



THREATS TO BIODIVERSITY – CLIMATE CHANGE

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ABSTRACT

Climate change is projected to have substantial impacts on biotic and abiotic conditions globally, particularly in northern regions such as the Northwest Territories (NWT) where temperatures are warming at a faster rate than the global average. Environmental changes such as altered temperature and precipitation are likely to influence biodiversity by affecting habitats (e.g. vegetation shifts and sea ice decline) and resource availability, leading to potential changes in species distributions, predator-prey interactions and phenology. Species at risk are especially vulnerable to these threats. Ecofish Research Ltd. conducted a literature review to identify and summarize projected changes to biotic and abiotic conditions in response to climate change in the NWT and potential impacts to species at risk. Specifically, we determined projected changes to climate and physical parameters in the NWT. We then examined potential effects of climate change on habitat, biotic interactions, phenology, physiological thresholds, and population level parameters for species at risk in the NWT. The NWT was projected to experience substantial climate change in the future, including continued temperature rise, sea ice decline, changes in precipitation, increased extreme weather events, declines in snow cover, and rising sea levels. We found that climate change was projected to negatively affect the one plant species on the NWT List of Species at Risk (hairy braya) (*Braya pilosa*). For all mammals examined, climate change was projected to negatively affect habitat availability (e.g. changes to vegetation and sea ice) and biotic interactions (e.g. predator-prey or food availability); caribou (*Rangifer tarandus*) (especially Peary caribou) (*R. tarandus pearyi*) and polar bears (*Ursus maritimus*) were identified as particularly vulnerable to climate change effects. Avian habitat loss as well as changes to phenology and breeding success were projected to occur due to climate change. Climate change was projected to negatively affect invertebrate habitats (especially through extreme weather events), species richness, and survival (particularly for bumble bees). Lastly, climate change was projected to negatively affect northern leopard frog (*Lithobates pipiens*) and western toad (*Anaxyrus boreas*) habitats, phenology (breeding and hibernation) and physiology. This report, and the literature cited therein, will help inform evaluation of threats to biodiversity resulting from climate change and contribute to assessments of threats and limiting factors for NWT Species at Risk Committee Status Reports.

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INTRODUCTION

Ecofish Research Ltd. (Ecofish) have conducted a literature review and synthesis on behalf of the Government of the Northwest Territories' (GNWT) Department of Environment and Climate Change (ECC) to describe anticipated changes to biotic and abiotic conditions in the context of climate change to assist with interpretation of threats to biodiversity in the Northwest Territories (NWT). The review focused on information that supports an interpretation of the Threats and Limiting Factors assessment in the Detailed Instructions for Preparation of a Species at Risk Committee (SARC) Status Report: Scientific Knowledge Component (GNWT SARC 2019).

Climate change will have far reaching impacts on biotic and abiotic conditions in the NWT and other northern regions where temperatures are warming at a faster rate than the global average. Changes that are already being observed and are expected to continue at an increased rate include loss of sea ice and rising sea levels (Vermaire et al. 2013, Kwok 2018), permafrost degradation (Derksen et al. 2019), coastal erosion (Obu et al. 2017), shifts in the habitat cover and range due to a northward advance of forest cover and shrubification of tundra (Cameron and Lantz 2016, Kitagawa et al. 2020), and changes to spatio-temporal patterns of natural disturbance (Rupp et al. 2006, Price et al. 2013). These changes and others are likely to have critical effects on biodiversity as rates of change may outstrip the ability of species to adapt or migrate, with loss of niche habitats increasing the vulnerability of already at-risk species.

The GNWT enacted the *Species At Risk (NWT) Act* in 2009 (GNWT 2009) in recognition of the shared responsibility to protect and conserve the rich biological diversity of the NWT. The Act requires that “the conservation of species at risk should use the best available information, including Aboriginal traditional knowledge, community knowledge and scientific knowledge and be based on an ecological approach.” (GNWT 2009). This report helps to satisfy the requirement to use the best available scientific knowledge to help guide the interpretation of threats to species at risk in the NWT. In particular, this report focuses on threats to species at risk in the NWT resulting from the direct and indirect effects that are projected to occur from climate change that may interact with a species' habitat, biotic interactions, phenology, physiological thresholds, and population level parameters. Projections of change to climate and physical parameters are presented, and then potential impacts to species at risk within the NWT are summarized for each species. These summaries are intentionally brief and point the reader to resources for more detailed investigation where necessary. The expectation is that this information will help to inform an interpretation of threats to each species because of climate change to aid in classification of those species by SARC.

METHODS

Given the abundance of climate change literature, a structured three-step approach to the literature review was used to maintain focus on key information. First, the project team assembled references previously collected by Ecofish staff as a starting point for the body of knowledge. Second, recognizing the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (ARs) as the most thorough and concise summary of climate change impacts available, *AR5 Climate Change 2014: Impacts Adaptation and Vulnerability* was used as a starting point to identify anticipated changes and risks to species and ecosystems that occur in the NWT. Since the NWT straddles the Arctic Circle, we drew from both Section 26: North America (Romero-Lankao et al. 2014) and Section 28: Polar Regions (Larsen et al. 2014) to identify key information sources relating to trends affecting NWT species and ecosystems. Further searches were conducted to gather and synthesize literature published in years since the publication of AR5. As a starting point, searches were conducted for papers that cite those resources from AR5 that are most pertinent to NWT species and ecosystems and climate change impacts. Searches were focused on 2013 through 2020 to reduce results to those published since AR5. Finally, the search was expanded using a number of search terms agreed upon by the project team. The purpose of limiting search terms was to ensure searches were targeted and repeatable, and to keep the number of resources requiring review to a manageable level. Where time allowed, searches for reports that cite key information sources identified through this process were conducted, where highly pertinent.

Reference citation software, Mendeley, was used to provide a database of references collected during the literature review. This database and PDF documents (where available) are provided with this report, along with tabular summaries of each reference in a spreadsheet file ("Ecofish_GNWTClimateChange_ReferenceTracker.xlsx"). Key information provided in the spreadsheets include biotic and abiotic conditions requested by ECC as well as others identified through the literature research. Additional parameters such as the associated taxa, geographical range, representative concentration pathways (RCPs), etc. were added to help authors and reviewers to easily focus on topics of interest or concern. Further, each row included a summary of key points for each citation.

Climate projections were collated for six locations across the NWT (Yellowknife, Tuktoyaktuk, Prince Patrick Island, Fort Simpson, Norman Wells and CanTung Mine) selected to represent differing ecological regions throughout the Territory and provide representation for any variation among climate effects therein. Projected changes in seasonal and annual air temperature, precipitation, growing season length, and the number of frost free days under both RCP4.5 and RCP8.5 scenarios were obtained using ClimateNA (Wang et al. 2016), a tool which provides interpolated historical data from weather stations and locally downscaled future projections. RCP4.5 and RCP8.5 scenarios correspond to two trajectories for atmospheric greenhouse gas concentrations that may occur under depending

on the level of action undertaken to reduce global emissions. RCP4.5 represents a moderate scenario in which emissions peak during the 2040s and then decline, while RCP8.5 assumes that emissions continue to rise for the remainder of the 21st century. The relative severity of respective climate effect on each variable was evaluated by comparing projections related to each RCP to interpolated historical data for the 1961-1990 climate normal (hereafter referred to as “baseline period”), and the most recent decade between 2011-2020.

Climate projections for other variables (permafrost extent, active layer thickness, and sea ice) that were not available for individual representative locations (either through ClimateNA or other available research) were summarized on a general basis according to information from peer-reviewed literature and contained in AR5 (IPCC 2014).

Focal species were selected based on a list provided by the GNWT for this project. Several species that are not currently listed in the Territory but are under consideration for listing were identified as optional for inclusion. Due to resource constraints, these optional species (e.g. peregrine falcon, American white pelican) were not included in this review.

At the species level, climate change interactions focused on the following categories:

- Physiological thresholds,
- Habitat quantity, quality, access,
- Biotic interactions (e.g. predator/prey, disease, invasive species),
- Phenology (e.g. timing of food, pollinators, migration, etc.), and
- Population dynamics (e.g. survival rates, reproduction rates, abundance).

Results of this synthesis are meant to inform the completion of NWT SARC threats and limiting factors assessments. Thus, our synthesis was focused on the parameters used for these assessments, which include the likelihood (based on timing and probability of effect within ten years), causal certainty (or confidence that a threat will have an impact on a population), and magnitude (i.e., spatial extent, severity, temporality, and overall level of concern) of climate change interactions. Summaries of the most important climate change interactions at the Kingdom/Phylum are provided in the Discussion.

RESULTS

Projections of Change

Details from the current state of knowledge on climate change that are summarized in the IPCC AR5 report (2014) describe existing and predicted effects from climate change relevant to the NWT and include the following:

- Substantial warming to date relative to historical baseline conditions for polar and high latitude regions, with rates of future warming expected to continue to exceed the global average over the next decades,
- Large decreases in active sea ice have occurred over recent decades, with current projections suggesting the Arctic Ocean is likely to become nearly free of ice in summer during this century,
- Climate change will continue to drive increasing weather intensity and severity, including more frequent extreme events (e.g. flooding and drought),
- Rising temperatures will cause decreases in the duration and extent of winter snow cover, earlier seasonal snowmelt timing, and enhance existing rates of permafrost thaw, and
- Oceans and coastal areas will see rising sea levels, and greater intensity and frequency of storms and storm surges.

Associated impacts from these changes (among many) include:

- Continued displacement of tundra by boreal forest, along with increases in treeline elevation for mountainous areas, with between 11-50% of tundra being displaced by forest within 100 years,
- Increasing shrub cover,
- Northward expansion of tundra at the highest latitudes,
- Changes in water storage and runoff patterns, as well as the type and abundance of wetland habitats,
- Range expansion in altitude and latitude of insect pests along with decreased overwintering mortality (due to warmer winters) may lead to greater frequency and extent of pest outbreaks,
- Shifts in timing and magnitude of biomass production (for example insect emergence) resulting in potential mismatch among food webs,
- Changes in primary productivity (increases) but also decreases in forage quality (due to lower nitrogen content), and
- Impacts to herbivores including ungulates from changes in vegetation includes decreases in lichen biomass that are key fodder for reindeer (some North American herds have already declined by 75-90%). Ungulate populations may face continued

and increasing pressure from other climate changes such as increased snowpacks and more frequent rain-on-snow events that restrict access to fodder during winter.

Historical and future predicted (RCP4.5 and RCP8.5 scenarios) local climate values obtained for each of the six selected locations across the NWT (Yellowknife, Tuktoyaktuk, Prince Patrick Island, Fort Simpson, Norman Wells and CanTung Mine) are summarized in Table 1-Table 6.

Mean annual air temperatures are expected to continue to increase under both RCP4.5 and RCP8.5 scenarios. Compared to historical baseline conditions (1961-1990), temperatures during the most recent decade from 2011-2020 have already increased in the NWT by between +1.5°C (at Fort Simpson) to +2.5°C at Tuktoyaktuk; consistent with projections that temperature increases will be greatest at higher latitudes. Based on RCP4.5 and RCP8.5 scenarios for the 2050s (based on projected average conditions for 2040-2069), annual mean temperatures across all six selected locations are likely to increase by between +3.1°C to +4.9°C, and +3.7°C to +6.1°C, respectively. Corresponding projections for the 2080s (based on conditions for 2070-2100) are for temperatures to increase by between +3.7°C to +6.1°C (RCP4.5) and +6.2°C to +10.8°C (RCP8.5) (Table 1-Table 6). On a seasonal basis, relative increases in air temperature are projected to be greatest during winter and lowest during summer. For example, RCP8.5 projections for the 2080s suggest average air temperature at Tuktoyaktuk is likely to be 13.7°C warmer in winter but only 5.1°C warmer during summer.

Baseline annual precipitation (1961-1990) varies widely across all six locations from 94 mm/year on Prince Patrick Island to 510 mm/year at CanTung Mine. Relative to baseline conditions, average precipitation has varied over the most recent decade (2011-2020) with increases in precipitation at some locations and decreases at others. Decreases in precipitation for some areas for the 2011-2020 period contradicts longer-term trends that indicate a widespread increase in mean precipitation over multiple decades (Bush and Lemmen 2019) but may be influenced by shorter-term climate-patterns or stochasticity. Over the long-term, increased precipitation is projected for all locations under both RCP4.5 and RCP8.5 scenarios. Projected changes in precipitation for the 2050s range from +24 mm/year to +64 mm/year (RCP4.5), and +32 mm/year to +81 mm/year (RCP8.5) across the territory. By the 2080s, projected changes in precipitation range from +31 mm/year to +83 mm/year (RCP4.5), and +56 mm/year to +130 mm/year (RCP8.5) (Table 1-Table 6). While mean annual precipitation is lowest at the most northern locations, the proportional increase in precipitation at these locations is anticipated to be the highest. For example, an increase in mean annual precipitation of +56 mm/year (RCP8.5) at Prince Patrick Island represents a 60% increase overall relative to baseline conditions between 1961-1990. On a seasonal basis, projected increases in precipitation are largest in summer and fall months for both scenarios and future time periods.

Growing season length was measured based on the average number of continuous days without frost during each year and varied across all six locations primarily according to latitude and elevation, ranging from 0 days on Prince Patrick Island to 140 days in Yellowknife during the baseline period (1961-1990). Longer growing seasons have been observed over the most recent decade (2011-2020); average growing season length increased between +4 to +21 days across all locations except Prince Patrick Island (which remained too cold to have a growing season) during this period. Under RCP4.5 and RCP8.5 scenarios, growing season length at all locations is projected to increase between +19 to +45 days or +24 to +55 days by the 2050s, respectively; and between +28 to +55 days or +40 to +90 days by the 2080s. Projected increases in the number of frost-free days due to warming temperatures follow a similar and consistent pattern across all locations.

Model projections indicate that more southerly locations (Yellowknife, CanTung Mine and Fort Simpson) will likely see decreased snowfall because increases in precipitation will include shifts to a higher proportion of precipitation falling as rain (IPCC 2014). At more northern locations (Tuktoyaktuk, Prince Patrick Island and Norman Wells), where average temperatures remain colder, snowfall is projected to increase, however, this increase will be proportionally less than the overall increase in precipitation.

Warming temperature conditions are expected to have profound effects on permafrost because continued warming will enhance rates of permafrost thaw and decrease overall permafrost extent (IPCC 2014). Existing observations suggest that active layer thickness has increased by approximately 10% since 2000 in the MacKenzie Valley (Derksen et al. 2019). Currently, available projections of changes to permafrost extent during the 21st century do not provide sufficient resolution to provide specific projections for each of the six chosen locations. However, larger-scale model projections suggest that by the end of the century permafrost in Canada will be reduced to between 54% (RCP4.5) and 26% (RCP8.5) of its historical extent, with the later scenario resulting in permafrost retreating to north of 65°N (Guo and Wang 2016).

Additionally, warming temperature trends are anticipated to result in the continuation of observed declines in Arctic Sea ice. Like permafrost, projections are not explicitly available for relevant selected locations in the NWT (i.e., Tuktoyaktuk and Prince Patrick Island). Broader observations however, indicate that summer sea ice area (particularly multi-year ice area) across the Canadian Arctic has declined at a rate of approximately 5-20% per decade since 1968 (Mudryk et al. 2018, Bush and Lemmen 2019, Derksen et al. 2019). The Canadian Arctic has also experienced declines in sea ice concentration in all seasons from 1981-2015, with the Canadian Arctic Archipelago having the strongest declines in sea ice concentration in summer and fall (Bush and Lemmen 2019). The Beaufort Sea and Canadian Arctic Archipelago have experienced the largest declines in multi-year ice, at rates of approximately 7% and 9% per decade, respectively (Bush and Lemmen 2019). Current projections for all emissions scenarios indicate continued reductions to sea ice concentration

and extent across the Canadian Arctic due to increased temperatures and resulting increases in melt season duration, which will likely result in most regions of the Canadian Arctic becoming sea ice-free for at least part of the summer period by 2050 (Bush and Lemmen 2019). Moreover, perennial sea ice will continue to be replaced by thinner seasonal sea ice that melts faster, contributing to further sea ice decline (Bush and Lemmen 2019, Derksen et al. 2019).

Table 1. Projections of change to physical climate parameters from normal (1961-1990) at Yellowknife. Differences relative to baseline climate conditions from 1961-1990 are included in parentheses.

Parameter		1961-1990			2011 - 2020			2050s									2080s					
		Mean	Min	Max	Mean	Min	Max	RCP4.5			RCP8.5			RCP4.5			RCP8.5					
								Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max			
Air Temperature (°C)	Annual	-5.5	-30.1	18.8	-3.8 (+1.7)	-26.7 (+3.4)	19.4 (+0.6)	-2 (+3.5)	-25 (+5.1)	21.1 (+2.3)	-1.3 (+4.2)	-23.9 (+6.2)	21.5 (+2.7)	-0.9 (+4.6)	-23.4 (+6.7)	21.9 (+3.1)	1.7 (+7.2)	-19.2 (+10.9)	23.9 (+5.1)			
	Winter	-25.6	-30.1	-21	-22.5 (+3.1)	-26.7 (+3.4)	-18.4 (+2.6)	-20.8 (+4.8)	-25 (+5.1)	-16.6 (+4.4)	-19.8 (+5.8)	-23.9 (+6.2)	-15.7 (+5.3)	-19.3 (+6.3)	-23.4 (+6.7)	-15.3 (+5.7)	-15.6 (+10)	-19.2 (+10.9)	-12 (+9)			
	Spring	-7.3	-13.4	-1.2	-6 (+1.3)	-12.2 (+1.2)	0.1 (+1.3)	-4.1 (+3.2)	-9.9 (+3.5)	1.6 (+2.8)	-3.4 (+3.9)	-9.1 (+4.3)	2.3 (+3.5)	-3.1 (+4.2)	-8.8 (+4.6)	2.5 (+3.7)	-0.7 (+6.6)	-6.2 (+7.2)	4.8 (+6)			
	Summer	13.8	8.8	18.8	14.8 (+1)	10.2 (+1.4)	19.4 (+0.6)	16.2 (+2.4)	11.3 (+2.5)	21.1 (+2.3)	16.7 (+2.9)	11.9 (+3.1)	21.5 (+2.7)	17.1 (+3.3)	12.3 (+3.5)	21.9 (+3.1)	19.1 (+5.3)	14.3 (+5.5)	23.9 (+5.1)			
	Fall	-3	-6.5	0.4	-1.4 (+1.6)	-4.6 (+1.9)	1.8 (+1.4)	0.6 (+3.6)	-2.6 (+3.9)	3.7 (+3.3)	1.4 (+4.4)	-1.8 (+4.7)	4.5 (+4.1)	1.8 (+4.8)	-1.3 (+5.2)	4.8 (+4.4)	4.2 (+7.2)	1.3 (+7.8)	7.1 (+6.7)			
Precipitation (mm)	Annual	277	-	-	245 (-32)	-	-	312 (+35)	-	-	325 (+48)	-	-	324 (+47)	-	-	352 (+75)	-	-			
	Winter	45	-	-	41 (-4)	-	-	52 (+7)	-	-	53 (+8)	-	-	54 (+9)	-	-	58 (+13)	-	-			
	Spring	42	-	-	36 (-6)	-	-	48 (+6)	-	-	50 (+8)	-	-	49 (+7)	-	-	54 (+12)	-	-			
	Summer	100	-	-	102 (+2)	-	-	110 (+10)	-	-	114 (+14)	-	-	114 (+14)	-	-	120 (+20)	-	-			
	Fall	91	-	-	67 (-24)	-	-	103 (+12)	-	-	108 (+17)	-	-	108 (+17)	-	-	120 (+29)	-	-			
	as snow	134	-	-	101 (-33)	-	-	126 (-8)	-	-	124 (-10)	-	-	122 (-12)	-	-	116 (-18)	-	-			
Length of growing season ¹		99	-	-	120 (+21)	-	-	122 (+23)	-	-	124 (+25)	-	-	129 (+30)	-	-	142 (+43)	-	-			
Number of frost-free days		127	-	-	140 (+13)	-	-	150 (+23)	-	-	155 (+28)	-	-	158 (+31)	-	-	174 (+47)	-	-			

¹Equal to the number of continuous frost-free days per year

Table 2. Projections of change to physical climate parameters from normal (1961-1990) at Tuktoyaktuk. Differences relative to baseline climate conditions from 1961-1990 are included in parentheses.

Parameter		1961-1990			2011 - 2020			2050s						2080s					
		Mean	Min	Max	Mean	Min	Max	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
								Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Air Temperature (°C)	Annual	-11	-30.3	11.8	-8.5 (+2.5)	-26 (+4.3)	12.2 (+0.4)	-6.4 (+4.6)	-23.5 (+6.8)	14 (+2.2)	-5.5 (+5.5)	-22 (+8.3)	14.5 (+2.7)	-5.1 (+5.9)	-21.4 (+8.9)	14.8 (+3)	-1.9 (+9.1)	-15.7 (+14.6)	16.6 (+4.8)
	Winter	-27.1	-30.3	-23.8	-23.2 (+3.9)	-26 (+4.3)	-20.4 (+3.4)	-20.6 (+6.5)	-23.5 (+6.8)	-17.7 (+6.1)	-19.2 (+7.9)	-22 (+8.3)	-16.3 (+7.5)	-18.6 (+8.5)	-21.4 (+8.9)	-15.8 (+8)	13.4 (+13.7)	-15.7 (+14.6)	-11 (+12.8)
	Spring	-16	-19.7	-12.4	-13.5 (+2.5)	-17 (+2.7)	-10 (+2.4)	-12 (+4)	-15.4 (+4.3)	-8.7 (+3.7)	-11.2 (+4.8)	-14.4 (+5.3)	-7.9 (+4.5)	-10.9 (+5.1)	-14.1 (+5.6)	-7.7 (+4.7)	-7.9 (+8.1)	-10.8 (+8.9)	-5 (+7.4)
	Summer	8	4.2	11.8	8.5 (+0.5)	4.9 (+0.7)	12.2 (+0.4)	10.3 (+2.3)	6.6 (+2.4)	14 (+2.2)	10.8 (+2.8)	7.2 (+3)	14.5 (+2.7)	11.2 (+3.2)	7.5 (+3.3)	14.8 (+3)	13.1 (+5.1)	9.5 (+5.3)	16.6 (+4.8)
	Fall	-8.9	-11.3	-6.5	-5.9 (+3)	-8 (+3.3)	-3.8 (+2.7)	-3.3 (+5.6)	-5.1 (+6.2)	-1.4 (+5.1)	-2.4 (+6.5)	-4.2 (+7.1)	-0.6 (+5.9)	-1.9 (+7)	-3.7 (+7.6)	-0.1 (+6.4)	0.6 (+9.5)	-1 (+10.3)	2.2 (+8.7)
Precipitation (mm)	Annual	143	-	-	146 (+3)	-	-	171 (+28)	-	-	178 (+35)	-	-	180 (+37)	-	-	204 (+61)	-	-
	Winter	20	-	-	18 (-2)	-	-	24 (+4)	-	-	25 (+5)	-	-	26 (+6)	-	-	30 (+10)	-	-
	Spring	16	-	-	15 (-1)	-	-	18 (+2)	-	-	19 (+3)	-	-	19 (+3)	-	-	22 (+6)	-	-
	Summer	62	-	-	73 (+11)	-	-	75 (+13)	-	-	77 (+15)	-	-	78 (+16)	-	-	89 (+27)	-	-
	Fall	45	-	-	40 (-5)	-	-	54 (+9)	-	-	56 (+11)	-	-	57 (+12)	-	-	63 (+18)	-	-
	as snow	76	-	-	65 (-11)	-	-	79 (+3)	-	-	80 (+4)	-	-	79 (+3)	-	-	78 (+2)	-	-
Length of growing season ¹		70	-	-	83 (+13)	-	-	104 (+34)	-	-	109 (+39)	-	-	113 (+43)	-	-	124 (+54)	-	-
Number of frost-free days		92	-	-	101 (+9)	-	-	116 (+24)	-	-	120 (+28)	-	-	123 (+31)	-	-	139 (+47)	-	-

¹Equal to the number of continuous frost-free days per year

Table 3. Projections of change to physical climate parameters from normal (1961-1990) at Prince Patrick Island. Differences relative to baseline climate conditions from 1961-1990 are included in parentheses.

Parameter		1961-1990			2011 - 2020			2050s						2080s					
		Mean	Min	Max	Mean	Min	Max	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
Air Temperature (°C)	Annual	-18.5	-37	3	-16.5 (+2)	-34 (+3)	3.8 (+0.8)	-13.6 (+4.9)	-30.3 (+6.7)	4.2 (+1.2)	-12.4 (+6.1)	-28.4 (+8.6)	4.4 (+1.4)	-11.9 (+6.6)	-27.6 (+9.4)	4.8 (+1.8)	-7.7 (+10.8)	-20 (+17)	6.4 (+3.4)
	Winter	-34.1	-37	-31.2	-31.1 (+3)	-34 (+3)	-28.2 (+3)	-27.5 (+6.6)	-30.3 (+6.7)	-24.7 (+6.5)	-25.6 (+8.5)	-28.4 (+8.6)	-22.9 (+8.3)	-24.9 (+9.2)	-27.6 (+9.4)	-22.3 (+8.9)	-17.6 (+16.5)	-20 (+17)	-15.3 (+15.9)
	Spring	-23.6	-26.4	-20.7	-21.8 (+1.8)	-25 (+1.4)	-18.6 (+2.1)	-19.5 (+4.1)	-22 (+4.4)	-17 (+3.7)	-18.6 (+5)	-21 (+5.4)	-16.2 (+4.5)	-18.2 (+5.4)	-20.6 (+5.8)	-15.8 (+4.9)	-14.6 (+9)	-16.7 (+9.7)	-12.6 (+8.1)
	Summer	1	-0.9	3	1.8 (+0.8)	-0.1 (+0.8)	3.8 (+0.8)	2.3 (+1.3)	0.4 (+1.3)	4.2 (+1.2)	2.6 (+1.6)	0.8 (+1.7)	4.4 (+1.4)	2.9 (+1.9)	1.1 (+2)	4.8 (+1.8)	4.5 (+3.5)	2.7 (+3.6)	6.4 (+3.4)
	Fall	-17.5	-20.3	-14.7	-15.1 (+2.4)	-18 (+2.3)	-12.2 (+2.5)	-9.8 (+7.7)	-12 (+8.3)	-7.7 (+7)	-8.1 (+9.4)	-10 (+10.3)	-6.1 (+8.6)	-7.4 (+10.1)	-9.3 (+11)	-5.4 (+9.3)	-2.9 (+14.6)	-4.4 (+15.9)	-1.4 (+13.3)
Precipitation (mm)	Annual	94	-	-	99 (+5)	-	-	118 (+24)	-	-	126 (+32)	-	-	125 (+31)	-	-	150 (+56)	-	-
	Winter	10	-	-	11 (+1)	-	-	13 (+3)	-	-	14 (+4)	-	-	15 (+5)	-	-	20 (+10)	-	-
	Spring	13	-	-	19 (+6)	-	-	16 (+3)	-	-	16 (+3)	-	-	16 (+3)	-	-	20 (+7)	-	-
	Summer	43	-	-	44 (+1)	-	-	52 (+9)	-	-	55 (+12)	-	-	53 (+10)	-	-	62 (+19)	-	-
	Fall	28	-	-	25 (-3)	-	-	37 (+9)	-	-	40 (+12)	-	-	41 (+13)	-	-	49 (+21)	-	-
	as snow	72	-	-	74 (+2)	-	-	84 (+12)	-	-	87 (+15)	-	-	85 (+13)	-	-	88 (+16)	-	-
Length of growing season ¹		0	-	-	0 (0)	-	-	42 (+42)	-	-	55 (+55)	-	-	55 (+55)	-	-	90 (+90)	-	-
Number of frost-free days		31	-	-	42 (+11)	-	-	52 (+21)	-	-	59 (+28)	-	-	64 (+33)	-	-	93 (+62)	-	-

¹Equal to the number of continuous frost-free days per year

Table 4. Projections of change to physical climate parameters from normal (1961-1990) at Fort Simpson. Differences relative to baseline climate conditions from 1961-1990 are included in parentheses.

Parameter		1961-1990			2011 - 2020			2050s						2080s					
		Mean	Min	Max	Mean	Min	Max	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
Air Temperature (°C)	Annual	-3.5	-28.5	21.9	-2 (+1.5)	-26.2 (+2.3)	23.4 (+1.5)	-0.2 (+3.3)	-23.8 (+4.7)	24 (+2.1)	0.5 (+4)	-22.8 (+5.7)	24.6 (+2.7)	0.8 (+4.3)	-22.3 (+6.2)	24.9 (+3)	3.2 (+6.7)	-18.7 (+9.8)	26.9 (+5)
	Winter	-23.9	-28.5	-19.2	-21.1 (+2.8)	-26.2 (+2.3)	-16 (+3.2)	-19.5 (+4.4)	-23.8 (+4.7)	-15.1 (+4.1)	-18.6 (+5.3)	-22.8 (+5.7)	-14.4 (+4.8)	-18.2 (+5.7)	-22.3 (+6.2)	-14 (+5.2)	-14.9 (+9)	-18.7 (+9.8)	-11.2 (+8)
	Spring	-2.3	-8.7	4.1	-1.2 (+1.1)	-8.2 (+0.5)	5.8 (+1.7)	0.8 (+3.1)	-5.4 (+3.3)	6.9 (+2.8)	1.4 (+3.7)	-4.7 (+4)	7.5 (+3.4)	1.6 (+3.9)	-4.4 (+4.3)	7.7 (+3.6)	3.8 (+6.1)	-2.1 (+6.6)	9.7 (+5.6)
	Summer	15.5	9	21.9	16.6 (+1.1)	9.7 (+0.7)	23.4 (+1.5)	17.8 (+2.3)	11.5 (+2.5)	24 (+2.1)	18.3 (+2.8)	12.1 (+3.1)	24.6 (+2.7)	18.7 (+3.2)	12.4 (+3.4)	24.9 (+3)	20.7 (+5.2)	14.5 (+5.5)	26.9 (+5)
	Fall	-3.3	-7.8	1.2	-2.2 (+1.1)	-7.3 (+0.5)	2.9 (+1.7)	0 (+3.3)	-4.2 (+3.6)	4.3 (+3.1)	0.8 (+4.1)	-3.4 (+4.4)	5 (+3.8)	1.1 (+4.4)	-3.1 (+4.7)	5.3 (+4.1)	3.3 (+6.6)	-0.7 (+7.1)	7.4 (+6.2)
Precipitation (mm)	Annual	355	-	-	374 (+19)	-	-	396 (+41)	-	-	408 (+53)	-	-	407 (+52)	-	-	442 (+87)	-	-
	Winter	56	-	-	61 (+5)	-	-	63 (+7)	-	-	65 (+9)	-	-	64 (+8)	-	-	70 (+14)	-	-
	Spring	63	-	-	60 (-3)	-	-	73 (+10)	-	-	75 (+12)	-	-	74 (+11)	-	-	83 (+20)	-	-
	Summer	146	-	-	165 (+19)	-	-	159 (+13)	-	-	163 (+17)	-	-	164 (+18)	-	-	171 (+25)	-	-
	Fall	90	-	-	88 (-2)	-	-	100 (+10)	-	-	105 (+15)	-	-	105 (+15)	-	-	117 (+27)	-	-
	as snow	147	-	-	144 (-3)	-	-	139 (-8)	-	-	136 (-11)	-	-	135 (-12)	-	-	130 (-17)	-	-
Length of growing season ¹		102	-	-	106 (+4)	-	-	123 (+21)	-	-	129 (+27)	-	-	131 (+29)	-	-	146 (+44)	-	-
Number of frost-free days		137	-	-	141 (+4)	-	-	157 (+20)	-	-	162 (+25)	-	-	164 (+27)	-	-	179 (+42)	-	-

¹Equal to the number of continuous frost-free days per year

Table 5. Projections of change to physical climate parameters from normal (1961-1990) at Norman Wells. Differences relative to baseline climate conditions from 1961-1990 are included in parentheses.

Parameter		1961-1990			2011 - 2020			2050s						2080s					
		Mean	Min	Max	Mean	Min	Max	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
								Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Air Temperature (°C)	Annual	-5.9	-29.3	20.9	-4 (+1.9)	-26.2 (+3.1)	21.5 (+0.6)	-2.4 (+3.5)	-24.4 (+4.9)	22.9 (+2)	-1.7 (+4.2)	-23.4 (+5.9)	23.5 (+2.6)	-1.4 (+4.5)	-22.9 (+6.4)	23.7 (+2.8)	1.2 (+7.1)	-19 (+10.3)	25.6 (+4.7)
	Winter	-25	-29.3	-20.7	-21.9 (+3.1)	-26.2 (+3.1)	-17.6 (+3.1)	-20.4 (+4.6)	-24.4 (+4.9)	-16.3 (+4.4)	-19.5 (+5.5)	-23.4 (+5.9)	-15.5 (+5.2)	-19 (+6)	-22.9 (+6.4)	-15.2 (+5.5)	-15.5 (+9.5)	-19 (+10.3)	-12.1 (+8.6)
	Spring	-6.1	-13.2	1	-4.6 (+1.5)	-11.5 (+1.7)	2.3 (+1.3)	-2.8 (+3.3)	-9.6 (+3.6)	4.1 (+3.1)	-2 (+4.1)	-8.8 (+4.4)	4.7 (+3.7)	-1.9 (+4.2)	-8.6 (+4.6)	4.9 (+3.9)	0.6 (+6.7)	-5.9 (+7.3)	7.1 (+6.1)
	Summer	13.8	6.7	20.9	14.7 (+0.9)	7.9 (+1.2)	21.5 (+0.6)	16 (+2.2)	9.1 (+2.4)	22.9 (+2)	16.5 (+2.7)	9.6 (+2.9)	23.5 (+2.6)	16.8 (+3)	9.9 (+3.2)	23.7 (+2.8)	18.8 (+5)	11.9 (+5.2)	25.6 (+4.7)
	Fall	-6.2	-10.9	-1.4	-4.3 (+1.9)	-9.2 (+1.7)	0.5 (+1.9)	-2.5 (+3.7)	-7 (+3.9)	1.9 (+3.3)	-1.8 (+4.4)	-6.2 (+4.7)	2.6 (+4)	-1.5 (+4.7)	-5.8 (+5.1)	2.9 (+4.3)	0.9 (+7.1)	-3.3 (+7.6)	5.1 (+6.5)
Precipitation (mm)	Annual	318	-	-	384 (+66)	-	-	367 (+49)	-	-	380 (+62)	-	-	379 (+61)	-	-	417 (+99)	-	-
	Winter	52	-	-	75 (+23)	-	-	60 (+8)	-	-	61 (+9)	-	-	62 (+10)	-	-	69 (+17)	-	-
	Spring	44	-	-	59 (+15)	-	-	51 (+7)	-	-	54 (+10)	-	-	53 (+9)	-	-	61 (+17)	-	-
	Summer	141	-	-	157 (+16)	-	-	161 (+20)	-	-	166 (+25)	-	-	167 (+26)	-	-	176 (+35)	-	-
	Fall	81	-	-	93 (+12)	-	-	95 (+14)	-	-	99 (+18)	-	-	98 (+17)	-	-	111 (+30)	-	-
	as snow	138	-	-	176 (+38)	-	-	146 (+8)	-	-	147 (+9)	-	-	146 (+8)	-	-	145 (+7)	-	-
Length of growing season ¹		82	-	-	99 (+17)	-	-	101 (+19)	-	-	106 (+24)	-	-	110 (+28)	-	-	122 (+40)	-	-
Number of frost-free days		112	-	-	124 (+12)	-	-	134 (+22)	-	-	138 (+26)	-	-	141 (+29)	-	-	155 (+43)	-	-

¹Equal to the number of continuous frost-free days per year

Table 6. Projections of change to physical climate parameters from normal (1961-1990) at CanTung Mine. Differences relative to baseline climate conditions from 1961-1990 are included in parentheses.

Parameter		1961-1990			2011 - 2020			2050s						2080s					
		Mean	Min	Max	Mean	Min	Max	RCP4.5			RCP8.5			RCP4.5			RCP8.5		
								Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Air Temperature (°C)	Annual	-5.5	-24	14.5	-3.7 (+1.8)	-20.9 (+3.1)	15.5 (+1)	-2.4 (+3.1)	-19.8 (+4.2)	17.1 (+2.6)	-1.8 (+3.7)	-19.2 (+4.8)	17.7 (+3.2)	-1.6 (+3.9)	-18.7 (+5.3)	18 (+3.5)	0.7 (+6.2)	-15.7 (+8.3)	20.1 (+5.6)
	Winter	-18.9	-24	-13.9	-16 (+2.9)	-20.9 (+3.1)	-11.1 (+2.8)	-15.1 (+3.8)	-19.8 (+4.2)	-10.5 (+3.4)	-14.6 (+4.3)	-19.2 (+4.8)	-10 (+3.9)	-14.2 (+4.7)	-18.7 (+5.3)	-9.8 (+4.1)	-11.6 (+7.3)	-15.7 (+8.3)	-7.5 (+6.4)
	Spring	-5.5	-11.3	0.4	-3.5 (+2)	-9.1 (+2.2)	2 (+1.6)	-2.5 (+3)	-8.1 (+3.2)	3.1 (+2.7)	-1.9 (+3.6)	-7.5 (+3.8)	3.6 (+3.2)	-1.8 (+3.7)	-7.3 (+4)	3.8 (+3.4)	0.4 (+5.9)	-4.9 (+6.4)	5.6 (+5.2)
	Summer	8.4	2.3	14.5	9.9 (+1.5)	4.2 (+1.9)	15.5 (+1)	11 (+2.6)	4.8 (+2.5)	17.1 (+2.6)	11.6 (+3.2)	5.4 (+3.1)	17.7 (+3.2)	11.9 (+3.5)	5.7 (+3.4)	18 (+3.5)	13.9 (+5.5)	7.8 (+5.5)	20.1 (+5.6)
	Fall	-6	-10.5	-1.6	-5.2 (+0.8)	-9.2 (+1.3)	-1.2 (+0.4)	-3.1 (+2.9)	-7.1 (+3.4)	1 (+2.6)	-2.4 (+3.6)	-6.4 (+4.1)	1.7 (+3.3)	-2.2 (+3.8)	-6.2 (+4.3)	1.9 (+3.5)	0 (+6)	-3.8 (+6.7)	3.8 (+5.4)
Precipitation (mm)	Annual	510	-	-	470 (-40)	-	-	574 (+64)	-	-	591 (+81)	-	-	593 (+83)	-	-	640 (+130)	-	-
	Winter	91	-	-	85 (-6)	-	-	102 (+11)	-	-	105 (+14)	-	-	104 (+13)	-	-	114 (+23)	-	-
	Spring	86	-	-	75 (-11)	-	-	99 (+13)	-	-	102 (+16)	-	-	103 (+17)	-	-	113 (+27)	-	-
	Summer	186	-	-	193 (+7)	-	-	203 (+17)	-	-	209 (+23)	-	-	211 (+25)	-	-	218 (+32)	-	-
	Fall	148	-	-	116 (-32)	-	-	169 (+21)	-	-	175 (+27)	-	-	175 (+27)	-	-	195 (+47)	-	-
	as snow	296	-	-	238 (-58)	-	-	295 (-1)	-	-	293 (-3)	-	-	289 (-7)	-	-	275 (-21)	-	-
Length of growing season ¹		48	-	-	63 (+15)	-	-	70 (+22)	-	-	77 (+29)	-	-	81 (+33)	-	-	104 (+56)	-	-
Number of frost-free days		81	-	-	105 (+24)	-	-	115 (+34)	-	-	121 (+40)	-	-	124 (+43)	-	-	147 (+66)	-	-

¹Equal to the number of continuous frost-free days per year

Vascular Plants

Hairy Braya (*Braya pilosa*)

Hairy braya has a limited range in areas that remained ice-free during the last ice age at Cape Bathurst (COSEWIC 2013). Its establishment is limited to areas of bare soil thought to be created and maintained by periods of standing water, erosion and disturbance from caribou hooves (COSEWIC 2013). Approximately 15% of the known population of hairy braya are found on actively eroding coastal habitat that are expected to be lost in the next 100 years, while a larger portion of the population remains susceptible to salinization by storm surges. Climate change is resulting in habitat loss through coastal erosion, and plant mortality from salt spray during storm surges (Harris 2004). The coastline is currently eroding at a rate of about 9-10 m/year and is increasing due to a reduction in sea ice and an increase in sea levels (Conference of Management Authorities (CMA) 2015). Changes in temperature that continue to decrease Arctic Sea ice increase the duration and severity of storm surges that erode coastal areas and rates of coastal erosion are increased as coastal soils are destabilized by permafrost thaw. Changes in temperatures and precipitation may affect remaining populations through stochastic events (e.g. drought, flooding, or other natural disturbance), as well as indirectly by impacting species (i.e., caribou) that may have an interacting role in creating/maintaining bare soils patches required for establishment and regeneration (COSEWIC 2013).

Mackenzie Hairgrass (*Deschampsia mackenzieana*)

Mackenzie hairgrass is an endemic species restricted to sand dune habitats of northwestern Saskatchewan and a small portion of southern NWT known collectively as the Athabasca dunes. Climate change is thought to be responsible for increasing rates of forest encroachment that now surpass rates of dune formation, leading to loss of habitat. Continued increases in temperature, and precipitation in particular are likely to continue this trend (COSEWIC 2018, Attanayake et al. 2019).

Mammals

Little Brown Myotis (*Myotis lucifugus*)

Climate change may result in changes in little brown myotis distributions via northward range expansions (Humphries et al. 2002, Ingersoll et al. 2013, Burns et al. 2015, Shively and Barboza 2017), as well as other habitat changes such as increased forest fires (dependent on summer temperature and precipitation; Blyth et al. 2016), increased insect infestations in the boreal forest affecting tree density and forest structure (Randall et al. 2011), and shifts in tree species and canopy structures for roosting (Lacki 2018, Jung 2020; Slough and Jung 2020). Changes in temperature and precipitation may reduce water availability, influence

food availability (i.e., insect activity and availability), affect thermoregulatory responses, and potentially influence the spread of white-nose syndrome, which could cause declines in bat reproduction, survival, and population abundance (Rodenhouse et al. 2009, Weller et al. 2009, Adams 2010, Frick et al. 2010, Maher et al. 2012, Sherwin et al. 2013, O'Shea et al. 2016, Willis 2017, Hammerson et al. 2017, Besler and Broders 2019, Layng et al. 2019).

Northern Myotis (*Myotis septentrionalis*)

Climate change may result in changes in northern myotis distributions via northward range expansions (Ingersoll et al. 2013, Burns et al. 2015), as well as other habitat changes such as increased forest fires (depending on temperature and precipitation patterns; Blyth et al. 2016) and shifts in tree species and canopy structures for roosting (Lausen 2009, Patriquin et al. 2016, Lacki 2018, Alston et al. 2019, Jung 2020). Changes in temperature and precipitation may reduce water availability and influence food availability through changes to insect populations, which could influence reproduction (Adams 2010, Hammerson et al. 2017, Layng et al. 2019).

Caribou (*Rangifer tarandus*)

Some potential climate change effects may impact all caribou subspecies and populations and are worthwhile discussing at the species level. Habitat quality and quantity is primarily dependent upon forage accessibility and quality. Caribou are generalist herbivores, able to digest a broad range of species and growth forms (Heggberget et al. 2002). Summer forage availability is rarely limited but winter forage quality and accessibility is considered a dominant influence on caribou abundance (Weladji et al. 2003, Forchhammer and Post 2004, Zalatan et al. 2006, Bastille-Rousseau et al. 2013).

Suitable non-breeding habitat for caribou is vegetated upland habitat, which can be affected by the amount and distribution of freshwater habitat. In the Arctic, changes in the coverage of freshwater habitat will respond to several factors, including increased evaporation and evapotranspiration from longer ice-free seasons, higher air/water temperatures, greater vegetation transpiration, increased infiltration due to permafrost thaw, earlier snowmelt, increases in spring snowmelt and river flow and decreased hydraulic gradients in near-coastal areas (Larsen et al. 2014). On balance, these factors are expected to reduce the area of freshwater habitat, leading to a potential increase in vegetated upland habitat (Prowse et al. 2006).

Colonization of currently unvegetated areas may increase due to greater vegetation production, caused by more rapid decomposition and higher nutrient availability (Dormann and Woodin 2002, Weintraub and Schimel 2005). Responses of plant species in the high Arctic may favour investments in reproduction rather than growth; an investment in producing greater seed crops under a higher temperature scenario may help species

colonize unvegetated ground (Arft et al. 1999). Overall, caribou habitat area is expected to increase somewhat but it is unlikely to be an important factor in caribou populations.

Winter forage availability is primarily affected by snow and ice condition and extent (Hansen et al. 2011). Snow conditions in the winter may reduce access to forage and have strong negative effects on both the growth rate and demographic structure of caribou populations (Post et al. 2009, Miller and Barry 2009b, Stien et al. 2010, Hansen et al. 2011, Berteaux et al. 2017). Extreme weather events from unseasonal warm spells and rain-on-snow events can cause changes in snow pack properties, and changes to freeze-thaw cycling that increase snow thermal conductivity and hardness and decrease snowpack thickness (Sturm and Benson 1997). It can also cause ground icing (Loe et al. 2016), creating areas of hard snow and ice where forage is inaccessible (Hansen et al. 2011). These effects diminish areas of suitable habitat, requiring greater travel to access foraging sites (Berteaux et al. 2017), increasing associated energetic costs (Loe et al. 2016) and potentially increasing vulnerability to predators. In Svalbard, the annual number of days with heavy rain-on-snow events had a strong negative effect on population growth rates (Hansen et al. 2011), and more moderate rain-on-snow events can reduce fecundity (Stien et al. 2012). In extreme cases, forage can become inaccessible. The most extreme rain-on-snow events have caused massive reindeer mortality in Norway, Siberia and Canada (Miller and Barry 2009b, Hansen et al. 2014, Sokolov et al. 2016).

Eighty percent of population variation in Svalbard reindeer was explained by mean winter ground-ice thickness (Kohler and Aanes 2004). Population die-offs of between 33% and 83% resulting from unfavourable snow conditions and poor forage access have been recorded on the Queen Elizabeth Islands (Miller and Barry 2009b).

Caribou responses to physiological factors are expected to be relatively neutral overall. Exposure to weather-related disturbances presents the greatest vulnerability while other factors are neutral or confer some resilience. The key caribou physiological response that confers some resilience to climate change is their ability to vary patterns of movement, forage and reproduction. For example, following a winter in which 98% of upland terrestrial habitat was covered with snow, some Svalbard reindeer adapted to foraging on kelp along the coastal ice line (Hansen and Aanes 2012). Caribou will display large behavioural changes to ground-icing, including exploratory movements across natural barriers (Stien et al. 2010), range expansion to steep mountainous habitat (Hansen et al. 2010), and movement to areas with better forage access (Loe et al. 2016).

Climate change interactions with phenology are not expected to be an important factor conferring resilience or vulnerability to caribou. The resource peaks tied to caribou survival and fecundity are associated with forage accessibility but not necessarily forage species phenology.

The interaction between caribou and other biota represents some vulnerability to climate change. Forage quality is expected to decrease, caused by a shift in the distribution of plant species and types. While caribou are generalist foragers, forage species and plant types vary in their nutrition and digestibility. Forage quality depends mainly on plant species composition in the diet (Heggberget et al. 2002). On average, vegetation biomass is expected to increase as a result of warming in the Arctic (Larsen et al. 2014). Future changes in Arctic vegetation are expected to be driven by increased nutrient availability, arising from temperature-induced increases in mineralization (Dormann and Woodin 2002). Forage quality may diminish if nitrogen content of key forage species diminishes because of higher CO₂ concentrations and increased temperatures resulting from climate change (Heggberget et al. 2002, Turunen et al. 2009).

Changes in forage species abundance, distribution and cover are also a likely response to climate change. In particular, shrubs are expected to increase at the expense of other plant functional types. Shrub biomass, cover and distribution have expanded in many areas of the Arctic over recent decades, likely as a result of climate change (Sturm et al. 2001 and 2005, Tape et al. 2006, Myers-Smith et al. 2011, Ropars and Boudreau 2012). On Ellesmere Island, bryophyte and evergreen shrub abundances increased while deciduous shrub, forb, graminoid and lichen cover did not change (Hudson and Henry 2009). Experimental manipulation of warmth, shading and fertilization revealed that responses are community-dependent: shrubs and bryophytes increased in two of three communities as a response to increased warming but lichen abundance decreased in all communities (Edwards and Henry 2016). Warmer climate in the Canadian Arctic increased plant biomass in summer pastures but was associated with an increase in poor quality forage shrubs such as birch and alder (*Betula nana exilis*, *Betula glandulosa*, and *Alnus viridus*), a decrease in high quality forage quality, and a concurrent decline in caribou populations (Fauchald et al. 2017). This may signal a transition from a system with low plant biomass to one dominated by low quality or non-edible shrubs and diminishing caribou populations (Fauchald et al. 2017). Most but not all studies support an expansion of shrub coverage in the Arctic and a resulting decrease in forage quality for caribou, for example, a meta-analysis of responses of tundra plants to experimental warming found a stronger positive response of herbaceous plants than woody plants to warming (Arft et al. 1999).

In the boreal forest, fire frequency and intensity are expected to increase as a result of climate change, resulting in dramatic reductions to lichen-producing vegetation types (i.e., spruce forests and tundra >60 years old), and likely causing population declines and distribution among boreal caribou (Gustine et al. 2014, Barber et al. 2018)

The physiological thresholds of caribou are not known. No studies were found that cited exceedance of physiological thresholds as a causal factor in survival or fecundity; however, heat stress and pest prevalence may increase because of climate change. For example, woodland caribou show a strong preference for areas with waterbodies and residual snow

patches to help reduce heat stress (Ion and Kershaw 1989, Racey 2005). An increase in temperatures is expected to reduce the effectiveness of these temperature refugia. Higher temperatures are also predicted to increase the number and range of parasitic insects such as mosquitoes (*Aedes* spp.), warble flies (*Hypoderma tarandi*) and winter ticks (*Dermacentor albipictus*) (Witter et al. 2012a, Culler et al. 2015, Simard et al. 2016, Joly et al. 2020). Thus, while physiological thresholds may not be a direct limiting factor in caribou populations, increased heat and predator stress may be additive to other factors and cause fitness or behavioural changes that ultimately reduce survival or fecundity.

Literature addressing climate change impacts to subspecies and populations at risk in the NWT are summarized below.

Dolphin and Union Caribou (*Rangifer tarandus groenlandicus* – Dolphin and Union population)

Increases in temperature are expected to result in changes in vegetation and sea ice cover, affecting Dolphin and Union caribou summer ranges and pasture quality (Fauchald et al. 2017). Climate change is likely to influence sea ice habitat and affect migration (Poole et al. 2010).

Boreal Caribou (*Rangifer tarandus caribou* – Woodland boreal population)

Climate change may influence boreal caribou habitat and affect movements (Bauduin et al. 2018). Increases in temperature are expected to result in changes in vegetation, community composition, and predation risk, as well as long term population persistence (Barber et al. 2018, Serrouya et al. 2021).

Peary Caribou (*Rangifer tarandus pearyi*)

Increases in temperature are expected to result in changes in vegetation, insect harassment, parasite exposure, and predation risk for Peary caribou (Festa-Bianchet et al. 2011, Kaluskar et al. 2020a and b). Changes in temperature and precipitation are expected to influence the incidence of severe winters and rain-on-snow events, which cause Peary caribou declines and affect the potential for recovery (Gunn et al. 2000, Miller and Gunn 2003, Tews et al. 2007b and 2007a, Miller and Barry 2009a, Langlois et al. 2017, Kaluskar et al. 2020a and 2020b). Climate change is likely to influence sea ice habitat and affect movements from reduced landscape connectivity, and population viability (Jenkins et al. 2016, Mallory and Boyce 2019).

Barren-ground Caribou (*Rangifer tarandus groenlandicus* – Barren-ground population)

Increases in temperature are expected to increase forest fire incidence and severity (depending on precipitation patterns), which could decrease the quality of available winter

habitat for barren-ground caribou (Barrier and Johnson 2012, Joly et al. 2012, Blyth et al. 2016). Increases in temperature are also expected to result in changes in vegetation quality and insect harassment (Brotton and Wall 1997, Witter et al. 2012b, Zamin et al. 2017, Mallory et al. 2018). Changes in temperature and precipitation are expected to reduce snow cover, with consequences for migration timing, foraging, reproduction, and survival (Dolant et al. 2018, Mallory et al. 2020).

Northern Mountain Caribou (*Rangifer tarandus caribou* – Woodland northern mountain population)

In addition to increased incidence of disease, parasites, and heat stress, changes in temperature and precipitation (snowfall) may result in changes in vegetation composition, forest fire frequency and severity, permafrost, and ice patch critical habitat, which would alter northern mountain caribou habitat availability as well as potentially increase predation risk (Environment Canada 2012, Hegel and Russell 2013, Species at Risk Committee 2020, White et al. 2020, Serrouya et al. 2021).

Collared Pika (*Ochotona collaris*)

For collared pika, projected increased temperatures, changes in the timing of snowmelt, altered precipitation, and increased freeze-thaw events may lead to vegetation changes, distribution shifts, increased competition with rodents, exposure to parasites, changes in food cache quality, changes in the timing of reproduction, and reduced survival (Franken and Hik 2004, Morrison and Hik 2007, Morrison et al. 2009, Sutton et al. 2016, Foley et al. 2017, White et al. 2018, Kukka et al. 2020).

Grizzly Bear (*Ursus arctos*)

Increased temperatures and altered precipitation may cause a shorter denning season for grizzly bears, reduced availability of suitable denning areas, increased human-bear conflicts, and changes in vegetation/foraging due to both a longer growing season and increased forest fires (Mattson 2001, Rodríguez et al. 2007, Graves et al. 2011, Fisher et al. 2014, Ripple et al. 2014, Roberts et al. 2014, Stenset et al. 2016, Pigeon et al. 2016, Lyons et al. 2018, Ransom et al. 2018, Berman et al. 2019, Hilderbrand et al. 2019, Tammela et al. 2020). Grizzly bear northward range expansion in response to climate change is expected to lead to changes in foraging ecology, predator-prey relationships, and competition (Rockwell et al. 2008, Barker et al. 2015, Pongracz et al. 2017, Clark et al. 2019, Barnas et al. 2020).

Wood Bison (*Bison athabasca*)

Higher temperatures, increased forest fires, drought, vegetation shifts, and changes in hydrology may reduce wood bison habitat (Mitchell and Gates 2002, Foote and Krogman 2006, Strong and Gates 2009, Korosi et al. 2017). Changing patterns in precipitation due to

climate change may be leading to increased prevalence of zoonotic diseases in wood bison such as Leptospirosis (Harms et al. 2019).

Wolverine (*Gulo gulo* - Western population)

Increased temperatures and snowpack declines are expected to affect wolverine distribution and reduce availability of denning areas, leading to range contractions and affecting population dynamics (Brodie and Post 2010, Copeland et al. 2010, McKelvey et al. 2011, Peacock 2011, Hof et al. 2012, Inman et al. 2012, Elmhagen et al. 2015, Heim et al. 2017, Magoun et al. 2017, Ray et al. 2018, Barsugli et al. 2020). Increased temperatures and freeze-thaw events may affect food availability, increase competition, and affect food cache quality (Lofroth et al. 2007, Inman and Packila 2015, Sutton et al. 2016, van der Veen et al. 2020), as well as increase risk of parasite emergence (Sharma et al. 2019, Watson et al. 2020).

Polar Bear (*Ursus maritimus*)

Climate change-induced sea ice loss affects migration, land use, denning, energetics, foraging, and fasting (Cherry et al. 2009 and 2013, McKinney et al. 2013 and 2017, Laidre et al. 2015, 2018 and, 2020, Atwood et al. 2016, Stern and Laidre 2016, Olson et al. 2017, Pilfold et al. 2017, Durner et al. 2017, Boucher et al. 2019, Johnson et al. 2019 and 2020). The Southern Beaufort Sea population has experienced declines in condition, reproduction, survival, and abundance related to sea ice decline (Rode et al. 2010, 2014 and 2018, Bromaghin et al. 2015). Projected sea ice declines will further reduce habitat and thus affect polar bear foraging ecology, energetics, reproduction, and survival, with expected population decline and potential extirpation in the Southern Beaufort Sea by mid-century (Amstrup et al. 2008, Laidre et al. 2008, Durner et al. 2009, Hunter et al. 2010, Molnár et al. 2010, 2011 and 2020, Castro de la Guardia et al. 2013, Hamilton and Derocher 2019).

Birds

Short-eared Owl (*Asio flammeus*)

Climate change is expected to alter the freeze and thaw cycle, which may result in changes to key prey population cycles, resulting in limited resource availability for the short-eared owl (Gilg et al. 2009). Changes in precipitation and temperature may increase shrub density in the tundra and the Arctic, which may further impact the availability of key prey species (Reid et al. 2011). Changes in resource availability will inevitably impact reproduction and nest survivorship, species distribution, and abundance (Gilg et al. 2009, Booms et al. 2014). In addition to climate change impacts, latitudes south of Alaska are shown to be of highest concern for the short-eared owl species, as a result of grassland habitat degradation due to agricultural and development activities (Swengel and Swengel 2013, Booms et al. 2014, Johnson et al. 2017).

Rusty Blackbird (*Euphagus carolinus*)

Climate change is expected to result in changes to the rusty blackbird's boreal wetland habitat through drying and alterations in the hydrological cycle (COSEWIC 2006, Hamel et al. 2009, Greenberg and Matsuoka 2010, Savard et al. 2011, Edmonds et al. 2012, Environment and Climate Change Canada 2015). Rising temperatures will further reduce the abundance of macroinvertebrate prey breeding in wetlands (McClure et al. 2012). Such changes will threaten key habitat and resource availability, as well as breeding and reproduction success. The breeding distribution of the rusty blackbird is expected to continue to track northward as warming southern habitat becomes unsuitable, leading to a contraction of the species' range (McClure et al. 2012, Environment and Climate Change Canada 2015, Stralberg et al. 2019).

Insects

Four insect species have been assessed under the *Species at Risk (NWT) Act*, including three bumble bees (*Bombus spp.*) and one beetle. Suckley's cuckoo bumble bee has not been assessed in the NWT at this time, but has been included here, given its association with the western bumble bee. Little research has been completed on climate change impacts to bumble bees but climate has been shown to play a role in species assemblages and distribution (Iserbyt and Rasmont 2013, Fourcade et al. 2019).

Gypsy Cuckoo Bumble Bee (*Bombus bohemicus*)

The gypsy cuckoo bumble bee inhabits a narrow range of mid to high elevation and high-altitude habitat and exhibits social parasitism when conceiving offspring. It thus relies on its host species for reproduction and survival and will be directly affected by declines in the populations of its host species (rusty-patched bumble bee, yellow-banded bumble bee and Western bumble bee). More frequent heat waves and droughts are expected to directly increase this cold-adapted bumble bee species' mortality due to physiological limitations (Williams et al. 2009, Soroye et al. 2020).

Suckley's Cuckoo Bumble Bee (*Bombus suckleyi*)

Limited research has been completed to determine the effects of climate change on the Suckley's cuckoo bumble bee. Similar to the gypsy cuckoo bumble bee, the Suckley's cuckoo bumble bee is currently in decline as a direct result of the decline of the Western bumble bee, which is its main host species (COSEWIC 2019). This trend is expected to continue because of contracting bumble bee ranges in response to climate change (COSEWIC 2019). Phenological mismatches are a risk for gypsy cuckoo bumble bee and other bumble bee species discussed here. Two bumble bee species that co-occur with Suckley's cuckoo bumble bee, among others, are emerging ten days earlier than a century ago due to climate change, potentially leading to a mismatch with host plant phenology (Bartomeus et al. 2011). To a

degree, advanced emergence of pollinators may help these species keep pace with earlier food plant flowering (Kudo and Ida 2013, Forrest 2015, Rafferty 2017); nonetheless, the risk of this mismatch is considered a potential effect in global insect population declines. Evidence suggests that the potential for pollinator-plant phenology mismatches may be highest among Arctic species (Høye et al. 2013, Rafferty 2017).

Western Bumble Bee (*Bombus occidentalis mckayi*)

The Western bumble bee mostly pollinates flowers with short petals due to the short length of its tongue. At least 50% of the species' range is in Canada and recent studies suggest that the species remains common (COSEWIC 2014, MacPhail et al. 2020). The southern subspecies of Western bumble bee (*B. occidentalis*) is currently experiencing a northward decline of unknown cause, suggesting the northern species is potentially at risk as a result of increasing temperatures surpassing its physiological thresholds (COSEWIC 2014). Like many other bumble bee species, known threats which could be worsened by a changing climate include disease transmission from exotic greenhouse bumble bees, pesticide use (neonicotinoid compounds), and habitat loss as a result of agriculture and development (COSEWIC 2014, Graves et al. 2020).

Yellow-banded Bumble Bee (*Bombus terricola*)

The yellow-banded bumble bee emerges particularly early in spring and has late production of queens and males at the end of summer making its nesting and plant forage availability particularly susceptible to extreme weather events in spring and fall, the intensity of which may increase as a result of climate change (Colla and Dumesht 2010, COSSARO 2016). The yellow-banded bumble bee has experienced a southern range contraction and a shift into higher elevation habitat because of warming temperatures and this trend is expected to continue, which will eventually limit habitat and resource availability (Kerr et al. 2012, Committee on the Status of Species at Risk in Ontario 2016, Jacobson et al. 2018). Decreasing body size has been observed in the yellow-banded bumble bee with increasing habitat elevation over time, suggesting a range shift to higher elevations may lead to decreased survivorship (Colla et al. 2006, Williams et al. 2009, CaraDonna et al. 2018, Nooten and Rehan 2020).

Transverse Lady Beetle (*Coccinella transversoguttata*)

Climate change is expected to lead to a northward range shift in the transverse lady beetle's habitat (Kawakami et al. 2014). The insect's predominantly heath habitat in Arctic and sub-Arctic ecosystems is expected to be susceptible to moisture regime changes associated with climate change (Hansen et al. 2016). Temperature shifts will significantly affect prey availability and quantity, which may alter reproduction and larval success (Kawakami et al. 2014 and 2015, Sloggett 2017, Linton and McCorquodale. 2019). Changes in temperatures and solar radiation can have an effect on phenological traits such as body size (Kawakami et

al. 2014 and 2015). Increased rainfall may decrease the probability of colonization at higher latitudes (Comont et al. 2013). The current global decline of the transverse lady beetle is generally concluded to be a result of invasive species (mainly the multicoloured Asian lady beetle and the seven-spotted lady beetle), which have led to intraguild predation, direct competition, and the introduction of pathogens (Turnock et al. 2003, Evans 2004, Comont et al. 2013, COSEWIC 2016, Environment and Natural Resources 2018, Linton and McCorquodale. 2019). The higher latitude habitat range of the transverse lady beetle will be susceptible to shifts in invasive species habitat ranges, which are expected to trend northward with climate change (Environment and Natural Resources 2018). Transverse lady beetle has some capacity to adapt to climate change through high reproductive and dispersal capacity, as well as summer dormancy, overwintering behaviour and cold tolerance that allow the species to survive in a wide variety of habitats and conditions (COSEWIC 2016). This adaptive capacity is expected to reduce vulnerability to climate change to a degree; thus, the overall level of vulnerability at the species level is not yet clear.

Amphibians

Northern Leopard Frog (*Lithobates pipiens* - Prairie and Western Boreal population)

Climate change may result in changes to Northern leopard frog habitats, particularly breeding and overwintering habitat, as hydrological changes alter wetlands while droughts and floods cause habitat loss (Pitchford et al. 2012, Mushet et al. 2013, Shank and Nixon 2014, Grant et al. 2015, Stockwell et al. 2016, Lannoo and Stiles 2020). Climate warming and precipitation changes are expected to affect host-pathogen interactions and potentially increase the risk of infections (Rollins-Smith 2017). Breeding phenology has already been impacted by climate warming in some areas (Klaus and Loughheed 2013) and climate change is predicted to reduce genetic diversity (Mushet et al. 2013, Stockwell et al. 2016).

Western Toad (*Anaxyrus boreas*)

While climate change-induced droughts may affect their habitats, Western toads have broader historical hydrological niches and are therefore likely to be less vulnerable than Northern leopard frogs (Shank and Nixon 2014, Slough and DeBruyn 2018, Thurman and Garcia 2019). Hibernation and breeding phenology may be affected by climate warming (Blaustein et al. 2001, Browne and Paszkowski 2010, Slough and DeBruyn 2018). Climate warming and droughts are expected to influence western toad physiology by increasing physiological costs, exceeding thermal and water loss limits, and affecting larval development (Bartelt et al. 2010, Thurman and Garcia 2017, Slough and DeBruyn 2018, Thurman and Garcia 2019, Lertzman-Lepofsky et al. 2020). Climate warming and precipitation changes are expected to affect host-pathogen interactions and potentially increase the risk of infections (Olson 2009, Schock et al. 2010, Kiesecker 2011, McKelvey and Buotte 2018, Bradley et al. 2019).

DISCUSSION

Climate change has caused impacts to human and natural systems on all continents and across all oceans in recent decades (IPCC 2014). Climate stresses related especially to severe heat, heavy precipitation and declining snowpack will increase in frequency and severity in North America (Romero-Lankao et al. 2014) and these stresses are expected to be particularly severe in polar regions (Larsen et al. 2014). Effects will occur within terrestrial and inland water systems (Settele et al. 2014), freshwater resources (Jiménez Cisneros et al. 2014) and especially coastal systems and low-lying areas due to the interacting effects of temperature, sea level rise and changes to sea ice (Wong et al. 2014). These effects are expected to exacerbate existing threats to species at risk, in particular at high latitudes (Larsen et al. 2014, Romero-Lankao et al. 2014). Changes to climate parameters such as temperature, the amount, timing and type of precipitation, and sea levels will cause indirect effects to the persistence and distribution of permafrost, the distribution of tundra and boreal forest, vegetation structure, timing and magnitude of biomass production, phenology, and migration of many species, as well as a multitude of inter-related factors (Larsen et al. 2014, Romero-Lankao et al. 2014).

Projected climate change effects vary according to a species status, distribution and interactions with other species and the physical environment. In the NWT, one plant species is on the NWT List of Species at Risk: hairy braya. Climate change is projected to negatively impact this species. Highly restricted habitats and small known population size for this endemic species means these populations are vulnerable to projected changes that include continued habitat loss for coastal erosion (COSEWIC 2013 and 2018, Attanayake et al. 2019). Moreover, the endemic nature of this species and reliance on unique and isolated habitats leaves it vulnerable to more widespread changes including weather extremes that affect moisture availability, and other factors related to mortality and productivity (e.g. winter survival). Hypothesized biotic interactions for habitat creation and establishment of hairy braya through soil disturbance by caribou will also be impacted by the concomitant effects of climate change on these species (COSEWIC 2013).

Climate change is likely to result in habitat loss, affect habitat use, reduce connectivity, and/or influence distributions for all mammals examined (Jenkins et al. 2016, Stern and Laidre 2016, Korosi et al. 2017, Bauduin et al. 2018, Slough and Jung 2020). This includes vegetation shifts, increased forest fire occurrence and intensity, sea ice habitat loss, altered wetlands, and changes in snowpack (Strong and Gates 2009, Barrier and Johnson 2012, Gustine et al. 2014, Laidre et al. 2020). Habitat changes are likely to be negative for most species except for grizzly bear and bat species, whose ranges are expected to expand in response to climate change (Humphries et al. 2002, Clark et al. 2019, Barnas et al. 2020). Caribou, collared pika, wood bison, wolverine, and polar bears were identified as particularly vulnerable to habitat loss associated with climate change (Durner et al. 2009, Copeland et al.

2010, Cherry et al. 2013, Barsugli et al. 2020, Kukka et al. 2020). Climate change may also affect biotic interactions for mammals, including changes in predator-prey interactions, food availability, competition, insect infestations, and parasite exposure (Inman and Packila 2015, Sharma et al. 2019, Barnas et al. 2020, Watson et al. 2020). Altered biotic interactions are likely to influence all mammals examined and this is expected to be especially prominent for caribou, collared pika, wolverine, and polar bears (Barker et al. 2015, Sutton et al. 2016, Foley et al. 2017, Clark et al. 2019, van der Veen et al. 2020). Overall, these changes in habitat availability and biotic interactions are expected to affect population dynamics, in particular for caribou (especially Peary caribou) and polar bears (Amstrup et al. 2008, Castro de la Guardia et al. 2013, Jenkins et al. 2016, Mallory and Boyce 2019).

Climate change is projected to result in southern habitat loss and northward species range shifts for short-eared owl and rusty blackbird (McClure et al. 2012, Swengel and Swengel 2013, Booms et al. 2014, Environment and Climate Change Canada 2015, Johnson et al. 2017, Stralberg et al. 2019). Vegetation shifts, hydrological changes and droughts are all expected to further contribute to habitat loss (COSEWIC 2006, Greenberg and Matsuoka 2010, Greenberg et al. 2011, Edmonds et al. 2012, Environment and Climate Change Canada 2015). Avian phenology and breeding success is highly dependent on resource availability and weather patterns and may be altered by the effects of climate change (McClure et al. 2012, Environment and Climate Change Canada 2015, Stralberg et al. 2019).

Climate change may result in contractions of bumble bee habitat ranges and affect species richness, especially in their southern ranges and particularly in species that inhabit regions at higher latitudes and elevations (Colla et al. 2012, Kerr et al. 2012, Arbetman et al. 2017, Jacobson et al. 2018, Mathiasson and Rehan 2019, Nooten and Rehan 2020). Extreme weather events, such as drought, heatwaves and fires are expected to aggravate habitat shifts and degradation through their effects on flowering species (Pradervand et al. 2014, Loffland et al. 2017, Graves et al. 2020). More frequent extreme weather events may also lead to increased mortalities as bumble bees meet their physiological thresholds. Bumble bee body size is expected to decrease as a response to decreasing resource availability (Sanderson et al. 2015, Nooten and Rehan 2020, Soroye et al. 2020). Changes in temperature and increased rainfall is expected to detrimentally affect breeding phenology (Colla and Packer 2008, Grixti et al. 2009, Bartomeus et al. 2011, Cameron et al. 2011, Colla et al. 2012, Soroye et al. 2020).

Climate change may change northern leopard frog and western toad habitats, particularly breeding and overwintering habitat, as hydrological changes alter wetlands while droughts and floods cause habitat loss (Mushet et al. 2013, Grant et al. 2015, Thurman and Garcia 2019, Lannoo and Stiles 2020). Hibernation and breeding phenology may be affected by climate warming (Blaustein et al. 2001, Browne and Paszkowski 2010, Klaus and Loughheed 2013, Slough and DeBruyn 2018). Climate warming and droughts are expected to influence amphibian physiology by increasing physiological costs, exceeding thermal and water loss limits, and affecting larval development (Bartelt et al. 2010, Thurman and Garcia 2017 and

2019, Slough and DeBruyn 2018, Lertzman-Lepofsky et al. 2020). Climate warming and precipitation changes are expected to affect host-pathogen interactions and potentially increase the risk of infections (Olson 2009, Schock et al. 2010, Kiesecker 2011, Rollins-Smith 2017, McKelvey and Buotte 2018, Bradley et al. 2019).

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