that could potentially inform selected ecosystems of the YNS. Replicating similar research on the YNS is ambitious, but additional partnerships may identify opportunities to progress the understanding of ecosystem transition probabilities, as they relate to the YNS.

Table 3. Data needs for replicating the spatial and quantitative analyses that are referred to in this section

Analysis	Current Location(s)	Needs for Replication on YNS
Subtle vegetation change monitoring	Ivvavik National Park (Gov. Canada 2020a)	MODIS data are available, and methodology is extendable across the entire study area
Ecosystem class vulnerability	Tuktut Nogait National Park (Zorn et al. 2017)	PEM-type edatopic grid data, downscaled climate data
Retrospective analysis of shrub proliferation	Tuktut Nogait National Park (Zorn et al. 2017)	LANDSAT data are publicly available for entire YNS, but SPOT data are only available for the eastern YNS
Ecotype transition probability quantification	Northwestern Alaska (DeGange et al. 2014, Marcot et al. 2015)	The YNS does not have the equivalent field data used to derive transition probabilities northwestern Alaska

Field Studies and Long-term Monitoring.

Existing field research is limited primarily to within the Ivvavik National Park and Herschel Island-Qikiqtaruk Territorial Park. Extending field research across the entire region will allow for a better understanding of vegetation change. Experimental tundra warming has shown that site-specific responses to climate change are heterogeneous (Bjorkman et al. 2020), and continued field research will be important to corroborate remote sensing data and further understand specific patterns in vegetation change, such as the relationship between substrate and vegetation growth, the influence of water availability on vegetation change, or species-specific responses to climate change (Myers-Smith et al. 2011a, Walker et al. 2016, Myers-Smith et al. 2019, Bjorkman et al. 2020). While the long term monitoring that occurs on Qikiqtaruk (Myers-Smith et al. 2011b, 2011a, Myers-Smith et al. 2019) will continue to inform the region, extending vegetation monitoring points to the eastern YNS will provide a better understanding of changes on a local level.

Expanding long-term monitoring stations to the eastern YNS will also enable better modeling efforts for a several high priority values in the future. For example, the wildlife vulnerability assessments in the western Alaskan arctic that are described in Chapter 4 base future predictions partially on the responses that have been documented over numerous vegetation monitoring plots (DeGange et al. 2014, Marcot et al. 2015). Adding new monitoring sites will likely be resource intensive, however recent advances such as the use of digital cameras for phenological monitoring (van der Kolk et al. 2016, Beamish et al. 2018, Myers-Smith et al. 2019) may allow for the creation of more monitoring sites that require fewer field visits.

The creation of monitoring sites closer to areas of frequent Inuvialuit land-use would allow for greater integration of Inuvialuit observation and knowledge in monitoring vegetation change on YNS. Inuvialuit land-users have also described increased shrub proliferation in the study area (WMAC NS and AHTC 2018a) and rely on local landscapes for berry harvesting and other food and medicinal plant gathering (WMAC NS and AHTC 2018b). Given the detailed interaction between land-users and local landscapes, continuing to support processes for communicating land-user observation of vegetation change to scientists may create a system for guiding future research efforts and informing land-user adaptation. Engaging Inuvialuit land-users in the selection of future research sites would also ensure that scientific monitoring occurs in areas of concern for land-users and contributes information that is relevant to traditional use.

Summary

Regionally, field research and broad spatial analyses have provided a good understanding of the vegetation changes that have occurred in the Western Canadian Arctic and the general patterns of change that can be expected in the future. Extending the landscape-level spatial analyses that occur in Ivvavik to cover the entire YNS, while also incorporating spatial analyses used in Tuktut Nogait is a potential avenue for increasing the coverage and understanding of vegetation change across the YNS (Table 4). Increased field monitoring, particularly in the eastern YNS will add a level of site-specific understanding to the region and presents an opportunity to integrate scientific monitoring with the observations and priorities of local land-users. This will ensure that research continues to meet the needs of local people and that scientific resources are best positioned to reflect the concerns of Inuvialuit land-users.

Table 4. Summary of gaps in vegetation change spatial analyses, quantitative analyses, and field research, and suggested measures to extend these analyses to the study area

Category	Identified Gap	Next Steps
Spatial Analyses	Retrospective vegetation change analysis	Replicate study in Tuktut Nogait on eastern YNS, pursue SPOT data for Ivvavik
Quantitative Analyses	Subtle vegetation change monitoring	Replicate research efforts in Ivvavik across the eastern YNS
Field Research	Extension of field monitoring sites across the study area, particularly the eastern YNS	Identify sites for field monitoring, consider remote monitoring techniques (cameras) where resources are limited
Field Research	Development of an Inuvialuit vegetation monitoring program, based on traditional use	Identify vegetation characteristics best suited for traditional monitoring (phenology, relative abundance, quality), select potential sites based on Inuvialuit use

Chapter 4: Fish and Wildlife Research and Vulnerability

Overview

Wildlife vulnerability to climate change is a broad topic that is directly linked to other changes on the landscape (e.g., vegetation change) in a complex manner that is poorly understood. Regionally, both species-specific research and broad, multi-species vulnerability assessments have informed study areas in the Western Canadian Arctic and Alaska (Regehr et al. 2010, Tape et al. 2013, 2016, DeGange et al. 2014, Gustine et al. 2014, Marcot et al. 2015, Zorn et al. 2017), and traditional knowledge has played a central role in documenting changes to wildlife and habitat across the arctic (Krupnik and Jolly 2002, Kittel et al. 2011, Joint Secretariat 2015, WMAC NS and AHTC 2018a).

The body of climate change research varies considerably across species, study areas, and specific impacts. A comprehensive review of the multitude of specific fish and wildlife studies that relate to arctic climate change is beyond the scope of this report. Additionally, many observed impacts may be specific to local or regional landscapes or species populations, and the applicability to the YNS should be interpreted cautiously. For example, phenological mismatch between caribou calving and nutrient availability has been documented to negatively impact recruitment in Greenland (Post and Forchhammer 2008), however recent research in Alaska suggests that this may not be a universal trend (Gustine et al. 2017).

To target our review towards research that is most likely to directly inform future work on the YNS, we have primarily reviewed literature from the Western Canadian Arctic or Alaska. However, in instances where additional research can inform this work, we have included these studies. We have categorized these studies based on their methodologies and have broadly grouped them as either indigenous knowledge research, field studies, or predictive modeling and vulnerability assessments with the latter two assumed to also integrate indigenous experts and land-users.

Indigenous Knowledge

Indigenous knowledge is particularly important for informing our understanding of climate change impacts in arctic ecosystems, as these patterns are complex, occur over a long period of time, and have only relatively recently been documented scientifically (Riedlinger and Berkes 2001, Kittel et al. 2011). Across the ISR, Inuvialuit land-users have contributed to the understanding of current and potential climate change impacts on a multitude of species (WMAC NS and AHTC 2008, 2009, 2018a, Joint Secretariat 2015, ABEKS 2020). These studies often describe discrete phenomena and their specific impact on a species. For example, the impact of increasing ice events on caribou (Nickels et al. 2005, WMAC NS and AHTC 2018a) or the effect of shrub proliferation on moose habitat (WMAC NS and AHTC 2008). The recent WMAC report on traditional knowledge of wildlife habitat on the YNS documents observed changes and concerns for caribou, grizzly bear, geese, polar bear, moose, and fish habitat (Table 5). Inuvialuit observation and monitoring is incorporated into management of Herschel Island-Qikiqtaruk Territorial Park and Ivvavik National Park (Parks Canada 2018, Yukon Parks 2019), and projects that rely upon indigenous experts will continue to provide critical insights into how climate change is affecting fish, wildlife and their habitats.

Table 5. Observed and predicted impacts of climate change on focal species habitat and behavior. Summary of climate change observations from Inuvialuit wildlife habitat interviews (WMAC and AHTC 2018a).

Species	Observed or Predicted Climate Change Impacts
Caribou	Changing migration routes, potentially due to landscape changes like slumping or increased fire More difficulty crossing major rivers due to faster snowmelt Shrub growth makes lichen less available Increasing freeze/thaw events makes winter lichen foraging more difficult Increased insect harassment in summer Heavier snowfall during winter storms
Moose	More willow growth, longer growing seasons, and earlier spring snowmelt improve moose habitat Drying lakes may negatively impact summer habitat Increased summer insect harassment More common wildfires may negatively impact moose
Grizzly Bear	Enter dens later in the fall and emerge earlier in the spring Slumping and hillside erosion may impact denning habitat
Dolly Varden Char	Shoreline and riverbank erosion increase sediment in rivers Earlier summer migration New species (salmon) entering the region Less summer ice in the ocean impacts near shore habitat Lower snowpack results in lower water levels in important creeks and spawning areas
Geese	Changes in migration patterns Erratic weather threatens geese when they first arrive on the YNS Warmer weather may benefit nesting geese

Field Studies

Field research varies across study areas, climate impacts, and focal species. Studies from the Western Canadian Arctic and Alaska assess a diverse range of topics, such as the threat of parasites and disease (Jenkins et al. 2006, Stephenson and Hartwig 2009), impacts of habitat alteration on species behavior (Pagano et al. 2012), northwards range expansion of species (Stephenson and Hartwig 2009, Tape et al. 2016, 2018), inter-species interactions (Gallant et al. 2012), and changes to phenology (Post and Forchhammer 2008, Gustine et al. 2017, Ross et al. 2017, Saalfeld et al. 2019). Table 6 provides species-specific examples of existing research in the region, however it is based on published literature, and does not include a multitude of non-published monitoring programs in place across the Parks, public lands, and communities in the Western Canadian Arctic and northern Alaska. Specifically, there is a considerable body of unpublished research that documents the population sizes and distributions of species such as moose, sheep, muskox, and polar bear over time on the YNS. These data, as well as the ecological integrity monitoring trends from Ivvavik National Park can be made available for additional analyses by research partners.

*Table 6. Climate change concerns and related research for fish and wildlife species in the arctic. Only studies from the Western Canadian Arctic and Alaska are included int this table. *research that has taken place either partially or completely on the YNS*

Species	Climate Change Concern	Research
Dall's Sheep	Northwards expansion of protostrongylid nematodes	Temperature dependent larval development of nematodes endemic to sub-arctic regions is currently (at the time of publication) limited by climate in arctic regions, future warming may allow northwards expansion (Jenkins et al. 2006)*
Polar Bear	Sea ice decline	Long distance swimming correlated to low ice years in the southern Beaufort (Pagano et al. 2012)
Polar Bear	Sea ice decline	Increased use of barrier islands for habitat as sea ice is less available (Gleason and Rode 2009)
Polar Bear	Sea ice decline	Increase in ice-free days associated with decline in polar bear survival and breeding (Regehr et al. 2010)*
Polar Bear/Grizzly Bear	Increased terrestrial interaction	Grizzly bears are the dominant competitor during interspecies interactions at terrestrial feeding site (Miller et al. 2015)
Polar Bear/Grizzly Bear	Hybridization as ranges increasingly overlap	Eight hybrid bears traced to single female polar bear ancestry, who mated with two grizzly bears, hybrid bears mated with grizzly bears, reducing concerns of genetic swamping of polar bears by grizzly bears (Pongracz et al. 2017)
Shorebirds	Changing snowmelt phenology	Shorebirds exhibit phenological mismatch, with hatch dates occurring after peak insect availability in early snowmelt years and before peak insect availability in late snowmelt years (Saalfeld et al. 2019)
Foxes	Red fox and arctic fox population dynamics	Four decades of den surveys along the YNS do not support the hypothesis that climate warming is responsible for increased red fox dominance in arctic fox habitat (Gallant et al. 2012)*
Beaver	Northwards range expansion	Increased occurrence of beaver in northern Alaska, likely a response to greater availability of woody vegetation and more ice-free water (Tape et al. 2018)
Dolly Varden Char	Increased sedimentation of rivers impacts critical habitat	Ongoing research and monitoring (Stephenson and Hartwig 2009, Parks Canada 2018, Yukon Parks 2019)*
Dolly Varden Char	Increased occurrence of non-native fish (e.g., Pacific salmon) in near-shore waters	Ongoing research and monitoring (Stephenson and Hartwig 2009, Parks Canada 2018, Yukon Parks 2019)*
Dolly Varden Char	Warmer temperatures in critical habitat	Ongoing research and monitoring (Stephenson and Hartwig 2009, Parks Canada 2018, Yukon Parks 2019)*

Species	Climate Change Concern	Research
Caribou	Phenological mismatch between calving timing and nutrient availability	Alaskan Western Arctic Herd not demonstrated to be impacted by phenological mismatch that has been predicted in other populations (Gustine et al. 2017)
Caribou	Impact of climate change on calving grounds, herd size, and migration	Radio collar data monitored and herd sizes estimated in global initiatives to track population response to climate variables (Russell et al. 2013, Gunn and Russell 2015, 2017, Russell and Gunn 2019)*
Arctic Lemmings	Impact of changing snow conditions on habitat	Snow depth is positively correlated with favorable lemming habitat, early fall snow cover provides important insulating capacity and is indicative of winter-long habitat suitability (Reid et al. 2012a)*
Arctic Lemmings/Short Eared Owls	Role of lemmings in owl habitat selection	Short eared owl nesting sites positively correlate with lemming abundance, 4-5 small rodents per hectare is necessary before owls will start nesting (Reid et al. 2012b)*
Moose	Northwards range expansion	Alaskan moose range expansion directly correlated to historic shrub proliferation (Tape et al. 2016)
Geese	Ground subsidence, sedimentation, and inundation create black brant foraging habitat	Observed shifts in black brant occurrence from inland sites to coastal sites is associated with an increase in high quality forage, which has expanded as a result of subsidence, sedimentation, and inundation along the Alaskan arctic coast (Tape et al. 2013)

Within the study area, the Porcupine Caribou Herd (PCH) is the focus of extensive research. The international significance, cultural importance, and ecological function of the PCH is reflected with in-depth research, monitoring, and community outreach (Kruse et al. 2004, WMAC NS and AHTC 2009, Gustine et al. 2014, Gunn and Russell 2015, 2017, Russell and Gunn 2019, ABEKS 2020), and climate change concerns are incorporated into herd-specific research (ABEKS 2014, Russell and Gunn 2019) as well as pan-arctic efforts to monitor trends in caribou and reindeer (Russell et al. 2013, Gunn and Russell 2015, 2017). Given the multitude of bodies that actively monitor the herd and the transboundary nature of research and management, this review does not attempt to summarize the state of knowledge as it relates to the PCH, nor does it seek to inform future research priorities, which have likely advanced well beyond those of many other species in the study area.

Among other species in the arctic, field research often seeks to understand the effect of a discrete abiotic variable on a specific species. For example, the decline in sea ice and its impact across marine species is the focus of extensive published literature and on-going research (Burek et al. 2008, Stephenson and Hartwig 2009, Regehr et al. 2010, 2010, Molnár et al. 2011, Pagano et al. 2012). In the southern Beaufort, sea ice decline has resulted in increased long-distance swimming by polar bears (Pagano et al. 2012) and greater use of terrestrial habitat (Gleason and Rode 2009). A reduction in ice extent may allow for the introduction of non-native marine mammals or fish species and associated disease or parasites (Burek et al. 2008), while also potentially altering food webs for anadromous fish species (Stephenson and Hartwig 2009).

Climate changes have also been documented to affect species distribution and facilitate the arrival of new species to arctic ecosystems. Along the YNS, near shore fisheries have seen an increase in non-native species, such as Pacific salmon, and ongoing research is documenting the changes that are occurring in species distribution along the coast of Ivvavik National Park (Parks Canada 2008). In western Alaska, a northwards expansion of beaver populations is associated with an increase in woody vegetation and ice free waters (Tape et al. 2018), and similar patterns have been observed in moose, both in Alaska (Tape et al. 2016), and through indigenous observation on the YNS (WMAC NS and AHTC 2018a).

Changes in phenology have been documented to affect multiple species. In Northern Alaska, early snowmelt conditions have resulted a mismatch between shorebird hatching and peak insect availability (Saalfeld et al. 2019). In the central Canadian arctic, early geese nesting, as a result of warmer spring, has been associated with lower nutrient availability and decreased clutch size (Ross et al. 2017). In Hudson Bay polar bear populations, migration is correlated to sea ice break up, and changing ice conditions are altering migration timing (Cherry et al. 2013). A phenological mismatch between caribou calving and spring green up is the subject of pan-arctic research, with results varying by study area (Post and Forchhammer 2008, Gustine et al. 2017, Mallory and Boyce 2018).

Research is not limited to understanding singular changes on species biology, but also considers complex and inter-related cumulative impacts of climate change, such as food web alteration. For example, research on lemming populations in Canadian arctic Parks suggests a minimum requisite population density to support nesting short eared owls, which may be impacted by changing vegetation or snow patterns (Reid et al. 2012a, 2012b). Increasing productivity in arctic lakes may result in a short-term increases in food availability and potential change to the anadromy of fish populations, such as arctic char (Reist et al. 2006). As Hudson Bay populations of polar bear are coming to shore earlier, due sea ice decline, they overlap with nesting snow geese, making up some of their caloric deficit by preying on eggs (Rockwell and Gormezano 2009). These examples highlight the importance of ongoing research and monitoring in understanding the greater significance and interrelatedness of individual changes to arctic systems.

Predictive Modeling and Vulnerability Assessments

Field studies, such as those referenced above, often inform modeling efforts and vulnerability assessments that provide an approach to further understand and predict climate change impacts to fish and wildlife. Generally, these models incorporate species' exposure, sensitivity, and adaptive capacity when determining climate change vulnerability and can be grouped into mechanistic, correlative, and trait-based assessments (Pacifici et al. 2015, Foden and Young 2016). Examples of these assessments exist across multiple arctic landscapes and methodologies are often shaped by the needs of local study areas and the quality and availability of site-specific input data.

Mechanistic models of wildlife vulnerability link physical changes to the environment with their effect on a particular species (Van Hemert et al. 2015). These models inform climate change research on a variety of species across the arctic. Retrospective modeling of moose habitat in Alaska has demonstrated the correlation between northwards shrub expansion and increasing moose populations (Tape et al. 2016). Research from the Arctic Coastal Plain of Alaska has shown that permafrost subsidence is increasing quality goose habitat (Tape et al. 2013). Modeling changes in arctic fire regimes and their impact on lichen availability has quantified future impacts to winter caribou range (Joly et al. 2012, Gustine et al. 2014). Extensive research on polar bears has demonstrated the impact of sea ice loss on diet, survival, and breeding success (Rockwell and Gormezano 2009, Regehr et al. 2010, Molnár et al. 2011). These models require a detailed understanding of both the specific environmental change in question and the behavioral or population level response of a species.

Broader vulnerability assessments, such as correlative approaches, are used in the absence of a detailed understanding of specific ecological processes and their impact on a species or to compare predictions across multiple species. Correlative models assess vulnerability based on habitat or landscape associations and the predicted changes to those environmental conditions (Pacifici et al. 2015, Foden and Young 2016). For example, research across the Alaskan arctic uses spatial predicted shifts in climate and biomes (SNAP 2012), field data, and expert opinion to identify ecotypes with a high transition probability and based wildlife vulnerability on known associations between species and ecotypes that are likely to change (DeGange et al. 2014, Marcot et al. 2015). Marcot et al. (2015) note that these broad modeling efforts are best viewed as a starting point for understanding vulnerabilities, and their outputs can be used to generate future testable hypotheses and guide additional research and monitoring.

Trait-based models measure climate change vulnerability by assessing life history traits of selected species, often through expert opinion or previous research, to determine species' exposure, sensitivity, and adaptive capacity to climate change (Foden et al. 2013, Pacifici et al. 2015, Hof et al. 2017). For example, research on arctic and subarctic breeding birds assessed species traits such as average life span, breeding habitat, and brood size, and used these traits to inform an assessment on climate vulnerability (Hof et al. 2017). In Tuktut Nogait National Park, a multi-species vulnerability assessment uses the NatureServe toolkit, which assesses species vulnerability based on an assortment of documented life history traits, paired with downscaled global circulation data (Young et al. 2016, Zorn et al. 2017). The results of this assessment categorize species as either extremely vulnerable, highly vulnerable, moderately vulnerable, less vulnerable, or having insufficient evidence. For example, species with specific habitat requirements and limited range (e.g., polar bears and northern collared lemmings) are classified as highly vulnerable, while generalist species that exist in boreal ecosystems as well as the arctic (e.g., wolves) are considered less vulnerable (Zorn et al. 2017).

Gaps and Future Research

Extending the ecological integrity monitoring that occurs in Ivvavik National Park and on Qikiqtaruk (Parks Canada 2008, 2018, Yukon Parks 2019) will help to increase the understanding of the current status of fish and wildlife on the eastern YNS and direct future climate change research. This can be done in conjunction with other research discussed in this report. For example, the aquatic sampling that occurs on the Firth River (Parks Canada 2008) meets many of the criteria discussed in the stream monitoring section of Chapter Four. Additionally, the creation of a framework to guide future academic research partnerships, as exists on Qikiqtaruk and in Ivvavik (Parks Canada 2008, 2018, Yukon Parks 2019), will facilitate more in-depth field studies of species-specific climate impacts.

The remoteness of the YNS presents challenges to expanding existing monitoring or establishing new research. Still, the lack of population monitoring across species and geographies limits efforts to understand their current and potentially changing status on the YNS. Extending the coverage of the existing land-user and scientific monitoring that already occurs in parts of the study area (Parks Canada 2008, 2018, DFO 2017, Yukon Parks 2019) may be the logical first step in increasing understanding of climate change impacts across the YNS. In instances where resource limitations make greater field efforts unfeasible, there is potential to incorporate new technologies and improved analytical techniques that may allow for effective and more efficient monitoring. For example, the use of satellite imagery has proven effective in remotely monitoring large arctic mammal populations, as have drone and more traditional flight surveys (Stapleton et al. 2014, Barnas et al. 2018, Wang et al. 2019).

In order to prioritize and guide future research and monitoring efforts, the YNS should develop a multi-species climate vulnerability assessment. While this assessment is unlikely to advance the understanding of species that have been the focus of extensive research, such as caribou and polar bear, it can provide new insights into the vulnerability of other species. An overarching assessment of comparative vulnerabilities across fish and wildlife that have not been the focus of significant research to date would help to inform planning and the prioritization of new or expanded research and monitoring efforts in the region.

The type and utility of vulnerability assessments are dependent partly upon the available data on ecological change in the study area (Table 7). Mechanistic and correlative models have higher data requirements. For example, to calculate change probabilities of species habitat ecotypes, vulnerability assessments in northwestern Alaska rely on field data and expert opinion that is not currently available for the YNS (DeGange et al. 2014, Marcot et al. 2015). However, the PEM for the YNS could be used in conjunction with downscaled global circulation models to broadly identify ecotypes that are vulnerable to change (e.g., Zorn et al. 2017). Identifying wildlife species that are associated with these ecotypes may be one approach towards a broad assessment of vulnerability. It may be more feasible to initially undertake trait-based vulnerability assessments or a customized blend of approaches that maximize information based on data availability. Tool-based approaches, such as NatureServe (Young et al. 2016) may provide a structured approach to vulnerability assessment. In either case, these efforts should be used as an initial assessment of species vulnerability, to prioritize future, more detailed research and monitoring efforts.

The wealth of Inuvialuit knowledge related to wildlife and wildlife habitat should inform climate change assessments. Aklavik community members have already identified focal species that represent a diversity of aquatic and terrestrial habitat types across the YNS, and contributed to a more detailed understanding of their ecological requirements and an initial assessment of climate change vulnerabilities (WMAC NS and AHTC 2018a). Future climate change research should build off this work. A land-user assessment of climate change scenarios and their potential impact on wildlife species can provide an expert opinion model based in traditional knowledge and be integrated into a quantitative vulnerability analysis.

Table 7. Broad categories of predictive climate change models used for assessing species vulnerability

Model Type	Description	Applicability to YNS
Correlative Habitat Association Model	-Models ecotype transition probabilities based on field data, expert opinion, and global climate models -Determines species vulnerability based on known associations with ecotypes that vulnerable to change	-YNS lacks the field data to inform ecotype transition probabilities -Possible to map areas of greatest potential climatic change and quantify ecotypes that exist in these areas
Trait-based Model	-Incorporates known life history traits of multiple species and uses predicted climatic shifts to categorize species vulnerability into low to high ranging categories	-Potential to use NatureServe and replicate the approach taken in Tuktut Nogait -Potential for expert informed model
Mechanistic Model	-Quantifies the impact of specific environmental change on a species response -Already informs some species in the study area (e.g., impacts of increasing fire on caribou winter range)	- Species-specific models currently inform some species (e.g., caribou) -Future identification of modeling needs could be a product of a more broad-based model

Summary

There is a vast and growing body of research on the complex responses of arctic wildlife to climate change. The depth of research varies significantly, based on study area, focal species, and climate change impact. Research that has taken place specifically on the YNS is limited compared to the pan-arctic body of knowledge, and while some studies can further the understanding of select fish and wildlife species, their results should be interpreted with caution as site-specific and population-specific responses to climate change may not apply universally. The research that has occurred on the YNS is critically important to understanding trends in species that are important to Inuvialuit land-users, however the existing body of knowledge is limited in scope.

The YNS would benefit from the development of baseline climate change vulnerability assessments for a broad suite of culturally and ecologically important fish and wildlife species. The specific nature of these assessments will vary based on the available data inputs. The species identified as vulnerable may then be prioritized for more in-depth research and analyses or as a focal species for monitoring efforts.

Additionally, extending the ecological integrity monitoring that occurs in Ivvavik and on Herschel Island-Qikiqtaruk will benefit the eastern YNS. This can be done in conjunction with other recommended monitoring activities in this report (e.g., vegetation and aquatics monitoring) and will provide a platform for incorporating Inuvialuit observation while obtaining additional quantitative data. Options for implementing effective population monitoring for fish and wildlife species identified as vulnerable to climate change should be considered. This monitoring program can then inform future in-depth field research projects to better understand species-specific responses to climate change.

Chapter 5: Erosion, Permafrost Thaw, and Aquatic and Marine Impacts

Overview

Arctic landscapes are undergoing dramatic changes as ground ice thaws, sea levels rise, and precipitation patterns change. Across the Circumpolar North, research increasingly highlights both the wide-ranging occurrence of these perturbations, as well as gaps in fully understanding the extent to which erosion, permafrost thaw, and changing watercourse features alter local ecosystems (Lantuit and Pollard 2008, Semiletov et al. 2011, Bring et al. 2017, Couture et al. 2018, Irrgang et al. 2018). Regionally, the Western Canadian Arctic is experiencing intensive permafrost slumping (Lantz and Kokelj 2008, Lantuit and Pollard 2008, Kokelj et al. 2013, Segal et al. 2015, 2016) and rapid coastal erosion (Lantuit and Pollard 2008, Radosavljevic et al. 2016, Couture et al. 2018, Irrgang et al. 2018, 2019), both of which occur to some degree along the YNS. These changes have potential to impact indigenous land-use and in many cases, Inuvialuit land-users have already faced disruptions to travel, fishing, and wildlife harvesting as a result of a transformed landscape. This chapter groups these vulnerabilities because they have the potential to affect ecological and cultural values similarly and future research needs may be complementary to one another.

Coastal Erosion

Existing Research

While coastal erosion has long been observed across the YNS, recent scientific research has offered an improved understanding of the rate and significance of this change (Konopczak et al. 2014, Couture et al. 2018, Irrgang et al. 2018, 2019). Comparisons of historic aerial imagery along a 210 km stretch of the Yukon coast demonstrated an erosion rate of -1.3 m/year during the 1950s through 1970, -.5 m/year from the 1970s through 1990s, and a recent increase in shoreline change rate to -1.3 m/year from the 1990s to 2011 (Irrgang et al. 2018). Erosion rates are highest along the western YNS, likely due to higher exposure to intense storm activity (Konopczak et al. 2014, Irrgang et al. 2018). However, shoreline change extends beyond the borders of Ivvavik National Park and impacts important parts of the eastern YNS, such as Shingle Point (Irrgang et al. 2018, 2019).

Coastal erosion has the potential to significantly impact key values across the YNS. Inuvialuit land-users have witnessed the loss of cultural sites as the coast erodes (WMAC NS and AHTC 2018b), and recent aerial imagery analysis has helped to quantify the extent of this loss (Irrgang et al. 2019). Future modeling scenarios suggest the potential for increased loss of cultural sites and infrastructure along the coast, either due to erosion or sea level rise (Irrgang et al. 2019). Erosion also poses a threat to Inuvialuit travel. Irrgang et al. (2019) highlight the threats that erosion poses to airstrips located at DEW Line sites in Ivvavik National Park, however shoreline erosion also impacts Inuvialuit travel along the coast, making it more difficult for land-users to navigate the shoreline, avoid gravel bars, or land boats (Papik et al. 2003, WMAC NS and AHTC 2018b).

As the magnitude and extent of arctic shoreline erosion is further understood at an international level, patterns along the YNS has are being incorporated into broader discussions of carbon cycling, nutrient loading, and climate change impacts across the North (Fritz et al. 2017, Couture et al. 2018, Grotheer et al. 2020). Recent research from the Yukon Coastal Plain has provided clearer insight into the level of carbon that is being added to Canada's Beaufort coastline, which has direct implications for discussions on global carbon budgets (Couture et al. 2018).

Information Gaps and Continued Research Needs

The most immediately apparent threat posed by coastal erosion is the loss of Inuvialuit cultural sites, infrastructure, and travel routes. In order to understand and respond to these threats, a greater documentation of cultural resources and their vulnerabilities is needed. While cultural sites inventorying has been completed in a systematic fashion within the boundaries of Ivvavik National Park, Irrgang et al. (2019) note that models of erosion vulnerability may not acknowledge additional sites that have not been inventoried in the eastern YNS. Similar research on Qikiqtaruk suggests prioritizing archaeological work in the immediate future in erosion and flooding prone sites in order to better understand the values that are threatened (Radosavljevic et al. 2016). Documenting these sites and updating relevant spatial data to inform future assessments of cultural vulnerabilities will provide a more accurate understanding on the implications of shoreline erosion.

The larger question of how to respond to these threats is a values-based decision, which requires the full input of the Inuvialuit community. In many cases, moving or actively preserving a cultural site may be deemed culturally inappropriate, however the recent traditional use study across the YNS suggests this belief may not be uniform across community members or specific sites (WMAC NS and AHTC 2018b), and previous community-based research has documented concern over this change (Nickels et al. 2005). Therefore, future community-based work should focus on achieving an official strategy for addressing these sites, and additional scientific research should be framed in a manner that supports this process with relevant information.

Shoreline erosion also has the potential to alter near shore marine food webs, which may affect Inuvialuit subsistence fishing to an extent that is not yet fully understood (Fritz et al. 2017). Shoreline erosion is responsible for a large input of terrestrial carbon into marine food webs, and nearshore sampling in the Beaufort Sea has shown the potential influence of this input on assimilation of carbon in arctic cod (Dunton et al. 2006). Additionally, sedimentation of coastal waters may disrupt Dolly Varden (locally referred to as char) migration corridors (IFMP 2010). The direct impact of sediment and nutrient loading on Inuvialuit subsistence harvesting is still unclear, however given the significant transformation occurring along near shore ecosystems and the importance of the harvesting that occurs here, future efforts to better understand these changes are directly relevant to Inuvialuit interests across the YNS.

The range in scale of erosion-related impacts, from point specific losses (e.g., loss of grave sites) to issues of broader ecological concern (e.g., marine food webs), suggest the need for an integrated approach to monitoring and adaptation along the YNS that pairs local knowledge and priorities with scientific research. Inuvialuit monitoring programs have the potential for documenting observations of changes as they are encountered across the Mackenzie Delta Region and along the YNS (Bennett and Lantz 2014) and many current ecological observations are made by Inuvialuit land-users who are employed in Ivvavik National Park or Herschel Island-Qikiqtaruk Territorial Park (Parks Canada 2008, 2018, WMAC NS and AHTC 2018a, Yukon Parks 2019). Table 8 illustrates the range in ecological and cultural values that can be integrated into an erosion monitoring program across multiple sites along the YNS. Developing research and monitoring of erosion and flooding prone sites with Inuvialuit land-users will ensure that research reflects the priorities of local land-users and help community members benefit more directly from the information that is being generated from these sites.

Table 8. Impacts of coastal erosion on specific values, existing research, and identified information gaps on the YNS.

Value	Erosion Threat	Existing Research	Research Gaps
Cultural sites and infrastructure	-Loss of heritage sites and land-user infrastructure as shorelines recede	-Noted in multiple TK-based research efforts -Irrgang et al. (2019) quantifies the extent to which the YNS has been affected and models future scenarios	-Systematic inventorying of features at selected sites in the eastern YNS -Development of an Inuvialuit led strategy for addressing the threat to cultural sites and infrastructure
Shoreline Travel	-Erosion changes coastline and makes certain areas less navigable by boat -Exacerbated by loss of sea ice, less predictable weather, and stronger storms	-Described in multiple TK-based research efforts	-Document areas of specific concern and discuss strategies for avoiding these passages -Formalize a central hub for shoreline observations that the community can access
Fisheries	-Potential for nutrient loading from erosion to alter near-shore ecosystems (including anadromous fish habitat)	-Little research exists globally	-Begin near-shore research and monitoring program -Collaborate with Inuvialuit land-users to place initial research sites at locations of community concern

Inland Permafrost Thaw and Slumping

Existing Research

Regionally, permafrost slumping is a major driver of landscape change across the Western Canadian Arctic (Kokelj et al. 2013, 2017, Segal et al. 2016). In areas where slumping rates are at their highest, such as southeastern Banks Island, landscape transformation has become incredibly dynamic (Segal et al. 2016, Kokelj et al. 2017). Recent research has focused on identifying the drivers of permafrost slumping (Segal et al. 2016, Kokelj et al. 2017), as well as the ecological impacts of this change (Chin et al. 2016, Levenstein et al. 2018). This research tends to focus on the landscapes that are most affected by slumping, such as the Peel Plateau (Kokelj et al. 2013, Chin et al. 2016, Levenstein et al. 2018) or Banks Island (Segal et al. 2016, Fraser et al. 2018), however slumping exists within the YNS (Kokelj et al. 2017) and it is not unnoticed by Inuvialuit land-users, who have expressed concern over slumping impacts in the region (WMAC NS and AHTC 2018a).

Information Gaps and Future Research

While inland permafrost slumping does not pose the dramatic and immediate threat to YNS landscapes and Inuvialuit traditional use that coastal erosion does, the potential for slumping of ice rich terrain to impact local ecosystems warrants further research and monitoring. Of particular concern may be the impact that permafrost thaw slumps have on adjacent stream systems, where increases in solute and sediment delivery can significantly alter stream food webs (Chin et al. 2016, Levenstein et al. 2018) or impact fish spawning beds (CliC/AMAP/IASC 2016). Inuvialuit land-users have also expressed concern over the impact slumping may have on other landscape values, such as grizzly bear den sites or caribou movement routes (WMAC NS and AHTC 2018a).

There is a need to develop a more formalized permafrost monitoring system across the eastern YNS. This could be done in conjunction with borehole monitoring that is taking place in Ivvavik (Government of Canada 2020b), and provide the basis for future research in the region. This research may be particularly useful along major river systems, where increased erosion has the potential to impact important fish species, such as Dolly Varden char (Reist et al. 2006, IFMP 2010, WMAC NS 2012) and may provide relevant information for stream flow monitoring (see next section).

Stream Flow Changes

Existing Research

Linked to discussions of coastal erosion and inland permafrost slumping are the significant changes that are occurring in arctic river systems. Changes in precipitation, runoff, ice melt, and ground cover all directly influence arctic rivers (Prowse et al. 2006, CliC/AMAP/IASC 2016). Pan-arctic research has largely focused on demonstrating the broadscale changes to river systems, such as discharge rates into the Arctic Ocean (Fichot et al. 2013, McClelland et al. 2014, Bring et al. 2017, Park et al. 2017), and documenting global patterns of ecological and hydrological significance (Vincent et al. 2011). Much of this research focuses on major drainage systems, such as the Mackenzie River Basin (e.g., Finchot et al. 2013) and major Eurasian Rivers (e.g., Semiletov et al. 2011), however much like coastal erosion, the global significance of this change is mirrored by local concerns of high priority. Inuvialuit land-users have identified impacts to river systems a source of concern for fish habitat, land-user travel, and even observe changing river conditions as an impediment for the Porcupine Caribou Herd (WMAC NS and AHTC 2018a). Therefore, while the changes occurring along the YNS can inform global discussions of climate change impacts, monitoring of flow rates, breakup timing, sediment load, temperature, and other hydrological metrics are of direct relevance to Inuvialuit land-users and local ecology.

Information Gaps and Further Research

The YNS would benefit from extending the network of existing research and monitoring stations that are primarily within Ivvavik National Park to more fully provide a network of sites throughout the region. Currently, there are hydrometric data stations on the Firth and Babbage Rivers (Government of Canada 2020c) and aquatic inventories in Ivvavik National Park (Parks Canada 2008), but little information is available for the other major rivers in the study area. Development of a more expansive and consistent monitoring regime, particularly along the eastern YNS, will be beneficial in understanding the changes that are affecting the region. These changes have direct relevance for Inuvialuit traditional use, as altered river flow, salinity, sedimentation, and temperature all have the potential to impact fish populations (Reist et al. 2006, IFMP 2010), impact wildlife habitat (WMAC NS and AHTC 2018a), or affect land-use (WMAC NS and AHTC 2018a, 2018b).

Work across the circumpolar arctic may be helpful in guiding future research efforts. The Arctic Council has created an Arctic Freshwater Biodiversity Monitoring Plan, which provides general guidelines for monitoring rivers across the arctic and detailed sampling protocols for abiotic and biotic focal ecosystem components (Culp et al. 2013). While the document is intended to guide global assessments of arctic change, it may be a useful resource in developing a more extensive stream monitoring system across the YNS (Table 9). The remoteness and lack of infrastructure across the YNS may make it difficult to fully employ these monitoring protocols across the study area, however many sampling measurements can be taken remotely or only require annual field visits. Many of the variables described in Table 8 are sampled as part of the ecological integrity monitoring in Ivvavik National Park (Parks Canada 2008) and are also measured in the Alaskan arctic (Whitman et al. 2011).

Table 9. Biotic and abiotic focal ecosystem components (FECs) for river monitoring, as suggested by the Arctic Council's Arctic Freshwater Biodiversity Monitoring Plan (Culp et al. 2013). A full implementation of this monitoring protocol is likely unrealistic across the study area, due to the remoteness of the region and lack of available infrastructure, however this represents a framework for building a systematic river monitoring network that focuses on priority issues in arctic freshwater systems.

Biotic FEC	Recommended Sampling	Abiotic FEC	Recommended Sampling
Benthic algae	Annually in late summer/early fall, taxonomic identification essential for assessing changes in community indices	**Water temperature**	Continuous logger data
Benthic macroinvertebrates	Annually, in ice free season	**Hydrologic and ice regimes**	Discharge levels over the ice-free season
Fish	Standardized by effort or area for better comparison	**Water Quality**	Dissolved phosphorus, unfiltered phosphorus, nitrogen, nitrate, dissolved organic carbon, colored dissolved organic matter, pH, alkalinity, conductivity, major ions, total suspended solids, and dissolved oxygen
Riparian Vegetation	Regularly spaced intervals along large river systems	**Climatic regime**	Surface air temperature, precipitation, relative humidity, wind speed and direction, snow depth
		Permafrost and active layer	Active layer measurements, borehole temperatures

Summary

The YNS is well positioned to build on existing research and monitoring efforts to better understand vulnerabilities and changes associated with coastal erosion, permafrost slumping, and changes to river flow. The extent of coastline change has been recently well documented in the region (Irrgang et al. 2018) and there is a clear link between this change and values of importance for Inuvialuit land-users (Radosavljevic et al. 2016, WMAC NS and AHTC 2018b, Irrgang et al. 2019). Future research may focus on site-specific needs in the region: inventorying cultural sites in vulnerable areas and identifying impacts to the Inuvialuit land-uses that are most vulnerable to change along the coast. Additional scientific research may investigate the impacts of coastal erosion on anadromous fish populations, coupling this with traditional use monitoring. Inland permafrost slumping is of less concern in the study area, compared to other sites in the Western Canadian Arctic, however increased monitoring of permafrost may be important, especially along major rivers. As multiple large rivers run through the study area, a more extensive stream flow monitoring program would provide a better understanding of the changes that are facing regional ecosystems and the traditional land-use associated with them.

These research priorities are directly linked to Inuvialuit land-use and traditional values. The Traditional Use Study of the YNS provides an excellent depiction of Inuvialuit travel routes, cultural sites, infrastructure, and harvesting areas across the YNS (WMAC NS and AHTC 2018b), all of which can be used to prioritize future research efforts. This would provide a better understanding of the level of vulnerability at certain sites and the specific threats that land-use may face. Incorporating land-user observations through an Inuvialuit monitoring program may increase the likelihood of detecting change in the region, and guide future scientific research efforts (Bennett and Lantz 2014). We have grouped these climate change impacts because they have the potential to affect Inuvialuit values similarly across the landscape and summarize suggested actions in Table 10.

Table 10. Summary of suggested research and monitoring for coastal erosion, inland permafrost thaw, and watercourse features in the study area

Environmental Change	Suggested Research, Monitoring, and Community Processes
Coastal Erosion	Extended systematic cultural inventorying to vulnerable areas in eastern YNS Facilitated discussions on culturally appropriate response to cultural sites threats Increased research on impacts of erosion and sedimentation on marine food webs
Inland permafrost thaw	Formalized permafrost monitoring, especially near water features
Impacts to Watercourse Features	Extend monitoring that occurs along Firth and Babbage Rivers to the eastern YNS Incorporate existing ecological integrity monitoring from Ivvavik (Parks Canada 2008) as well as global recommendations for aquatic sampling (Culp et al. 2013)

Chapter 6: Conclusion and Summary

Arctic ecosystems are undergoing vast and rapid ecological change. In the context of the YNS, this has a direct impact on Inuvialuit land-users. This report is a summary of major climate change research of direct relevance to the land, fish, wildlife, and traditional use of the YNS. Specifically, it is an assessment of the gaps in research, monitoring, and understanding of these changes and an identification of strategies to better support Inuvialuit land-users in adapting to climate change on the YNS. While the scope of this report is not comprehensive of all environmental changes that are affecting arctic ecosystems, it is organized in a manner to support the development of additional field efforts, modeling, and community-based monitoring that would be beneficial and feasible given the extent of current research.

This report places an emphasis on extending the coverage of research and monitoring activities to better understand climate change on the eastern YNS. The proximity of the eastern YNS to the community of Aklavik and the frequency of use by Inuvialuit community members means that any additional understanding of climate change impacts has the potential to significantly inform land-user decisions and support continued traditional use in the face of global climate change. While the entire study area is discussed in this report, research and monitoring efforts on Herschel Island-Qikiqtaruk Territorial Park and in Ivvavik National Park are significantly beyond those on the eastern YNS, where there are many opportunities to improve the level of understanding as it relates to climate change impacts on local ecosystems.

WMAC(NS) and the Aklavik HTC are well positioned to build off existing research partnerships to better monitor and address climate change on the YNS. This document can serve as a guide for directing the efforts of future endeavors between WMAC (NS), Aklavik HTC, and partners, such as Yukon Government, the Government of Canada, the Inuvialuit Game Council, the Inuvialuit Regional Corporation, the Aklavik Community Corporation, Yukon University, the Aurora Research Institute, and other academic institutions. As the scale of climate change research on the YNS expands, these partnerships can serve a critical role in addressing the priorities described in this report.

Table 11 provides a broad summary of the suggested research, monitoring, and community-based activities to better understand and respond to climate change on the YNS. Many of these activities are an extension of pre-existing research, for example, extending the coverage of vegetation monitoring or stream sampling that occurs in Ivvavik or Qikiqtaruk to the eastern YNS. Broadening the scope of existing research on the YNS, while also pursuing new research, such as traditional use vulnerability and species vulnerability assessments, has the potential to benefit the continued efforts of WMAC (NS) to contribute to conservation and management across the YNS.

Table 3. Summary of suggested research, assessment, planning and monitoring activities suggested in this report.

	Potential Activity	Description
Research, Assessment and Adaption Planning	Traditional use vulnerability assessment and adaptation planning	Identify challenges, needs and opportunities related to accessing and using the YNS; identify ways to support and enhance on-going and future use in face of changing conditions
	Systematic archaeological inventory of eastern YNS	Inventorying the eastern YNS will allow for a more complete assessment of erosion and flooding vulnerability of cultural sites per Irrgang et al. (2019)
	Development of Inuvialuit-led approach towards addressing vulnerable cultural sites	Discuss the range of options in protecting cultural sites and develop consensus response to threatened cultural sites and traditional use areas
	Historical vegetation change analysis	Use historical aerial imagery to document change in vegetation cover over time
	Quantification of PEM units vulnerable to change	Identify PEM units likely to change based on downscaled GCMs
	Near shore impacts of erosion on fisheries research	Site-specific research on the impacts of increased sedimentation on anadromous fish habitat
	Fish and Wildlife vulnerability assessment	Broadscale assessment to identify species most vulnerable to climate change impacts
Monitoring	Place-based vulnerability monitoring at important use areas	Document specific threats to cultural sites, travel routes, harvesting zones, and other areas or activities
	Stream monitoring extended across major rivers in study area	Monitor rivers throughout study area for changes in flow, biota, sedimentation, and chemistry
	MODIS vegetation change monitoring extended to eastern YNS	Extend the monitoring efforts in Ivvavik to eastern YNS
	Inland permafrost/active layer monitoring	Extend permafrost monitoring to eastern YNS for a more complete understanding of inland vulnerabilities
	Development of long-term vegetation monitoring sites across YNS	Extend vegetation monitoring efforts throughout the eastern YNS, so that data can inform future planning and modeling
	Installation of weather stations across eastern YNS	Weather data will support all research and monitoring projects
	Development of community-based monitoring system and user-friendly environmental observation database	Integrate with existing efforts across multiple governance bodies (IRC, AHTC, WMAC NS), in order to support ISR-wide adaptation efforts
	Development of Inuvialuit-led approach towards addressing vulnerable cultural sites	Discuss the range of options in protecting cultural sites and develop consensus response to threatened cultural sites and traditional use areas

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