Assessing Climate Change Vulnerability of Breeding Birds in Arctic Alaska

A report prepared for the Arctic Landscape Conservation Cooperative

Joe Liebezeit, Erika Rowland, Molly Cross, Steve Zack

WILDLIFE CONSERVATION SOCIETY

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CONTENTS

Executive Summary 1
Section 1. Introduction 3
Vulnerability Assessment Basics 7
Section 2. Methods 8
Vulnerability assessments of bird life cycle components 8
Regions considered in the Vulnerability Assessment 10
Climate Change Vulnerability Index Tool 10
Geospatial Inputs to the CCVI 13
Sensitivity survey and expert solicitation 16
Visualizing species sensitivity and climate change vulnerability 16
Section 3. Results 18
Climate exposure 18
Indirect exposure 18
Species sensitivity 19
Relative vulnerability to climate change 21
Alternate climate scenarios 23
Sources of climate change vulnerability 23
Section 4. Discussion 25
Climate change vulnerability of Arctic Alaska birds 25
Comparisons with other vulnerability assessments 26
Climate change vulnerability in context 27
Information Gaps 27
Limitations of the CCVI tool 28
Other Uncertainties 29
Informing research, conservation and management 29
Considerations for focusing future efforts 29
Conservation and management activities 30
Conclusion 32
References 33
Acknowledgements 37
Appendix A: Hamon AET:PET Aridity Index 38
Appendix B: Species Accounts 39
Appendix C: Summary of the Climate Change Vulnerability Assessments For Winter Range and Passage Migration 148
Appendix D: Sensitivity Survey Experts 154
Appendix E: Workshop 156
Appendix F: Revised Sensitivity Questions 159

Executive Summary

Climate change is occurring at an accelerated rate in the Arctic compared to most other places on the earth. Temperature and moisture changes are leading to warming permafrost, increased coastal erosion, more frequent fires, and shrub invasion, altering geomorphology, hydrology, and habitat structure. These rapid changes in habitats, especially those associated with hydrology, are ultimately influencing wildlife populations. Arctic Alaska harbors some of the most important breeding and staging grounds for millions of birds representing over 90 species. Many of these species are migratory, wintering at disparate sites across the planet, and some are already experiencing population declines and/or are species of conservation concern. As climate change has become a focal issue for agencies and other institutions in recent years, one of the recognized needs is the application of science-driven assessments to reconsider landscape management, wildlife research, and conservation priorities in this context. To help address these emerging needs the Wildlife Conservation Society conducted a climate change vulnerability assessment for arctic breeding birds to help guide climate-informed wildlife management in the region. The specific goals of this assessment were to: 1) provide a climate change vulnerability ranking for 54 Arctic Alaskan breeding bird species; 2) evaluate the relative contribution of specific sensitivity and exposure factors to individual species rankings; 3) consider how this assessment may be integrated with other approaches; and 4) appraise the effectiveness of the NatureServe Climate Change Vulnerability Index (CCVI) tool.

The CCVI tool was developed by NatureServe specifically to compare the added vulnerability posed by climate change to species in a region. We assessed vulnerability with reference to changes projected for 2050 and restricted in geographic scope to the Alaska portion of the Arctic LCC region. The CCVI is a spreadsheet based algorithm that integrates information on species sensitivity, direct exposure to projected atmospheric changes in climate, and indirect exposure factors. Direct exposure factors, temperature and moisture balance change, were incorporated as geospatial inputs. We ran the tool with data from five global circulation models, two emissions scenarios, and at two spatial resolutions. Indirect exposure factors included sea-level rise, dispersal relative to barriers, and human mitigation in response to climate change. Sensitivity factors (life history traits making a species more or less vulnerable) were scored by species experts on survey forms based on published literature and their personal knowledge.

The CCVI results ranked two species as highly vulnerable (Gyrfalcon, Common Eider), seven as moderately vulnerable (Brant, Steller's Eider, Pomarine Jaeger, Yellow-billed Loon, Buff-breasted Sandpiper, Red Phalarope, Ruddy Turnstone), and five as likely to increase (Savannah Sparrow, Lapland Longspur, White-crowned Sparrow, American Tree Sparrow, Common Redpoll). The assessment outcome suggests that the most important contributions to the climate change vulnerability for the 54 bird species include: 1) being a specialists in at least one life history trait and/or having a strong coastal orientation; 2) the quality and nature of interactions with other species; 3) restrictions associated with physical habitat and diet; 4) dependence on other species to meet habitat needs; and 5) changes in disturbance regimes that would negatively affect the speices. Physiological hydrological niche (i.e., dependence on wetland habitats in the arctic) was thought to

have the greatest potential to influence vulnerability; although its effect on outcomes was diminished by the way the tool applies exposure weights to sensitivity factors. Currently available projections for Arctic Alaska suggest negligible change in moisture balance driven by atmospheric demand.

There was insufficient information to address questions, both for particular sensitivity factors and for certain species or taxon groups. These and other information gaps highlight the need for more research or synthesis of existing data to fill this void. Key needs identified to better understand the climate change vulnerability of birds in Arctic Alaska include: 1) the effects of temperature increases on surface hydrology, wetland availability, and vegetation change; 2) information on nearly all aspects of phenology and its relationship with and response to changing environmental conditions; 3) greater knowledge of the genetic diversity of species, its relationship to climatic gradients, and its role in climate change response.

Climate change vulnerability indices are one of several approaches to understanding the effects of climate change on species, each with its own limitations. While the CCVI tool does not examine statistical or mechanistic relationships between sensitivity and exposure factors and does not integrate climate stressors affecting migratory birds outside of their breeding grounds, this assessment represents a starting point to help prioritize management, conservation, and research efforts with respect to breeding birds in the Alaskan Arctic.

Long-tailed Jaegers on the coastal plain of Alaska (Photo: S. Zack *@ WCS)*

Section 1. Introduction

Of all places on the earth, climate change is occurring most dramatically at the poles (Gillett et al. 2008). In the Arctic, air temperature has increased at almost twice the global average rate in the past 100 years, accompanied by significantly altered weather patterns, increased glacial and polar pack ice melt, and sea level rise (IPCC 2007). More specifically, in Arctic Alaska mean annual temperature is rising at a rate of 0.45 °C per decade (Data from M. Shulski reported in Martin et al. 2009; Figure 1.1). Over the next 60 years, mean annual temperatures are expected to increase approximately 5 °C (Figure 1.2) and to 7 °C by the end of the century with most of the warming occurring in winter (Martin et al. 2009). Annual precipitation is expected to increase 20-40% over the next 60 years (Figure 1.3) although increasing temperatures may lessen the effects of increased precipitation by driving an increase in evapotranspiration rates (TWS SNAP http://www.snap.uaf.edu/data.php). While in some Arctic sites there is evidence of tundra drying, the pattern is spatially heterogeneous (e.g., Riordan et al. 2006). It is uncertain whether the future will bring a net annual drying or moistening. Moreover, it is unclear how surface hydrology and geomorphology changes will either exacerbate or compensate for shifts in atmospheric moisture (Martin et al. 2009). Regionally, recent temperature and moisture changes are leading to warming permafrost (Romanovsky et al. 2007), increased coastal erosion (Jones et al. 2009), more frequent fires (Racine and Jandt 2008), and shrub invasion (Tape et al. 2006), likely altering geomorphology, hydrology, and habitat structure (see Martin et al. 2009 for a thorough review).

Key resources of concern in the Arctic are the vast productive wetlands in northern Alaska (particularly in the Arctic Coastal Plain) and the birds that migrate from all over the globe during the brief summer season to breed. Avian research in the region points to the unique importance of large parts of Arctic Alaska in harboring some of the most important avian breeding grounds in the entire circumpolar Arctic (Andres et

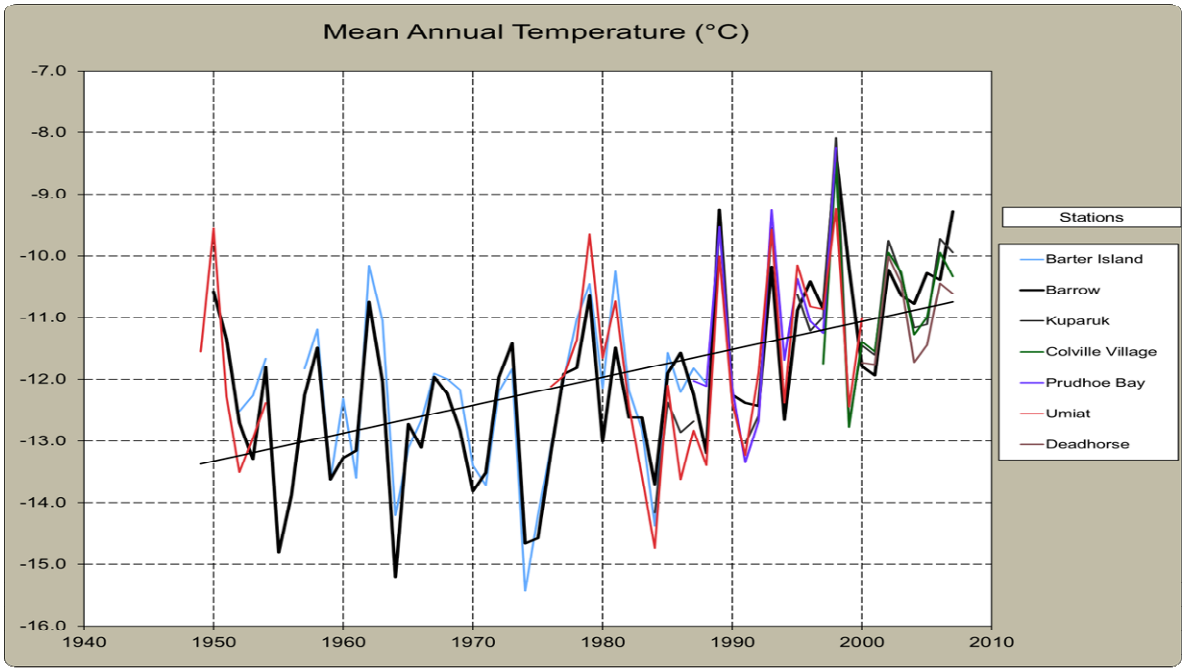


Figure 1.1. 50-year trend in mean annual temperature at seven sites on the North Slope (Source: M. Shulski *in* Martin et al. 2009).

al. 2012). Over 90 species of birds, representing millions of individuals that regularly nest in this region (Johnson and Herter 1989), are the most conspicuous and diverse vertebrates in the ecosystem. In particular, significant populations of shorebirds (Pitelka 1974, Johnson et al. 2007, Liebezeit et al. 2011, Andres et al. 2012), waterfowl (King and Hodges 1979), and water birds (Earnst et al. 2005) come to Arctic Alaska to nest every year. A number of species which rely on Alaskan Arctic breeding and staging grounds have experienced population declines and/or are species of conservation concern. These include 10 shorebird species (Alaska Shorebird Group 2008, Morrison et al. 2006, Bart et al. 2007) and others such as the Yellow-billed Loon (*Gavia adamsii*). Two species, the Spectacled and Steller's Eiders (*Somateria fischeri, Polysticta stelleri*) are listed as threatened under the U.S. Endangered Species Act (U.S. Department of Interior 1993, 1997).

Initial explorations of climate change impacts to breeding birds in the region range from potentially negative to positive effects but are challenged by a paucity of baseline information (Martin et al. 2009, Zack and Liebezeit 2010). Scientific research, monitoring, and modeling studies for understanding how these changes are impacting important biophysical processes, let alone the wildlife and bird populations in Arctic Alaska, are absent or in initial stages. The high costs and logistical difficulty of conducting scientific research and monitoring in the remote arctic has historically made it challenging to develop long-term and region-wide field-based programs to measure wildlife populations. It is likely, though, that some Arctic-breeding bird species will (and may already) be negatively impacted, while others will benefit from a warming climate.

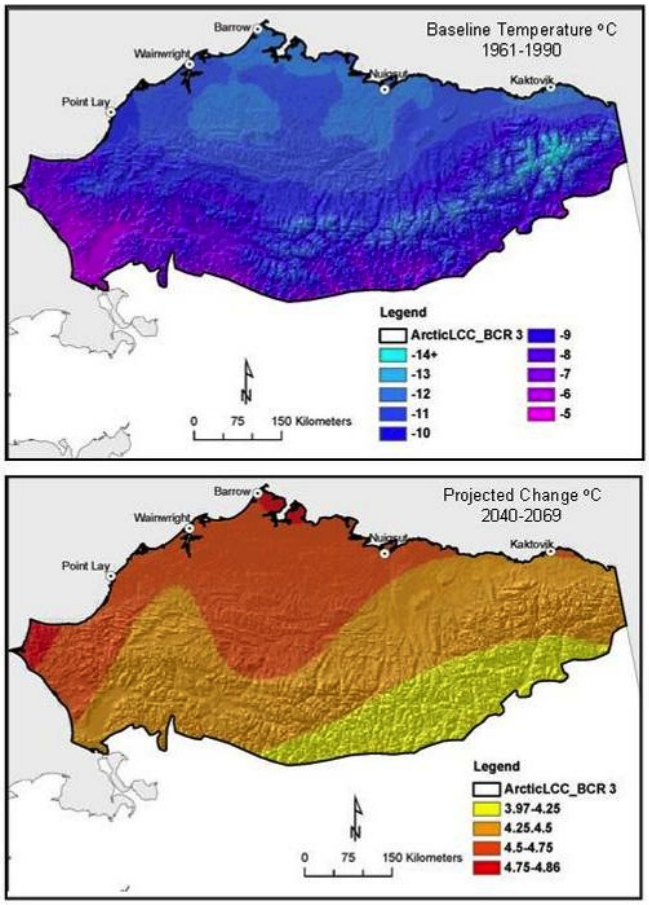


Figure 1.2. (Upper panel) Mean annual temperature for the Arctic LCC region (°C) and (Lower panel) change in mean annual temperature (°C) projected for 2040-2069. Maps created by WCS using CRU historical climate data and 5-Model Composite– A1B projections (SNAP 2011).

As climate change continues to accelerate in the far north and ultimately influences wildlife populations in the region, including the avifauna, land managers will be more challenged to prepare for, and cope with, impending impacts. At a global scale ecologists have predicted major changes in the viability and distribution of wildlife populations and the habitats that support them. Already range and phenological shifts for multiple taxa have been detected (Parmesan and Yohe 2003, Rosenzweig et al. 2008). Although the ability of species to adapt to climate changes has been tested for

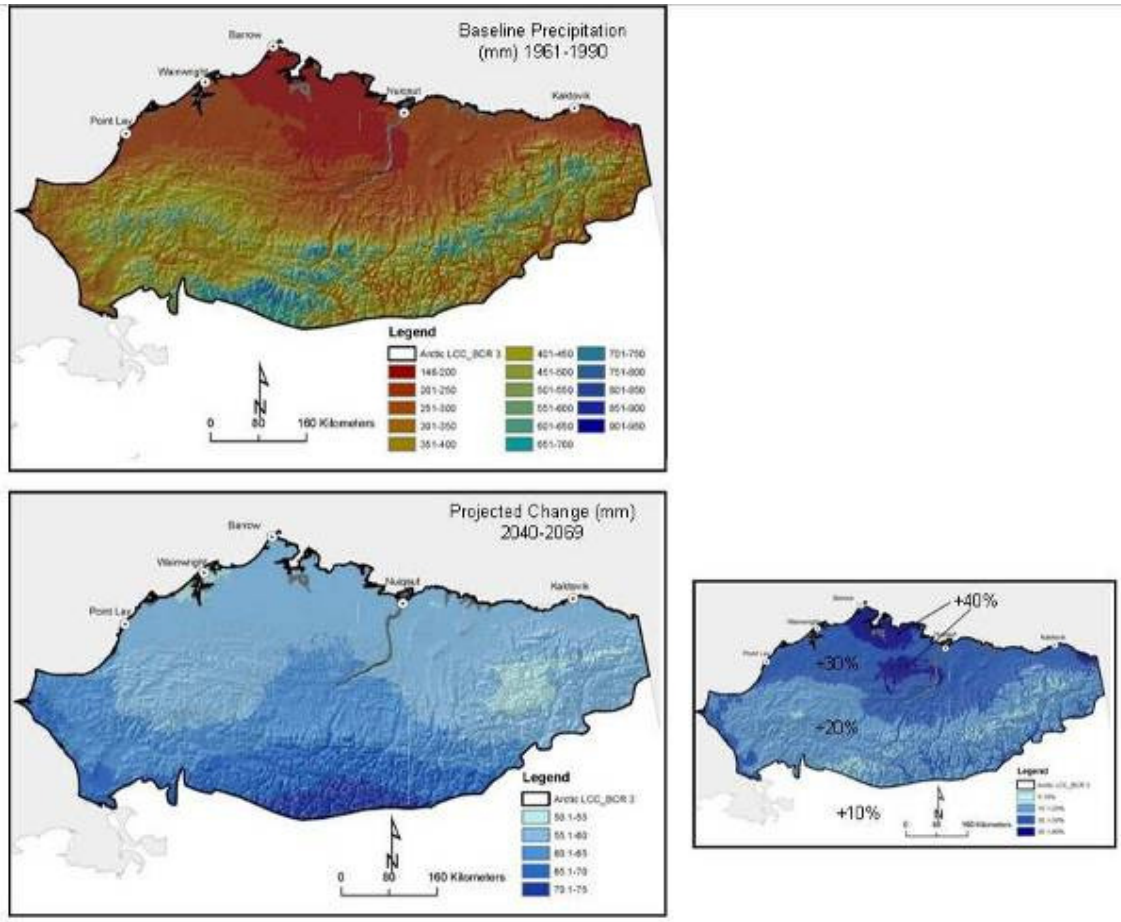


Figure 1.3. (Upper Panel) Mean annual precipitation for the Arctic LCC region (mm) and (Lower Panel) change in the mean annual precipitation in mm (left) and in % change (right) projected for 2040-2069. Maps created by WCS using CRU historical climate data and 5-Model Composite– A1B projections (SNAP 2011).

eons, both at the physiological and behavioral level (Parmesan 2006), the speed with which the climate is currently changing may preclude adaptation in many species (Visser 2008).

The combination of this rapid pace of climate change with increasing human impacts could lead to accelerated rates of extinction for many species (IPCC 2007). Wildlife managers and conservationists will require additional kinds of information to make decisions about their goals for wildlife populations in changing conditions and about the consistency of land uses and other policy choices with these goals. As such, explicitly addressing climate change impacts, often called "climate change adaptation", is becoming an important new approach in natural resource management (Glick et al. 2011).

Federal and state agencies have recently established programs with a mandate to manage wildlife with respect to climate change. The Department of Interior-led - Landscape Conservation Cooperatives (LCCs) and U.S. Geological Survey - Climate Science Centers (CSCs) are charged with integrating federal agency and partner science and management expertise in a coordinated response to climate change and other landscape-scale stressors in many regions. A specific goal of the Arctic LCC charter is to develop "effective conservation planning dependent on knowledge of the

relative vulnerabilities of habitats, species, and species assemblages" (Arctic LCC 2010). In addition, the state of Alaska Department of Fish and Game State Wildlife Action Plan is due for revision in 2015, at which time they may be forced to contend with the new threats emerging as a result of climate change. Agencies, academicians, and non-governmental organizations have recognized the need to use science-driven assessments and syntheses to reconsider wildlife research, management, and conservation priorities with respect to climate change. As a contribution toward these emerging needs, the Wildlife Conservation Society (WCS) conducted a climate change vulnerability assessment to help guide climate-informed wildlife management in the region.

Recognized as one effective method for integrating climate change considerations into conservation and other planning efforts, climate change vulnerability assessments can provide key inputs to early steps in the process. Vulnerability assessments combine information about the characteristics of a target or resource (species, habitat, or process) that make it sensitive to climate change with the magnitude of projected exposure to that change, and its capacity to adapt to the changes (see text box on next page). With these components, vulnerability assessments can help us identify what is likely to be most affected by projected climate changes and why they are likely vulnerable (Glick et al. 2011). They can offer important contributions to a climate change adaptation strategy (Figure 1.4) by guiding management and planning priorities, assisting in informing and developing management strategies, and enabling a more efficient allocation of resources (Glick et al. 2011). Assessment outcomes can also provide information for scientists to develop testable hypotheses for monitoring and research.

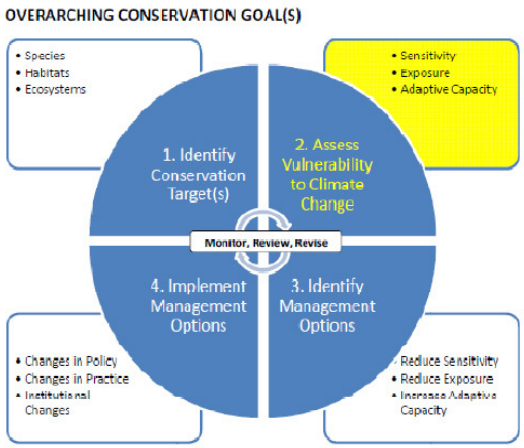


Figure 1.4. Overarching framework for developing climate change adaptation strategies (Source: Glick and Stein 2011)

Climate change vulnerability assessment results, in and of themselves, do not dictate an agency's management, research, or conservation priorities. Land managers and decision makers must also consider other management priorities, costs, and logistical issues before taking action on the basis of a vulnerability assessment. Vulnerability assessments pull together the best available information about a resource of interest, which is often based on expert opinion and considered less rigorous by some (Martin et al. 2011). The final results should be interpreted within this context, and, in many cases, are best viewed as a starting point or one of several complementary sources of information integrated to provide guidance on addressing a management or conservation problem.

The specific goals of our assessment were to:

1. Provide a climate change vulnerability ranking for 54 Arctic Alaskan breeding bird species, using the NatureServe Climate Change Vulnerability Index (CCVI) tool (Young et al. 2010). Ranks may range from highly vulnerable, presumed stable, to likely benefit from climate change.

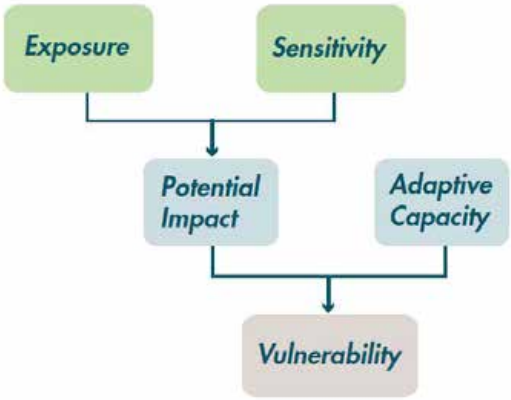
- For 17 shorebird species provide a climate change vulnerability ranking for their wintering and migration grounds to combine with the breeding ground result for an overall vulnerability ranking spanning their entire annual cycle.

2. Evaluate the relative contribution of specific sensitivity and exposure factors to individual species rankings to better understand how and why climate might be impacting species now and into the future in the region.
3. Consider how this assessment can be integrated with other approaches to help prioritize management, research, and conservation.
4. Comment on the effectiveness of the CCVI tool in this assessment.

In this report we provide the results of our vulnerability assessment of Arctic breeding-bird species to climate change, and some thoughts about the process of conducting the assessment and the application of output.

Vulnerability Assessment Basics

In the context of climate change, vulnerability is defined as the extent to which a species, habitat, or ecosystem is susceptible to negative impacts from climate change impacts (Schneider et al. 2007). A vulnerability assessment is a function of the *sensitivity* of a system or species to climate changes, its *exposure* to those changes, and its *capacity to adapt* to those changes (IPCC 2007, Glick et al. 2011; see figure below). Sensitivity refers to intrinsic traits of a system or species (e.g. physiological tolerances) that make them vulnerable to climate change. In contrast, exposure refers to extrinsic factors (e.g. increasing temperatures) that a system or species is likely to experience. The adaptive capacity refers to opportunities available that may improve a species' or system's ability to cope with sensitivity or exposure stressors (e.g. dispersal to different temperature gradient). The interplay of these three factors defines the relative vulnerability. There are a number of different approaches to conducting a vulnerability assessment (Rowland et al. 2011) ranging from simple conceptual model flowcharts to more advanced predictive modeling. All of these approaches are based on the core components described above.



The relationship of the key components of a vulnerability assessment (Source: Glick et al. 2011).

Section 2. Methods

There are numerous approaches to conducting climate change vulnerability assessments for targets ranging from ecosystem processes to individual species, which are more or less appropriate in different situations and often best applied in a step-wise or complementary way (Glick et al. 2009, Rowland et al. 2011). The NatureServe Climate Change Vulnerability Index tool (CCVI-Version 2.1) is designed to provide a relatively rapid assessment of multiple species and is best suited to regions in which vulnerability assessments are just getting underway. It offers a structured starting point for developing an understanding of relative vulnerability based on a consistent set of synthesized information (Young et al. 2010). The tool addresses factors relevant to vulnerability to climate change only; thus, results are meant to be considered in conjunction with other conservation status assessments (e.g. IUCN Red List, Audubon Watchlist, Endangered Species Act). We used this tool to initially examine impacts that projected climate changes for Arctic Alaska (Arctic LCC region, Figure 2.1) might have on 54 species of birds that breed in the region (Table 2.1). Vulnerability was assessed with reference to changes projected for 2050, a timeframe chosen to consider the implications of near-term changed to more current management and conservation adaptation strategies. The vulnerability assessment exercise included: 1) a survey of individual species experts to inform sensitivity (i.e., life history trait) inputs, 2) application of the CCVI tool, 3) a workshop during which preliminary results and methods were vetted by participating experts, and 4) a revision informed by the workshop discussions to generate final results.

Vulnerability assessments of bird life cycle components

We considered 54 of the approximately 90 species of birds that regularly use the terrestrial and freshwater habitats in Arctic Alaska (Table 2.1.) (Johnson and Herter 1989). Our assessment included 17 shorebird, 16 land bird species (passerines, raptors, ptarmigan), 21 waterbird species (loons, ducks, geese, gulls, terns, jaegers). We did not include all commonly nesting species in the assessment because of funding and time constraints; however, we did include a cross-section of bird species representing the main taxonomic groups. We selected species that were known to have important populations in the region, were of conservation concern, and/or were believed to be predisposed to climate change impacts based on existing information (e.g. breeding range constraints).

The primary focus of this effort was to improve our understanding of the climate change vulnerability of the 54 bird species during their breeding season in Arctic Alaska. However, we also recognized that most of these birds are migratory and only spend a small portion of their lives in the Arctic. Many of these species may experience climate change stressors in other parts of their range. For this reason, we conducted separate vulnerability assessments for 17 shorebird species focused on their wintering grounds and key passage migration areas, respectively. We chose shorebirds for this pilot effort as they undertake some of the longest migrations of birds in Arctic Alaska, and climate change vulnerability likely varies spatially and temporally. We integrated the wintering ground and passage migration area results with those of the breeding season to calculate an overall vulnerability score. The results of the additional assessments are preliminary since information on shorebird

Table 2.1. Fifty-four species included in the vulnerability assessment.

Common Name	Scientific Name
Waterfowl	
Tundra Swan	*Cygnus columbianus*
Greater White-fronted Goose	*Anser albifrons*
Snow Goose	*Chen caerulescens*
Brant	*Branta bernicla*
Canada/Cackling goose	*Branta canadensis*
Northern Pintail	*Anas acuta*
Greater Scaup	*Aythya marila*
Steller's Eider	*Polysticta stelleri*
Spectacled Eider	*Somateria fischeri*
King Eider	*Somateria spectabilis*
Common Eider	*Somateria mollisima*
Long-tailed Duck	*Clangula hyemalis*
Grouse	
Willow Ptarmigan	*Lagopus lagopus*
Rock Ptarmigan	*Lagopus muta*
Loons	
Red-throated Loon	*Gavia stellata*
Pacific Loon	*Gavia pacifica*
Yellow-billed Loon	*Gavia adamsii*
Raptors	
Rough-legged Hawk	*Buteo lagopus*
Gyrfalcon	*Falco rusticolus*
Peregrine Falcon	*Falco peregrinus*
Shorebirds	
Black-bellied Plover	*Pluvialis squatarola*
American Golden-plover	*Pluvialis dominica*
Whimbrel	*Numenius phaeopus*
Bar-tailed Godwit	*Limosa lapponica*
Ruddy Tturnstone	*Arenaria interpres*
Red Knot	Calidris canutus
Semipalmated Sandpiper	*Calidris pusilla*
Western Sandpiper	*Calidris mauri*
White-rumped Sandpiper	*Calidris fuscicollis*
Baird's Sandpiper	*Calidris bairdii*
Pectoral Sandpiper	*Calidris melanotos*
Dunlin	*Calidris alpina*
Stilt Sandpiper	*Calidris himantopus*
Buff-breasted Sandpiper	*Tryngites subruficollis*
Long-billed Dowitcher	*Limnodromus scolopaceus*
Red-necked Phalarope	*Phalaropus lobatus*
Red Phalarope	*Phalaropus fulicarius*
Gulls and Terns	
Glaucous Gull	*Larus hyperboreus*
Sabine's Gull	*Xema sabini*
Arctic Tern	*Sterna paradisaea*
Jaegers	
Pomarine Jaeger	*Stercorarius pomarinus*
Parasitic Jaeger	*Stercorarius parasiticus*
Long-tailed Jaeger	*Stercorarius longicaudus*
Owls	
Snowy Owl	*Bubo scandiacus*
Short-eared Owl	*Asio flammeus*
Passerines	
Common Raven	*Corvus corax*
American Tree Sparrow	*Spizella arborea*
Savannah Sparrow	*Passerculus sandwichensis*
White-crowned Sparrow	*Zonotrichia leucophrys*
Lapland Longspur	*Calcarius lapponicus*
Smith's Longspur	*Calcarius pictus*
Snow Bunting	*Plectrophenax nivalis*
Common Redpoll	*Carduelis flammea*
Hoary Redpoll	*Carduelis hornemanni*

usage of stopover and wintering areas (particularly in South America and Asia) are poorly understood, and expert feedback on the method we developed for the passage migration component recommended major modifications. These issues were too significant to address within the project timeframe and include in our final results. The methods for assessing vulnerability on the winter grounds and key passage migration areas are presented as a pilot study in Appendix C.

Regions considered in the vulnerability assessment

For breeding season vulnerability we considered the area of interest to be the part of Arctic Alaska bounded by Bird Conservation Region (BCR) 3 – "Arctic Plains and Mountains" (www.nabci-us.org/bcr3.html) which approximates the Arctic LCC boundary. BCR's were developed by the North American Bird Conservation Initiative (NABCI) and represent "ecologically distinct regions in North America with similar bird communities, habitats, and resource management issues" (www.nabci-us.org/bcrs.htm). In Alaska, BCR 3 encompasses 240,000 km^2 of low-lying coastal tundra ("Arctic Coastal Plain"), uplands of the foothills of the Brooks Range, and montane areas of the Brooks Range. Seventy percent of this BCR is federally managed as part of the Arctic National Wildlife Refuge, the National Petroleum Reserve-Alaska, and a number of National Parks, Monuments, and Preserves (Figure 2.1).

Climate Change Vulnerability Index Tool

The CCVI is a spreadsheet based algorithm that integrates information on species sensitivity, direct exposure to projected atmospheric changes in climate, sea level rise, and other indirect factors (e.g. natural and anthropogenic barriers) that might influence the response of the species. Information on documented or modeled responses may be incorporated; however, this information is optional and was available for a limited number of the species we assessed (i.e., 18 of the 54 species). User inputs to the sensitivity and indirect factors are guided by descriptions provided by tool developers to help assign a "score" for each factor on an ordinal scale that ranges from "greatly increases" (3), "increases" (2), "slightly increases" (1) vulnerability to "slightly decreases" (-1) and "decreases" (-2) vulnerability. There is also a neutral (0) option for those factors with little relevance to the species' response to climate change. A choice for "insufficient data" may also be selected if necessary. Factors may be scored at more than one level in the ordinal scale if there is uncertainty about the effects on species response. When this happens, the tool uses the average of the entered values to calculate the vulnerability index. Numerical scores for the sensitivity factors are weighted by the climate exposure (using atmospheric temperature and moisture reflecting the interaction of precipitation and temperature to describe the potential for drying) based on the magnitude of change projected for the portion of the species range that falls within the assessment area (Fig. 2.2 and Table 2.2). The average of the sensitivity scores for a factor, weighted by the exposure factors, are added to compute an overall numerical vulnerability index for each species. The tool also generates 1000 Monte Carlo simulations of the numerical index. These simulations are of particular interest when multiple scores are selected for a given sensitivity factor, which was the case for at least one factor for every species we assessed. Each simulation uses only one of the multiple levels originally selected, generating a range of vulnerability index

results by assuming that each level is equally likely to represent the "true" value.

Numerical indices are converted to categorical outputs based on thresholds associated with various combinations of sensitivity and exposure (Table 2.3). The numerical index allows for a ranking of relative vulnerability across a group of species within a specific assessment area, while categorical outputs facilitate grouping by degrees of vulnerability. For detailed information about the tool and underlying algorithm, see Young et al. (in press).

We report the categorical output (degree of vulnerability), the tool-assigned "confidence level" resulting from the Monte Carlo simulations, and the numerical index score.

We also report the range of numerical index scores generated by the Monte Carlo simulations to offer insight into the sensitivity of the tool output to uncertainties in both the exposure and sensitivity factor inputs (see details on CCVI inputs below). While the relative climate change vulnerability of a group of species is useful, the scores for the sensitivity factors that indicate the underlying sources of potential vulnerability identified through this exercise are of greater relevance to subsequent adaptation planning efforts (see Dubois et al. 2011 example). We provide detailed summaries with an individualized factor-scoring table for each assessed species in Appendix B.

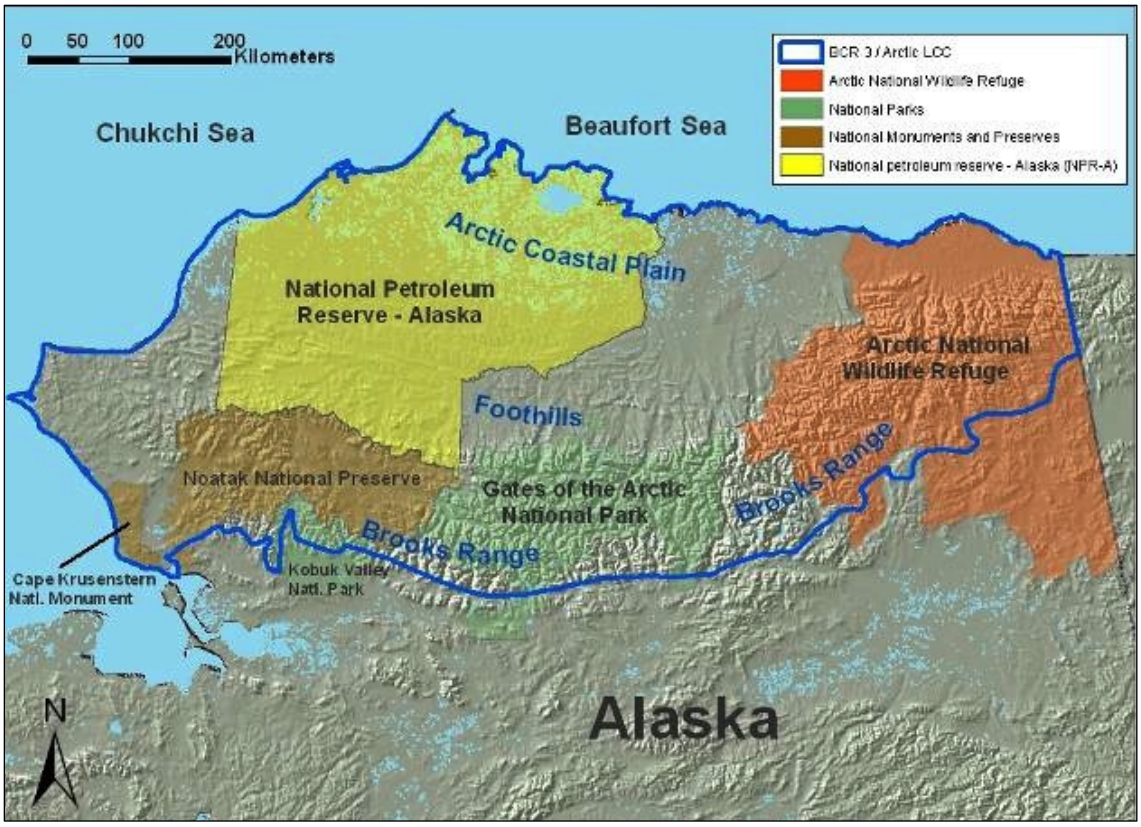


Figure 2.1. Arctic LCC (BCR 3) region of Arctic Alaska. Maps created by WCS using Alaska 300m digital elevation model. USGS EROS, Anchorage, Alaska and other map layers downloaded from the Alaska State Geo-spatial Data Clearinghouse (http://www.asgdc.state.ak.us/). Map projection: Alaska Albers Equal Area Conic.

Table 2.2. Exposure weightings for sensitivity and indirect exposure factors. Weights for temperature and moisture are assigned 1.0, 1.5, 2.0, depending on the number of standard deviations the projected change for the range of a given species is above the average projected change for the entire state of Alaska. A weight of 0.5 is assigned if the increase is <0. The "climate stress" weighting is an average of the temperature and moisture weightings (for example, if the weight for temperature was 2 and the weight for moisture was 0.5, the combined weighting for the factors would be 1.25). Thus, for factors subject to combined weightings, the effects of extreme exposure are mediated. Sea level rise is not weighted because climate change is already integrated (Young et al. in press).

Combined Climate Weighting	*Temperature Change Weight Only*	*Moisture Change Weight Only*
Natural barriers	Physiological thermal niche	Physiological hydrological niche
Human response to CC	Historical thermal niche	Historical hydrological niche
Association with disturbance regime		
Physical habitat restrictions		
Biotic habitat dependence		
Dietary versatility		
Interactions with other species		
Genetic variation		

Note: The CCVI tool does not consider the uncertainty in climate projections (i.e., exposure factors for each individual calculation of species' vulnerability). This uncertainty can be incorporated by running the tool several times, each using the output from different projections.

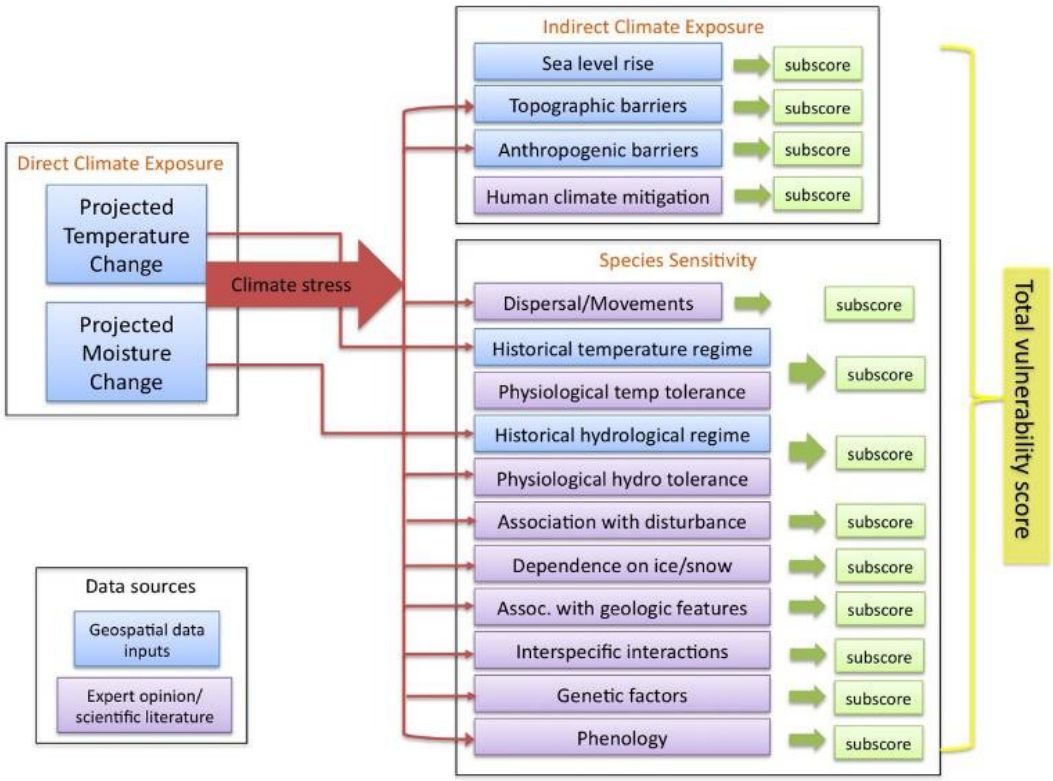


Figure 2.2. Schematic of the NatureServe Climate Change Vulnerability Index (CCVI). The vulnerability score based on the exposure/sensitivity sum is calculated as: $\Sigma f_i w_i$, where f is the value assigned to each factor according to how it influences sensitivity and w is the specific exposure weighting for each factor i.

Table 2.3. Numerical index score thresholds and corresponding vulnerability categories (degree of vulnerability) as assigned by the CCVI. Vulnerability thresholds are based on hypothetical examples of exposure and sensitivity combinations that might lead to different levels of vulnerability (Young et al. in press).

Index Score	*Vulnerability Category*
>10.0	Extremely Vulnerable (EV)
7.0-9.9	Highly Vulnerable (HV)
4.0-6.9	Moderately Vulnerable (MV)
-2-3.99	Presumed Stable (PS)
<-2.0	Increase Likely (IL)

Geospatial Inputs to the CCVI

Geospatial data provide inputs for those contributions highlighted in blue in Fig. 2.2. All data for this assessment were processed and analyzed using ESRI ArcGIS/ArcMap software (ESRI 2009). Geospatial information was incorporated into the algorithm from the outputs of overlay analysis and classification tools.

Species range maps: Initial species range maps were downloaded from NatureServe Explorer (Ridgely et al. 2007, http://www.natureserve.org/explorer). Breeding, passage and winter migration distributions were separated, and breeding ranges were clipped to the assessment area (BCR 3/Arctic LCC boundary). To ensure that the maps most accurately reflected current knowledge on breeding distributions, species' experts were asked to comment on the range maps as part of the sensitivity survey (described below). Many suggested using the Birds of North America (http://bna.birds.cornell.edu/bna/species) account maps; for shorebirds, the data provided in Johnson et al. (2007) and Bart et al. (2012) was frequently recommended; others suggested specific changes based on recent conservation plans (e.g. WHSRN Species Conservation Plans) or their personal knowledge of current ranges. Breeding ranges were edited to reflect recommended range corrections, with the revised version used in the climate exposure, sea level rise exposure, and historical temperature and hydrological niche analyses.

Climate exposure: The primary source for historical and future climate data inputs were the products available through the Scenarios Network for Alaska and Arctic Planning at a resolution of 2-km (SNAP-http://www.snap.uaf.edu/). We also used temperature and moisture data available from Climate Wizard (50-km resolution, www.climatewizardcustom.org/). For future climate, projections averaged for the period 2040-2069 were used to represent 2050 to account for year-to-year variation. The CCVI tool weighted sensitivity factors based on the magnitude of climate change projected for the range of the species being assessed. Because the category boundaries in the tool as distributed were based on climate projections for the conterminous United States only, we altered the magnitude of change category boundaries to reflect changes projected for Alaska (For further explanation, see CCVI Modification #1 below).

Because we were interested in the influence of different climate projections on CCVI results, we ran the tool with data generated by six different scenarios of future climate based on five global circulation models (representing the average and extremes of individual models), two emissions scenarios (A1B and A2), and at two spatial resolutions (50 km and 2 km-Table 2.3). We observed few differences in the vulnerability results using different climate projection inputs. For this reason we report only results from the exposure inputs that capture the range of future climate, highlighted in bold in Table 2.3.

CCVI Modification #1: Temperature Exposure Categories

The CCVI tool uses projected changes in the magnitude of atmospheric temperature and moisture (Hamon AET:PET reflecting the interaction of precipitation and temperature as the potential for drying; see Appendix A for detail) to assess climate exposure for each species. The magnitude of change categories in the CCVI are based on +/- standard deviations from the average change in temperature/moisture projected for the conterminous United States (i.e., did not include Alaska). Due to the high magnitude of temperature change projected for Alaska, the exposure inputs for all species fell in the highest magnitude category. Because the CCVI provides information about relative vulnerability within a specific assessment area (here the BCR3/Arctic LCC region), we re-scaled the temperature categories to reflect the standard deviations from the average projected change in temperature for the state of Alaska to offer the potential for some differentiation between species we reviewed.

Table 2.3. Summary of the multiple climate projections used in different runs of the CCVI tool to compare influence on species' vulnerability in the Arctic LCC (CW indicates Climate Wizard data).

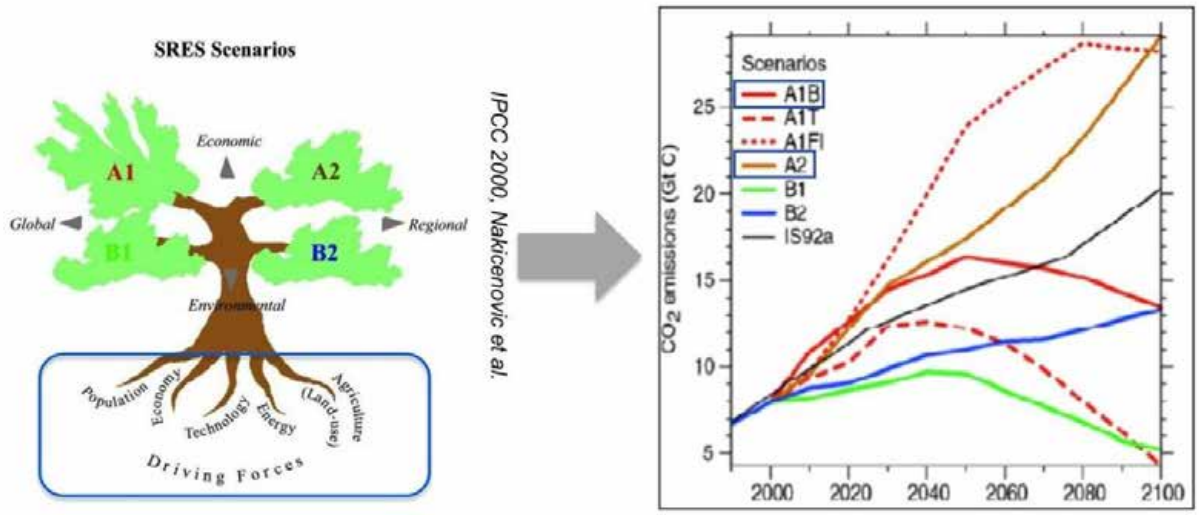
Emission Scenario	***Model (GCM)***
1. A1B	**Temp: SNAP 5-model composite*/Moisture: CW 5-model average (SNAP models)**
2. A1B	**Temp: SNAP CCCMA model/Moisture: CW CCCMA model**
3. A1B	**Temp: SNAP ECHAM5 model/Moisture: CW 5-model average (SNAP models)**
4. A1B	**Temp: SNAP 5-model composite* /Moisture: TWS/SNAP-PET 5-model average**
5. A2	Temp: SNAP 5-model composite* /Moisture: CW 5-model average (SNAP models)
6. A2	Temp: CW 5-model average (SNAP models) /Moisture: CW 5-model average (SNAP models)

*Output of 5 climate models downscaled to 2 km by SNAP based on performance assessment for north: ECHAM5, GFDL21, MIROC, HAD, CCCMA

Arctic coastal plain of Alaska (Photo: S. Zack @ WCS)

Emission Scenarios and Climate Projections

The exposure inputs for this vulnerability assessment were based on the A1B and A2 emission scenarios as projected by the five climate models that best replicate Alaska's historical climate (SNAP- http://www.snap.uaf.edu/). The A1B and A2 emission scenarios are narratives that represent plausible approximations of future conditions based on assumptions about technological changes, and social, economic and policy developments that incorporate feedback mechanisms that lead to the crossing of critical thresholds. These two scenarios, quantified as greenhouse gas concentrations, respectively characterize different futures with (1) a moderate increase in emissions followed by a decline, and (2) a steady increase in emissions*. The outputs for the ECHAM5 and CCCMA general circulation models (GCMs), developed by the Max Planck Institute of Meteorology and Canadian Center for Climate Modeling and Analysis), roughly bracket the high and low ends of the range of temperature projections for the Arctic LCC region.



*Note that recent trends in actual emissions have exceeded these scenario-based projections (Raupach et al. 2007).

Sea-level rise impacts: We used the sea level rise inundation model and data provided by the Center for Remote Sensing of Ice Sheets (CReSIS) with global coverage (https://www.cresis.ku.edu/data/sea-level-rise-maps) to calculate the percentage of the species range potentially affected (Indirect Exposure B1). In this model, sea level rise or inundation zones were calculated from the Global Land One-km Base Elevation (GLOBE) digital elevation model, a raster elevation dataset covering the entire world. The sea-level rise data was available in 1-m increments. We considered several sea level rise projections and recent observations to inform our data selection (Rhamstorf et al. 2007, Vemeer and Rhamstorf 2009, Overpeck and Weiss 2009). These ranged from 0.75-1.9 m to as much as 4-6 m, linked to the uncertain dynamics of the Antarctic ice sheet, by the end of the 21st century. The rate of melting of ice masses in Antarctica and Greenland and their contribution to sea-level rise have the potential to trigger an increase of several meters but this continues to be uncertain (e.g., Areneborg et al. 2012). We examined the effects on the sea-level rise factor scoring using both the 1-m and 2-m data sets. Using the 1-m data set implied that sea level rise would not contribute to the climate change vulnerability of any of the species we assessed. While this may be an accurate reflection of the impact of sea level rise on these species for mid-century, the result was due, in part, to the misalignment between species distribution and sea level rise data layers along the Arctic coastline, resulting in sea level rise occurring offshore.

We chose to use the 2-m overlay in the vulnerability assessment as a plausible future to capture the potentially important impacts of sea level rise for species with coastally limited distributions. The 2-meter data shifted the sea-level rise score from "neutral" to "slightly increased vulnerability" for 7 of the 54 species.

Sensitivity survey and expert solicitation

We asked individual species experts to score the sensitivity factors of the CCVI (13 of 23; see Fig 2.2.). Some factors have sub-categories, and others require a geospatial overlay to assess. Most species experts were agency, academic, non-governmental, or private industry scientists with advanced degrees that have spent multiple years studying some aspect of their focal species and were familiar with the respective body of literature. We solicited responses from 83 species experts of which 51 responded by completing sensitivity surveys and providing information on one measure of indirect climate exposure – "human climate mitigation" (Appendix C). The sensitivity surveys were based on those used in a vulnerability assessment conducted in the State of Florida using the CCVI (Dubois et al. 2011).

Experts were instructed to respond to questions taken verbatim from the CCVI guidance document, provide citations and written justifications for their responses, and assign a "confidence level" to their response using a 1-5 scale. Sensitivity survey responses were entered into the CCVI and run with the various climate exposure and other geospatial inputs to generate preliminary climate change vulnerability results for the 54 species.

We presented preliminary results (not reported here) during a workshop in Anchorage, Alaska on December 7-9th, 2011. The 31 participants represented a majority of the species' experts who returned a sensitivity survey. It became clear; both in reading survey responses and through discussions at the workshop, that individual experts interpreted some questions differently. In addition, experts expressed some discomfort in answering sensitivity questions that also required some understanding and/or speculation about climate exposure and ecosystem responses.

To address these issues, a sub-group of six avian experts (Appendix D) and WCS climate change program staff revised the problematic sensitivity factor questions after the workshop and re-evaluated the original responses of the larger expert group in light of this agreed upon language and standardized interpretation (Appendix F). The original responses and supporting information provided by species experts were circulated to the sub-group and we asked all six experts to revise the original responses on their own. We then met as a group to discuss any suggested changes to the original scores and to explore any within-group differences in the revised responses. We did not strive to reach consensus, but sought to ensure that relevant nuances in reasoning were recorded and question interpretation was consistent. Because the CCVI can accommodate multiple scores for any one factor, all of the re-evaluated responses were used to generate the revised vulnerability assessment results.

Visualizing species sensitivity and climate change vulnerability

We illustrate similarities and differences between the sensitivities and climate change vulnerabilities of the 54 bird species with a principle components analysis (PCA) based on a variance-covariance matrix (because of the standard scale of the variables) and Euclidean distance measure using PAST software (Hammer et al. 2001). While not an ideal multivariate method for categorical

data, interpretations of scatter-plots and axis loadings (i.e., those characteristics that drive scatter-plot patterns) are relatively straightforward (McCune and Mefford 1999). Numerical scores for all of the indirect exposure and sensitivity factors were included except the genetic and phenology factors. These were omitted because they were scored as "insufficient data" for many species. The resulting matrix included 14 variables and 54 species. For the purposes of this analysis, we used the numerical average for any factor with multiple different scores reflecting the uncertainty of respondents. The PCA scatter-plots were then color-coded to reflect the categorical vulnerability index assigned by the CCVI using the three different climate exposure inputs of the revised assessment.

Caribou pair near a pingo on the arctic coastal plain of Alaska. (Photo: S. Zack @ WCS)

CCVI Modification #2: Natural Barriers to Distribution Shifts

The CCVI guidance suggests that most birds should not experience natural barriers that would limit their dispersal (by flight) in response to climate change. But range shifts for bird species whose distributions are limited to the coast of the Arctic Coastal Plain in the Arctic LCC are assumed to be impaired because there is no landmass to the north. Therefore, the Arctic Ocean represents a barrier to birds that have restricted distributions along the northernmost circumpolar coastlines. While birds may be able to shift distributions longitudinally, we scored the northern 1/3rd of the Arctic Coastal Plain as "slightly increases" vulnerability, rather than "neutral" (Appendix F).

CCVI Modification #3: Predicted Impacts of Land Use Change Resulting from Human Response to Climate Change

Because of the limited accessibility of the Arctic LCC region and the low levels of current human activity, we considered only ongoing and highly plausible activities. These included shoreline erosion fortification and the conversion of ice roads related to residential and energy development to all-weather roads. Other climate change related mitigation activities (e.g., wind farm developments, hydro dams, natural gas infrastructure, coal mining) were deemed either unlikely to occur in the region or to be only localized in scale in the next 50 years. We also did not consider secondary impacts such as increased nest predation or hunting related to a more extensive road system).

CCVI Modification #4: Dependence on Specific Disturbance Regimes

This factor addressed species' responses to disturbance regimes that are likely to be altered by climate change. We limited our consideration of potential impacts to the following list of disturbances for the Arctic LCC region: (1) Increased coastal erosion and overwash linked to storm frequency/intensity; (2) Thermokarst processes/events-lake drainage, ice wedge degradation, upland slumps affecting aquatic systems, (3) Upland tundra fire; (4) Extreme rain/snow events; (5) Expansion of pathogens in adjacent regions.

Section 3. Results

Here we present a general summary of the vulnerability scores for the 54 bird species breeding in Arctic Alaska, and how the components of vulnerability evaluated by the CCVI (direct climate exposure, indirect exposure, and sensitivity) contributed differentially to the results. For a detailed look at the factors influencing the vulnerability of particular species, see the individual Species' Accounts in Appendix B.

Climate exposure

The CCVI uses future temperature and moisture changes generated by GCMs. The magnitude of projected temperature change is great for many northern latitudes, and the region of the Arctic LCC in Alaska is no exception. The projected warming for 2050 (2040-2069 average) for all emission scenarios and models exceeded +3.1^{o}C across the Arctic LCC region. For 23 of the 54 species, temperature exposure for the 2050 timeframe was +4.3^{o}C or greater for the A1B SRES emissions scenario and composite of all five SNAP climate models. The ranges of these 23 species were generally restricted to the north-central and western parts of Alaska's Arctic LCC region.

Projected changes in moisture (as measured by the Hamon AET:PET aridity index) between the historical and future time period were minimal, regardless of emission scenario or GCM model used. The magnitude of moisture changes for all species fell in the CCVI's lowest category, having little direct negative influence on the species' vulnerabilities reported below. However, the low magnitude of moisture change does temper the impact of the high magnitude of temperature, moderating its influence on the eight sensitivity factors weighted by the combined exposure.

Indirect exposure

In a region with a relatively light human footprint and few anthropogenic barriers to within range movement or shifts, only 3 of the 4 indirect exposure factors were relevant to northern Alaska: sea level rise, natural barriers to dispersal, and human responses to climate change. Sea level rise (SLR) and other disturbances linked to storminess during the lengthening open-water season (e.g., erosion and wash-over) have the potential to strongly affect species that use coastal habitats. The CCVI separates its evaluation of these influences by using a GIS overlay for SLR, and a qualitative evaluation of species' sensitivity to associated disturbances. Only seven of the bird species we examined (Brant, Snow Goose, Steller's Eider, Buff-breasted Sandpiper, White-rumped Sandpiper, Dunlin, and Common Eider) will potentially lose 10% or more of their range in the Alaska portion of the Arctic LCC to inundation under a 2-m SLR scenario.

We assumed that the Arctic Ocean represents a barrier to climate change movements of birds that are restricted to the northernmost coastline of Alaska. Therefore, 11 species with the majority of their breeding population within the northern 1/3rd of the Arctic Coastal Plain were assigned a score of "slightly increased vulnerability" with regard to natural distribution barriers (Ruddy Turnstone, Stilt Sandpiper, Common Eider, Spectacled Eider, White-rumped Sandpiper, Pomarine Jaeger, Buff-breasted Sandpiper, Steller's Eider, King Eider, Snow Goose, and Brant).

Expert participants noted 30 species whose vulnerability might be increased slightly by human responses to climate change, using the list of adaptation or mitigation activities considered feasible for Arctic Alaska during the next 50 years (see Methods).

Species sensitivity

We included several bird groups in our assessment, ranging from terrestrial to freshwater aquatic and marine species, and, not surprisingly, the species within these groups often shared similar scores for the sensitivity factors. Many of the species have extensive ranges, whether migratory or resident, and experience varying climate conditions throughout their annual life cycle. As a result, temperature was indicated as a physiologically limiting factor for only a few species and, even in those cases, only slightly increased vulnerability. However, due to dependencies on different types of wetland or marine settings, physiological hydrological niche was thought to have the greatest potential of all the sensitivity factors to influence vulnerability ("Increase" and "Greatly increase"). All but two species received scores indicating this sensitivity might lead to at least a slight increase in vulnerability. For roughly half of the birds, some type of interspecific interaction (e.g., predator-prey relationships) was identified as possibly shaping the species' response to climate change.

The remaining sensitivity factors typically had either neutral to potentially positive or ambiguous influence on the breeding birds we assessed. There were few species for which either restrictions to physical habitat elements or limited diet might limit their ability to respond to changing climate. The net effect of changes to important disturbance regimes was universally considered difficult to determine since different disturbances might shift population abundance and/or range in opposite directions. In addition, most experts expressed low confidence in their assessment of the effects of climate change on disturbances and the subsequent effects to species (Figure 3.1). Much of the information needed to score the genetic and phenological response factors was also unknown. Of the 18 species for which information about their documented or modeled response to climate change was available, all but two (Gyrfalcon and King Eider) showed little to no associated shifts in distribution or abundance and received "neutral" scores in this optional section of the CCVI tool.

The PCA scatter-plot in Figure 3.2 illustrates some of the similarities and differences between the 54 bird species in the factors contributing to their overall climate change vulnerability. The axis loadings (Figure 3.2.b.) indicate which of the sensitivity factors most strongly influence the species' patterns. Historical and physiological hydrological niche, and to a lesser degree sensitivity to SLR, human response to climate change, and dispersal barriers, separate species along axis 1 (x-axis), with the more sensitive species on the positive end. Birds are grouped along axis 2 (y-axis) primarily with regard to physical habitat restrictions (e.g., geological substrates and cliffs). Most of the species with habitat restrictions are located nearest the top of the plot (e.g., Gyrfalcon, Snow Bunting, Common Eider). Physiological hydrological niche also contributes to the axis 2 patterns. Therefore, all of the species sensitive to either historical or physiological hydrological niche are in the lower or upper right quadrant of the scatter-plot. Not surprisingly, this includes many of the waterfowl and shorebirds that are dependent on water to varying degrees during the breeding season.

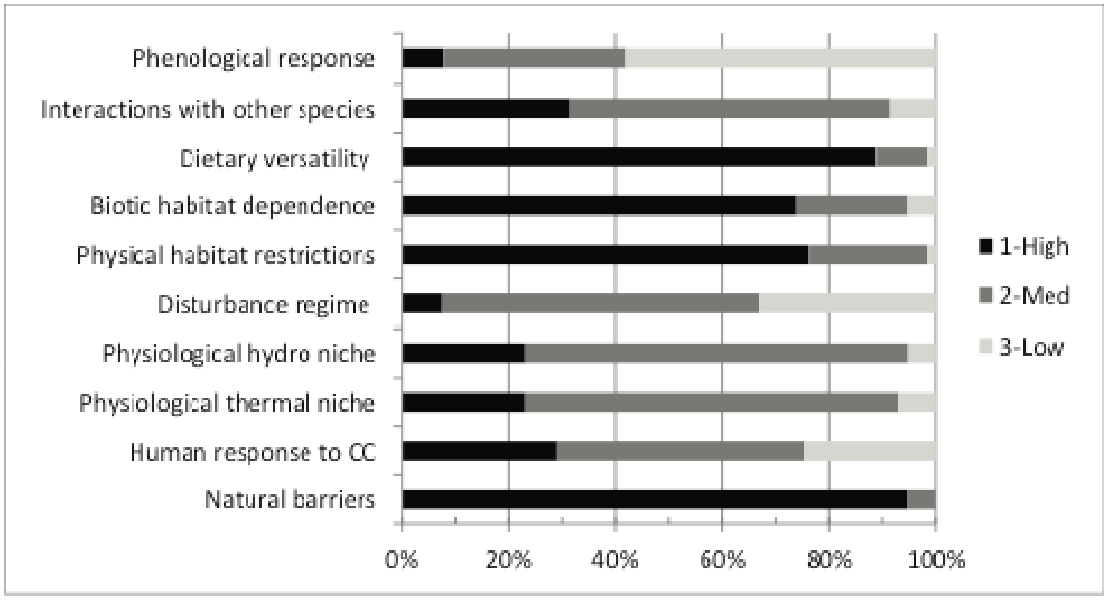


Figure 3.1. Categorical "confidence" assigned to the factor scores by the expert sub-group (6 reviewers and their responses for the 54 species) that re-evaluated the sensitivity responses of the original group of individual species' experts. Bars represent the relative proportions of "high", "medium", and "low" confidence ratings for each factor.

A male Pectoral Sandpiper. A common breeder in Arctic Alaska. (Photo: S. Zack @ WCS)

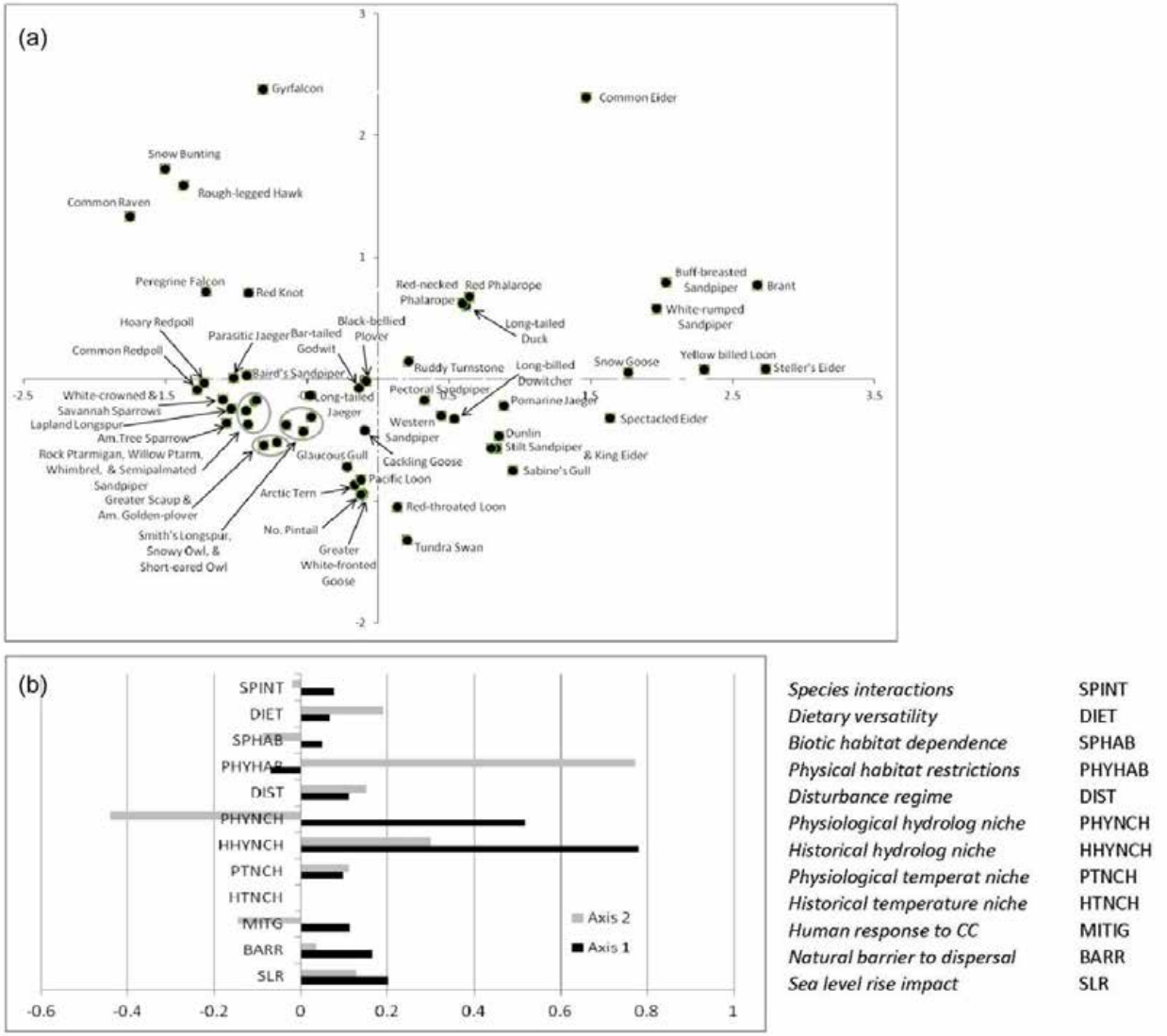


Figure 3.2. (a) The sensitivity "scores" (ordinal numerical values) displayed in multivariate space (PCA) to illustrate similarities between species in the sensitivity component of climate change vulnerability. (b) The PCA loadings of the sensitivity factors on axis 1 (x-axis) and axis 2 (y-axis). Loading values indicate which factors explain the most variability along the two axes.

Relative vulnerability to climate change

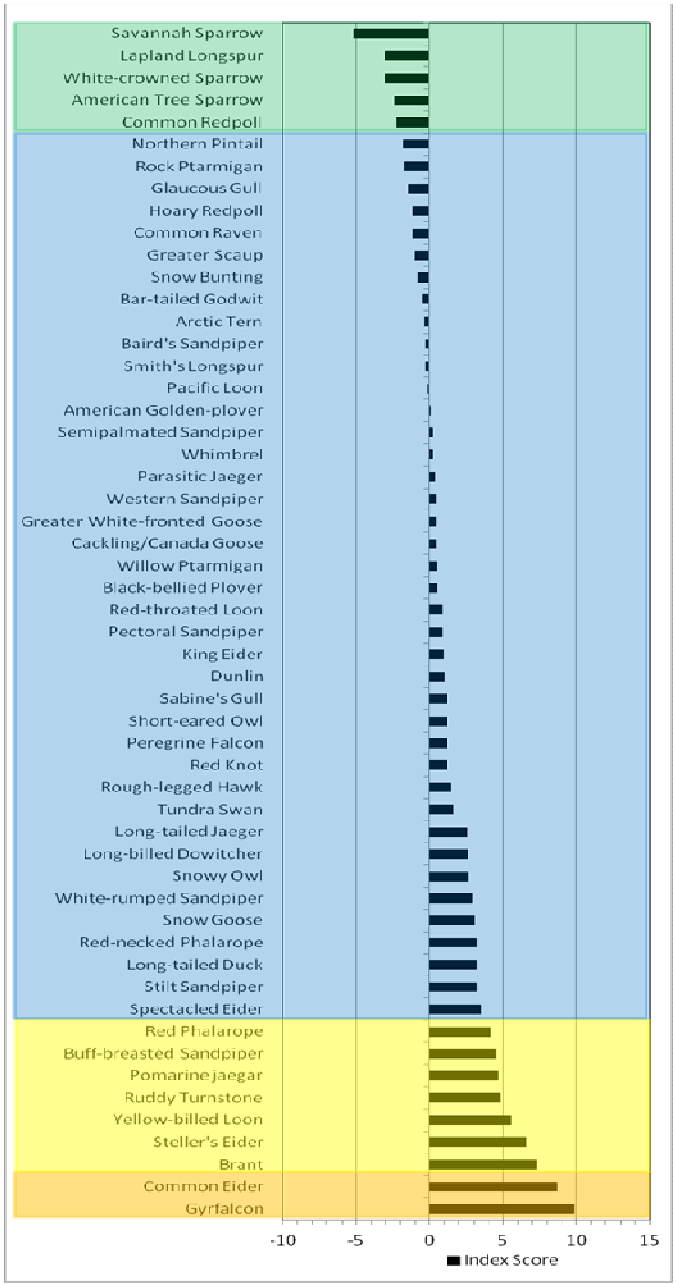
Using the climate projections for the A1B emission scenario from the composite of all five SNAP climate models combined with the sensitivity factor inputs, the CCVI tool identified nine of the fifty-four species as either highly vulnerable (n=2) or moderately vulnerable (n=7) to the potential impacts of climate change in the Arctic LCC region of Alaska (Figure 3.3). The majority of the bird species whether migratory or year-round residents, were presumed to be stable. The results suggest that five passerine species (the three sparrows, the Lapland Longspur, and the Common Redpoll) may even increase their presence in the region.

The distribution of the Monte Carlo simulation results for each bird species with respect to the five vulnerability categories is shown in Figure 3.4. The tool assigns "confidence" in the original result based on the proportions of outcomes falling in the different categories. For example, confidence in the result of "moderately

vulnerable" for the Yellow-billed Loon is considered "low" because the simulation results are almost evenly distributed between the highly vulnerable, moderately vulnerable and presumed stable categories. In contrast, the confidence in the result for the Semipalmated Sandpiper is considered "high" because over 80% of the simulation outcomes fell in the presumed stable category.

Figure 3.3. The numerical vulnerability scores and index categories as assigned by the CCVI tool using the initial climate scenario as the exposure inputs (Temp: SNAP 5-model composite/Moisture: CW 5-model average (SNAP models).

Index Score	*Vulnerability Category*
>10.0	Extremely vulnerable (red)
7.0-9.9	Highly vulnerable (orange)
4.0-6.9	Moderately vulnerable (yellow)
-2.0-3.99	Presumed stable (blue)
<-2.0	Increase likely (green)



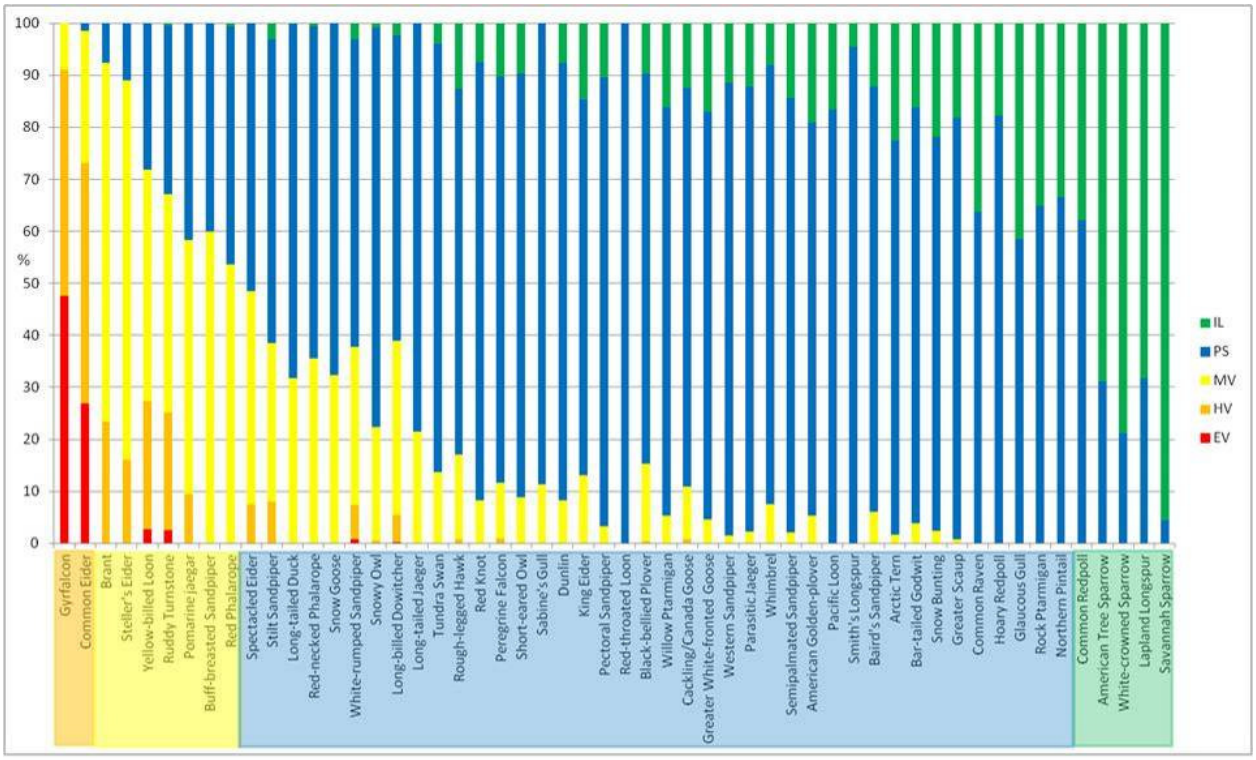


Figure 3.4. The proportion of the Monte Carlo simulations in different vulnerability categories for each species (colored stacked bars). The colored overlays below the x-axis indicate the vulnerability category assigned to each species by the CCVI tool calculations (as shown in Figure 3.3). The proportions are used as a measure of "confidence" (Low-Moderate-High-Very High) in the numerical score/vulnerability category generated by the tool algorithm (see species accounts). IL=Increase Likely, PS=Presumed Stable, MV=Moderately Vulnerable, HV=Highly Vulnerable, EV=Extremely Vulnerable.

Alternate climate scenarios

We explored the sensitivity of the CCVI tool outputs to different climate exposure inputs. A comparison of the vulnerability results for the five different combinations of climate projections and spatial resolution (see Methods) shows little variation (Figure 3.5). The vulnerability outcomes were only altered by the projections from the CCCM (Canadian Center for Climate Modeling and Analysis) global circulation model, the SNAP model that produces the lowest magnitude of warming (roughly 1°C cooler than the other models). Using inputs from that model, Gyrfalcon and Common Eider shifted from highly to moderately vulnerable and Buff-breasted Sandpiper moved from moderately vulnerable to presumed stable. Only the three alternate climate projections representing the greatest differentiation in inputs are shown in the tables.

Sources of climate change vulnerability

Figure 3.6 indicates the degree to which each of the sensitivity factors examined in the assessment are contributing to the climate change vulnerability of the nine species that fell into the moderately or highly vulnerable categories. For many of these bird species, the quality and nature of interactions with other species, restrictions associated with physical habitat and diet, dependence on other species to meet habitat needs, and changes in disturbance regimes that affect them, are important for considering whether there might be appropriate response options that can be explicitly identified.

a.	5-Model Composite/A1B		Temperature Scope				
Common Name	Index Score	CC Vuln	A >4.3C	A 3.8C	A 3.1C	A 2.5C	A <2.5C
Gyrfalcon	9.82	HV	92	8	0	0	0
Common Eider	8.65	HV	100	0	0	0	0
Brant	7.26	MV	100	0	0	0	0
Steller's Eider	6.53	MV	100	0	0	0	0
Pomarine Jaeger	4.60	MV	100	0	0	0	0
Ruddy Turnstone	4.83	MV	100	0	0	0	0
Buff-breasted Sandpiper	4.49	MV	100	0	0	0	0
Red Phalarope	4.16	MV	100	0	0	0	0
Yellow-billed Loon	4.09	MV	100	0	0	0	0
Spectacled Eider	3.49	PS	100	0	0	0	0
Peregrine Falcon	3.33	PS	78	22	0	0	0
Long-tailed Duck	3.16	PS	100	0	0	0	0
Red-necked Phalarope	3.16	PS	100	0	0	0	0

b.	CCCM/A1B		Temperature Scope				
Common Name	Index Score	CC Vuln.	A >4.3C	A 3.8C	A 3.1C	A 2.5C	A <2.5C
Gyrfalcon	6.22	MV	0	8	86	6	0
Common Eider	5.51	MV	0	18	82	0	0
Brant	6.39	MV	0	100	0	0	0
Steller's Eider	5.07	MV	0	0	100	0	0
Pomarine Jaeger	4.60	MV	100	0	0	0	0
Ruddy Turnstone	4.83	MV	99	1	0	0	0
Buff-breasted Sandpiper	3.69	PS	0	0	100	0	0
Red Phalarope	4.16	MV	100	0	0	0	0
Yellow-billed Loon	4.09	MV	100	0	0	0	0
Spectacled Eider	3.09	PS	0	100	0	0	0
Peregrine Falcon	3.33	PS	78	22	0	0	0
Long-tailed Duck	2.36	PS	0	11	89	0	0
Red-necked Phalarope	3.16	PS	100	0	0	0	0

Index Score	Vulnerability Category
>10.0	Extremely Vulnerable (EV)
7.0-9.9	Highly Vulnerable (HV)
4.0-6.9	Moderately Vulnerable (MV)
-2-3.99	Presumed Stable (PS)
<-2.0	Increase Likely (IL)

c.	ECHAM/A1B		Temperature Scope				
Common Name	Index Score	CC Vuln.	A >4.3C	A 3.8C	A 3.1C	A 2.5C	A <2.5C
Gyrfalcon	9.83	HV	100	0	0	0	0
Common Eider	8.65	HV	100	0	0	0	0
Brant	7.26	MV	100	0	0	0	0
Steller's Eider	6.53	MV	100	0	0	0	0
Pomarine Jaeger	4.60	MV	100	0	0	0	0
Ruddy Turnstone	4.83	MV	100	0	0	0	0
Buff-breasted Sandpiper	4.49	MV	100	0	0	0	0
Red Phalarope	4.16	MV	100	0	0	0	0
Yellow-billed Loon	4.09	MV	100	0	0	0	0
Spectacled Eider	3.39	PS	100	0	0	0	0
Peregrine Falcon	3.33	PS	100	0	0	0	0
Long-tailed Duck	3.16	PS	100	0	0	0	0
Red-necked Phalarope	3.16	PS	100	0	0	0	0

Figure 3.5. Changes in the CCVI tool score and vulnerability category output using input from different global circulation models (GCMs) for presumed stable through highly vulnerable bird species. (a) Temperature data: A1B SRES emission scenario, SNAP 5-model composite (ECHAM5, GFDL2.1, MIROC, HAD, CCCMA), 2 km resolution; (b) Temperature data: A1B SRES emission scenario, SNAP CCCMA GCM output, 2 km resolution; (c) Temperature data: A1B SRES emission scenario, SNAP 5-model composite ECHAM5 GCM, 2 km resolution. While the index scores vary somewhat across models, only those highlighted in blue changed category from the initial run in Figure 3.6a. [Note: Moisture projections from all models show little change to increases for the assessment region. Moisture had little influence over CCVI results in this assessment and is not shown here.]

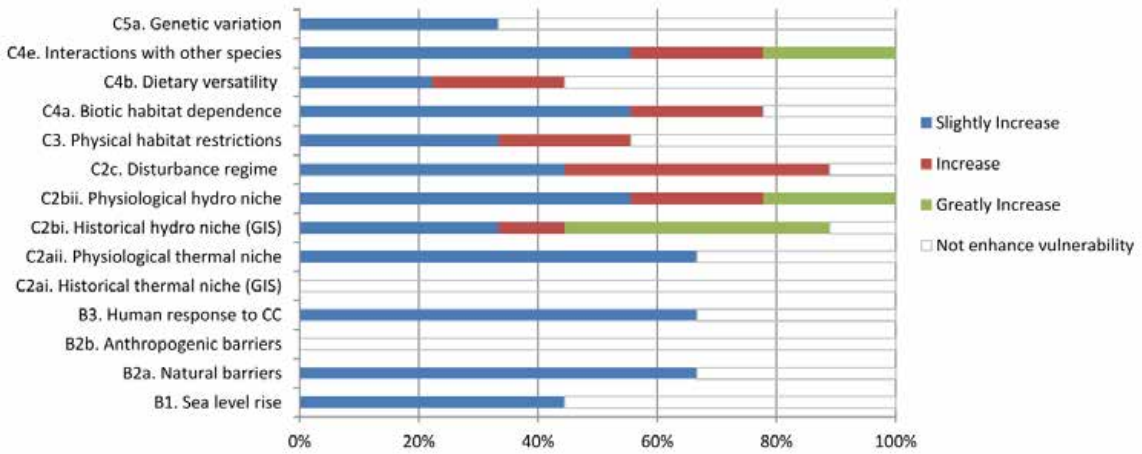


Figure 3.6. Contribution of the different sensitivity and indirect exposure factors to climate change vulnerability for the nine species in our Arctic breeding bird assessment that ranked moderately or highly vulnerable.

Section 4. Discussion

This report details the first effort to characterize the vulnerability of Arctic Alaska breeding birds to climate change. The primary value of this assessment lies in the process of breaking a complex phenomenon into constituent parts so that we can begin to identify why species in a particular geography are vulnerable, whether there are actions we can take to address those vulnerabilities, and what data gaps may exist.

Climate change vulnerability of Arctic Alaska birds

Differentiating the sources: The outcomes of this vulnerability assessment rest on the cumulative influences of multiple potential sources of vulnerability to climate. In some cases, those sources differed across species. For example, the sensitivities leading to the "highly vulnerable" rank for Gyrfalcon and Common Eiders contrast markedly as a result of their differing hydrologic niches, diets, and other life history traits. Both species were identified as being sensitive to climate change effects on relatively rare physical habitats, although for notably different reasons. Overwash and erosion from increasing storm frequency (Jones et al. 2009) may have a devastating effect on barrier-island nest sites, on which Common Eiders depend. For the Gyrfalcon, changing thermal conditions at cliff face nesting sites could negatively influence nesting success.

There were some identified sources of vulnerability that were common to many species. Physiological hydrologic niche was scored as a key sensitivity factor for over half the species in the assessment, including 7 of the 9 species ranked as moderately vulnerable or higher. This is not surprising as many of the species that breed in the region rely on wetland habitats for both nesting and foraging (e.g., most shorebirds and waterfowl). However, hydrological sensitivity was not the most significant contributor to an overall vulnerability ranking because annual changes in moisture (as measured by the ratio of precipitation to PET) in the region (one component of exposure) is projected to be low. There were several waterfowl and shorebird species that, despite an assignment of a "greatly increased vulnerability" score for this sensitivity factor, were not identified as vulnerable by their overall score. This is, in

large part, due to the guidance and strucuture of the CCVI tool. The tool guidance recommends using annual values for exposure, to capture the cumulative change and potential impacts, with the result of masking significant changes to different seasons, which may impact the ecological system. In addition, hydrological sensitivity is weighted only by the moisture component of exposure. In this way, the effects of an actual contribution to vulnerability may be diminished in the assessment results.

In some cases, vulnerability results were driven by single (or a small number of) key factors. Specialized species (e.g., those with restricted diets), as well as those with ranges restricted to coastal areas, and therefore some sensitivity to sea-level-rise and changes to other coastal disturbance processes linked to loss of ice cover, tended to rank higher with respect to climate change vulnerability. The most dramatic example is for Pomarine Jaegers in that they are thought to nest only in years when their key food source (brown lemmings) are present in sufficient numbers. There is some evidence suggesting that changes in climate are shifting that predator-prey cycle with likely negative impacts on jaeger breeding potential (Ims and Fugli 2005, Post et al. 2009).

For detailed accounts of the sources of vulnerability for individual species, consult Appendix B.

Comparisons with other vulnerability assessments

Although few peer-reviewed studies of the potential vulnerability of birds to climate change exist, there are three other efforts that offer insights relevant to the results of our Alaska Arctic breeding bird assessment: 1) the 2010 State of the Birds report (NABCI 2010) focusing on habitat types throughout the U.S.; 2) a climate-change vulnerability assessment for California's at-risk bird species (Gardali et al. 2012); and 3) an Arctic LCC taxon-oriented evaluation of climate change science needs (Arctic LCC 2012). Each of these assessments examines bird vulnerabilities at different scales and from different perspectives. The 2010 State of the Birds report conducted an assessment of climate change impacts on habitats. Gardali et al. (2012) used a species-based approach incorporating many of the same factors as the CCVI tool, while most notably adding species distribution-modeling component based on projected climate changes. The effort of the Arctic LCC in Alaska identified ecological processes most relevant to predetermined taxon groups.

The various assessments share some overlap in approach and yield several findings in common with our assessment for particular bird species or groups of birds. First, the likely impact of temperature increases on surface hydrology, wetland availability, and vegetation change was widely recognized as critically important in all of the assessments. Birds associated with wetlands had the largest representation on the vulnerable list relative to those associated with other habitats in both the Arctic Alaska (this report) and California-based (Gardali et al. 2012) species assessments. Two of the three assessments noted the sensitivity to climate-driven changes of wetland habitats and the geophysical processes that support them, especially in the Arctic.

Shifts in phenology are also considered critical in a changing climate by all assessments. However, there appears to be relatively little information about phenology for most species. In some assessments, life history characteristics that predispose a species to timing issues can be used in lieu of clear documentation. In the State of the Birds assessment "migration status" captured concerns about phenology by assuming that longer distance migrants

would be more vulnerable lacking cues about breeding ground conditions and subject to a greater risk of a mismatch in food availability and timing of arrival. In a comparable way, we included migration distance as a proxy linked to phenology in our pilot effort examining species vulnerability across the full life cycle (breeding, migration, wintering) for shorebirds (see Appendix C). Early research findings suggest that some shorebirds and passerines may have the capacity to adjust their life history strategies and track some phenological changes. Nest initiation, in the Arctic and elsewhere, has advanced for some species alongside changes in green-up timing (D. Ward, J. Liebezeit, unpublished data). For the most part, other key phenology events (e.g., chick hatch and insect emergence) are only beginning to be examined in this and other regions.

The Arctic-specific assessments (this report and Arctic LCC 2012) complement each other and provide reinforcement for many of the same priorities and concerns, blending a refined focus on species-specific vulnerabilities with their connections to changes in biophysical processes. In both, changes in extreme weather and other events (e.g., longer open water season) that may alter coastal habitat conditions were noted as a climate-related source of vulnerability. For many coastally-restricted species, direct impacts such as the flooding of nests, as well as the transformation of habitats through salt water intrusion were considered particularly important. Interactions between species were also considered important, whether viewed as a biophysical process or specific relationship. In our assessment, experts identified nearly half the birds as at least slightly vulnerable to some type of interspecific interaction (most of which were predator-prey relationships).

Climate change vulnerability in context

The results we present here are not intended to offer a definitive statement on climate change vulnerabilities, but rather offer preliminary assertions about the climate change vulnerability of the species we assessed and suggest numerous hypotheses about the factors underlying them. Interpretations of our results should be tempered by uncertainties and unknowns related to all projections of climate change and associated biophysical responses (e.g., Littell et al. 2011). The use of multiple climate scenarios increases the rigor of our assessment, as does the inclusions of the multiple sensitivity scores for some species. But there remain several issues that need to be considered when interpreting the results.

Information gaps

There are large knowledge gaps in understanding important biophysical processes and individual species biology. Clearly, wet tundra and aquatic habitats are important for many breeding bird species in Arctic Alaska and even slight changes in these habitats may be detrimental to many species. Experts based their ranking for this factor on the potential for tundra habitats to experience net drying in the coming decades, in turn altering habitat structure and availability of food resources. While a drying trend appears to be occurring at some sites in the circumpolar arctic (Smith et al. 2005, Smol and Douglas 2007), currently available projections for Arctic Alaska (TWS-SNAP 2012) from some climate models actually suggest minimal change to a slight annual gain in net atmospheric moisture balance. However, the geomorphic processes relevant to ground and surface hydrology are not considered in these projections (i.e. estimates of the relationship between PET and precipitation changes). Warming arctic temperatures and the interplay between permafrost melt,

thermokarst disturbances, drainage patterns, and subsequent habitat changes are complicated and understudied (Martin et al. 2009). Efforts are now targeting research towards improving our understanding of climate change effects on some of these aspects of surface hydrology.

There was also insufficient information to address questions about genetics and phenology for most species. Species with low genetic variation are generally thought to be more vulnerable to climate change (see Young et al. 2010). However, there is a widely acknowledged paucity of studies documenting genetic variation other than a few targeted efforts (see species accounts for citations) and some general assessments at a broader taxonomic level (e.g., Baker and Strauch 1988). Long-term data sets and/or region-wide data sets relevant to phenology do exist for some waterfowl (e.g. Larned et al. 2012), shorebirds (R. Lanctot, unpublished data; J. Liebezeit, unpublished data,), and other bird groups in the Arctic LCC region. Some of these data are being used to examine the relationship between remotely sensed variables (e.g., NDVI) and bird arrival and nest initiation (D. Ward et al. unpublished). For the majority of birds, however, long-term data are non-existent, inadequate for phenology assessments, or available but not currently applied to assessing such changes.

Limitations of the CCVI tool

Climate change vulnerability indices are one approach to understanding the effects of climate on species (e.g., Rowland et al. 2011). As with all approaches, there are limitations to the NatureServe CCVI tool and how it is applied. Most importantly, the CCVI tool does not examine statistical or mechanistic relationships between the species traits and their exposure to climate change. Rather, the tool was designed to offer a relatively coarse, quick, and consistent look at the potential vulnerability of multiple species in a way that accounts for numerous factors. It is structured to readily add new information and revise the assessments as knowledge of the species and system increases and may be used to identify need for more targeted research efforts.

There are also issues related to the manner in which we conducted our assessment. The CCVI tool was developed to consider a wide range of both plant and animals species in an area. Our narrow focus on birds tested its ability to parse out more nuanced differences in sensitivities and relative vulnerabilities between closely related species. As illustrated by the modifications suggested by expert participants and documented in the Methods section, the generalized language on sensitivity factors from the CCVI guidance was sometimes challenging to relate to birds in the Arctic and, in a few cases, irrelevant altogether. Although participants did not identify any missing sensitivity factors prior to its application, many of them recommended that the differential weighting of particular sensitivity factors on vulnerability outcomes be allowed. For example, some workshop participants questioned whether factors such as disturbance effects and genetic influence on climate change response should carry equal weight. Another challenge, regarding the effects of climate-related changes in disturbance regimes, is that changes in some types of disturbance might benefit a species while others might be detrimental, making the net effect difficult to determine and score.

Finally, many species we examined range widely across the world and are exposed to different climate stressors at their wintering and staging areas. We explored climate change impacts for the shorebird subgroup across their flyways (Appendix C),

but there are great challenges to conducting a rigorous vulnerability assessment across the breeding, passage, and wintering ranges (see Appendix C for further discussion). At least one effort is currently attempting to address those challenges (Galbraith et al. In Prep).

Pacific Loon (Photo: S. Zack @ WCS)

Other uncertainties

Eliciting expert knowledge to inform conservation issues is a common endeavor (e.g., Martin et al. 2012). Although there are well-recognized limitations, expert knowledge may be the best available data source in situations where empirical data is limited or absent. Elicitation can be constructive, if the effort is designed thoughtfully. While we distributed written surveys to species experts based nearly verbatim on the language in the NatureServe CCVI guidance, individuals sometimes interpreted questions differently. Reasons include: 1) language ambiguity in the surveys (e.g., it was not clear if a change in lemming population cycles should be captured under "interspecies interaction" or "disturbance"); 2) questions confounding elements of climate exposure with sensitivity (e.g., whether or not a species was sensitive to a disturbance combined with the likelihood of that disturbance regime being affected by climate change); and 3) confusion about the scale of interpretation (e.g., whether experts should be considering a species' thermal niche in the context of the Arctic LCC region alone or across its entire range). In addition, we were unable to find more than one respondent per species for the majority of species for the initial survey to offer insight on the potential variance in expert perspectives. Workshop discussions, question modifications, and reassessment with a smaller working group providing responses for all species (i.e., six responses per species) allowed us to address the issues that, in hindsight, would have been better dealt with at the start of the project.

Informing research, conservation and management

Climate change vulnerability assessments are not intended to be end points, but rather the initial input to further discussions or planning. This report provides a wealth of knowledge gleaned from species experts and should be exploited in refining our understanding of vulnerabilities of Alaskan Arctic breeding birds, guiding research and helping to formulate testable hypotheses in the context of climate change. It can also serve as a reference for those starting to consider changes to management and conservation practices with respect to climate change.

Considerations for focusing future efforts

While the relative ranking offers insights about species vulnerabilities, this information alone does not pre-determine whether to focus on the most or least vulnerable species, or what actions to take. Species not ranked as vulnerable to climate change may merit consideration in management planning and decisions for other reasons. For example, an increase in the abundance of Common Ravens (ranked as "presumed stable") has potentially negative implications for other species in the

region since they sometimes prey on the eggs and young of nesting birds.

The results also do not speak to the response of species to climate change outside of the Arctic LCC region of Alaska. The 54 species we considered in the assessment reflect a representative cross-section of species in the Alaskan Arctic; however, species that currently do not occur (or barely occur) within the assessment area could move into the region and subsequently affect other species. For example, Common Loons could expand their range northward from interior Alaska and compete with Yellow-billed Loons for resources. Similarly, some dabbling duck species that are currently present but are more common breeders to the south (e.g. Mallard, Northern Shoveler) may increase and compete with species occupying similar niches to the north.

It is appropriate to interpret our assessment and other efforts to understand climate change vulnerability in combination with existing conservation rankings (see also Young et al. 2010), as climate change may exacerbate stressors that are already affecting many bird species (e.g., Gardali et al. 2012). Three of the four species currently listed under the US Endangered Species Act or recently considered for such listing in Arctic Alaska were ranked as vulnerable in our assessment (e.g., Steller's Eider, Buff-breasted Sandpiper, Yellow-billed Loon; Figure 4.1). Spectacled Eiders, another listed species, was near the vulnerability threshold. For these species, our results reinforce considerations for continued protections. At the same time, our assessment might raise concerns about climate change vulnerabilities for species otherwise considered stable with respect to the effects of non-climate stressors (e.g. Gyrfalcon, Common Eider).

It may also be prudent to more thoroughly consider the key sources of sensitivity identified for species that are presumed stable but near the moderately vulnerable threshold. While from a relative perspective these species may not be of greatest concern, a single key climate-related sensitivity has the potential to be detrimental. It may be useful to focus research agendas and proactively develop response strategies and monitoring plans that can be integrated into relevant management plans.

Conservation and management activities

It should be acknowledged that tools for reducing climate change vulnerabilities may be somewhat limited in Arctic Alaska. The region's vast size and remoteness, and the sensitivity of its habitats to change, make it difficult to contemplate actions commensurate with the potential impacts (Zack and Liebezeit 2012). The results of this assessment enhance our understanding of the potential responses of particular species to climate change and may contribute to thinking about future conservation actions and land protection in the context of energy and other development issues. Attempting to identify climate refugia and enhancing the protection of large units of land may, at present, be the best strategy for conserving species as climate drives changes in the region. Our assessment suggests several species for which climate-induced landscape changes might reduce the quality or availability of suitable habitat in currently utilized locations.

Species Common Name	Climate Change Vulnerability CCVI-Arctic AK	Other Vulnerability Indices: State of Alaska Priorities (2012)[1]	IUCN	Audubon Watchlist 2010	NatureServe Global/AK	ESA	COSEWIC[2]
Gyrfalcon		VIII					
Common Eider		III		Red (nigrum)			
Brant		II		Yellow (nigrican)			
Steller's Eider		II		Red (nigrican)		Threatened	
Yellow-billed Loon		IX	Near threatened	Red		Candidate	
Ruddy Turnstone		II		Yellow			morinella Mid priority candidate
Pomarine Jaeger		III					
Buff-breasted Sandpiper		II	Near threatened	Red			
Red Phalarope		II					Low priority candidate
Spectacled Eider		II		Red		Threatened	
Stilt Sandpiper		III		Yellow			
Long-tailed Duck		IX					
Red-necked Phalarope		V					High priority candidate
Snow Goose		VIII					
White-rumped Sandpiper		II		Yellow			
Snowy Owl		III					
Long-billed Dowitcher		VIII					
Red Knot		I		Red (roselaari)			
Peregrine Falcon		IX					
Short-eared Owl		I		Yellow			
Dunlin		III		Red			
King Eider		II					Low priority candidate
Red-throated Loon		IX		Red			
Black-bellied Plover		III					
Western Sandpiper		II		Yellow			
Whimbrel		VIII		Yellow (rufiventris)			
Semipalmated Sandpiper		VIII		Yellow			
American golden-Plover		VIII		Red			
Baird's Sandpiper		VIII					
Bar-tailed Godwit		II		Red (baueri)			
Greater Scaup		IX					Low priority candidate
Smith's Longspur		I		Yellow			

Extremely vulnerable · Highly vulnerable · Moderately vulnerable · Presumed stable

Other orange species State AK: American Tree Sparrow, Hoary Redpoll, Parasitic Jaeger, Long-tailed Jaeger, Rough-legged Hawk, Artic Tern.

Figure 4.1. The vulnerability results of the Alaskan Arctic breeding bird climate change vulnerability assessment alongside non-climate vulnerabilities identified through other assessments and indices. Color codes across indices are roughly comparable. [1]Gotthardt, T.A., K.M. Walton, T.L. Fields. 2012. Setting priorities for Alaska's species of greatest need: the Alaska Species Ranking System (ASRS). Alaska Natural Heritage Program, Univeristy of Alaska Anchorage, AK. 46 pp.[2]Canada's endangered wildlife designation.

These species may be appropriate focal species for identifying *in situ* refugia where the degree of climate impacts may be most limited, as well as *ex situ* refugia where conditions may become more favorable in the future (e.g., Ashcroft 2010, Keppel et al. 2012).

Although our assessment was focused on the breeding grounds of the focal bird species with the intention of informing

management strategies in Arctic Alaska, important climate change and other impacts are occurring outside the breeding season for some species. A few species with populations that are thought to be declining (e.g., American Golden-plover, Dunlin) were not ranked as particularly vulnerable to climate change impacts in Arctic Alaska. Most of these species are thought to be declining due to habitat loss and alteration on migration stopover sites or wintering grounds (Brown et al. 2001). For other species ranked as vulnerable or near-vulnerable to climate change in Arctic Alaska, specific sites in wintering ranges or along the routes of passage migration may offer the greatest opportunities for management actions that mitigate the impacts of changing climate. This may be especially important in cases where vulnerabilities on a species' Alaska breeding grounds cannot be directly ameliorated.

Common Eider flying over the Beaufort Sea. (Photo: S. Zack @ WCS)

Conclusion

Despite obvious challenges, this assessment represents a starting point to help prioritize management actions and conservation planning efforts with respect to Arctic breeding birds. Through the assessment process we identified particular factors that are likely the most important contributors to increased vulnerability to climate change. Conversely, we perhaps better understand which factors likely do not contribute greatly to vulnerability for the bird species considered. We also identified important gaps in our knowledge specific to climate change impacts. The last two accomplishments can help inform subsequent research efforts through prioritization and hypothesis development. While climate change will greatly challenge wildlife and habitats in Arctic Alaska, this effort provides one tool useful in safeguarding these valuable resources.

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Appendix A

Hamon AET:PET Aridity Index

Temperature and precipitation are two fundamental climate outputs from the GCM projections, from which many other bioclimatic variables are derived, as well as being the key inputs to many biophysical response and impact models. Organisms and biophysical processes may respond directly to changes in temperature, but often responses to changes in precipitation (e.g., rain, snow) are influenced by temperature. Through processes such as evaporation and transpiration, temperature mediates the availability of moisture in a system (e.g., soil moisture availability).

The vulnerability of system components may not be adequately captured with respect to precipitation without considering the effects of changes in temperature on net moisture availability. In places such as Arctic Alaska, where projected changes in the magnitude of warming are high, there is an increased potential for drying (i.e., moisture demand). Corresponding increases in precipitation (moisture supply) may be able to offset the drying to some degree, if precipitation is also projected to increase. For these reasons, the CCVI tool uses a moisture (availability) metric, rather than gross precipitation as an exposure factor (Young et al. 2010).

Potential evapotranspiration (PET) is, simply stated, the atmospheric demand for moisture, driven by temperature and other variables (e.g., wind speed, relative humidity). There are different ways to characterize the relationship between moisture supply and demand, such as P-PET (where P=precipitation) or the ratio between P and PET. The latter may be expressed as AET:PET, where AET=actual evapotranspiration and is often equated with precipitation and may be capped at PET (Girvetz and Zganjar *in review*). These formulae integrating the effects of temperature and precipitation on moisture availability are called aridity indices.

There are several methods for estimating the potential evapotranspiration component of these aridity indices (e.g., Lu et al. 2005). The Hamon method widely is used, including applications in the Arctic (e.g., Hay and McCabe 2010). The Hamon method derives PET based on average temperature and latitude (as a proxy for day length) and is highly correlated with temperature. The key assumption underlying this method using future projections is that no changes in cloud cover or relative humidity will accompany future changes in climate (McAfee et al. *in review*).

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Appendix B

Species Accounts

Photos: S. Zack @ WCS

Tundra Swan (*Cygnus columbianus*)

Vulnerability: **Presumed Stable** Confidence: High

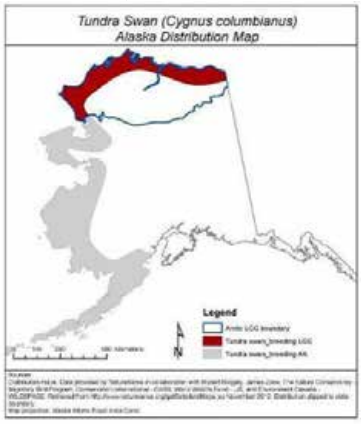
The Tundra Swan is the more widespread and northerly ranging of the two native swan species in North America. In Arctic Alaska, they nest in wet to dry tundra habitat types preferring islands in lakes or ponds, or naturally occurring frost heaves at the intersection of polygon pond rims. Nesting territories almost always include a large lake that the family will use as a safe haven from terrestrial predators (Limpert and Earnst 1994). During the breeding season, their diet is primarily vegetarian, eating emergent and submerged vegetation in lakes and ponds. They also graze on terrestrial vegetation near the water (Limpert and Earnst 1994). Most North Slope breeders winter on the east coast Mid-Atlantic States (Limpert and Earnst 1994). The current Arctic Coastal Plain population is estimated at approximately 10,000 (Larned et al. 2012).

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America and other range descriptions (Johnson and Herter 1989, Bart et al. 2012).

Human Response to CC: Human activities in response to climate change, in particular, shoreline fortification against erosion could impact Tundra Swans as they sometimes use near coastal areas for resting and foraging during migratory staging (Limpert and Earnst 1994). However, such activity will likely be localized in the near future so it was considered to slightly increase vulnerability, if at all.

Physiological Hydro Niche: Tundra Swans were ranked as particularly vulnerable to changes in hydrologic niche because of their dependence on lakes for breeding and molting (to avoid predation) and aquatic vegetation (for foraging). Non-breeding flocks also rely heavily on lakes. If substantial drying occurs, this species could experience a considerable negative impact. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. However, its interaction with hydrologic processes is very poorly understood (Martin et al. 2009).

Disturbance Regime: Climate-mediated disturbance events, namely thermokarst, could both create and destroy good foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Likewise, predicted increased storm frequency (Jones et al. 2009) could reduce availability of their primary forage (submerged/emergent vegetation) as water turbulence in bays and rivers could increase (S. Earnst, pers. comm.).



Biotic Habitat Dependence: Tundra Swans depend on *Arctophila* grass for brood-rearing cover thus the "biotic habitat dependence category" was considered a source of vulnerability. The broad range of responses in this category (from "neutral" to "greatly increased" vulnerability) reflects the uncertainty

Tundra Swan (*Cygnus columbianus*)
Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche					*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*	*				
C4a. Biotic habitat dependence			*	*	*	*	
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

in how climate-change would affect this relationship.

Phenological Response: A long-term data set (1987-1990) indicates Tundra Swan breeding was associated with the timing of river break-up, and incubation and brood-rearing success were higher in earlier years (S. Earnst, unpublished data). However this finding was preliminary, and, in general, the relationship between seasonal temperature / precipitation and phenology for this species in the Alaska portion of the Arctic LCC has not been studied comprehensively.

In summary, despite some vulnerability, current information suggests Tundra Swans will remain "stable" and be able to adjust to climate-mediated changes in their breeding range within the time frame of this assessment.

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Greater White-fronted Goose (*Anser albifrons*)

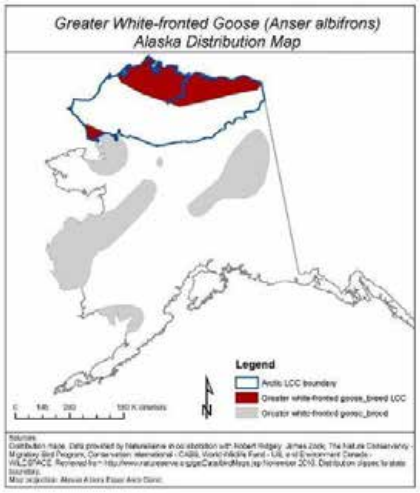
Vulnerability**: Presumed Stable** Confidence: Moderate

The Greater White-fronted Goose, with a nearly circumpolar distribution, has the most expansive range of any species in its genus. In Alaska, this species breeds in large numbers in both the Yukon-Kuskokwim Delta and also on the Arctic Coastal Plain, but they will also nest in the interior. On the coastal plain breeding habitat ranges from lowland wet to upland dry tundra often near ponds or lakes (Ely and Dzubin 1994). The Greater White-fronted Goose diet is dominated by vegetative matter, primarily grass and sedge rhizomes, tubers, and berries (Ely and Dzubin 1994). Arctic Alaskan populations winter on the Gulf Coastal plain in Louisiana and Texas as well as northern Mexico (Ely and Dzubin 1994). The Alaskan Arctic Coastal Plain population is estimated at 200,000 and population growth has been rapid in the past decade but has recently leveled off (Larned et al. 2012).

Range: We used the extant NatureServe map for the assessment as it matched other range map sources and descriptions (Johnson and Herter 1989, Ely and Dzubin1994).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Greater White-fronted Goose ranked neutral in most categories with the exception of physiological hydrologic niche for which they were evaluated to have a "slightly to greatly increased" vulnerability. This response was driven primarily by this species reliance on water bodies for breeding and foraging. A drying trend could have negative impacts by reducing availability of suitable habitats. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Human Response to CC: All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact Greater White-fronted Geese, particularly near Teshekpuk Lake, however other sources of human activity related to climate change mitigation will be much less pervasive in the near future so would likely only slightly increase vulnerability.



Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Likewise, predicted increased coastal erosion and resulting salinization (Jones et al. 2009) could both negatively and positively affect post-breeding aggregations of staging birds by destroying and creating foraging / molting habitat.

Greater White-fronted Goose (*Anser albifrons*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation			*				
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Interactions with Other Species: In terms of "interactions with other species", it is possible that red fox nest predation could increase if they become more numerous (Pamperin et al. 2006) and geese would not be able to defend nests as successfully as against the smaller arctic foxes.
Physiological Thermo Niche: Because this species experiences much warmer conditions at interior Alaska breeding sites, they should be able to adapt physiologically to a warmer Arctic environment.
Phenological Response: Timing of nesting has advanced about 10 days since the 1970s likely in response to increasing spring and summer temperatures (D. Ward, pers. comm.) however it is unknown if they can synchronize timing to changing schedules of other species and processes they depend on (e.g. spring green up timing).

In summary, this assessment suggests that Greater White-fronted Geese will likely be adaptable enough to cope with climate changes predicted to occur in Arctic Alaska, at least during the 50 year timeline of this assessment.

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Snow Goose (*Chen Caerulescens*)
Vulnerability: **Presumed Stable** **Confidence:** Moderate

The Snow Goose is a common breeder in Arctic Alaska, typically nesting in small, dense colonies scattered near the coast. This species nests on flat tundra, near ponds, shallow lakes, streams, and islands in river deltas (Mowbray et al. 2000). During the breeding season, their diet is primarily vegetarian, eating both aquatic and drier tundra vegetation (Mowbray et al. 2000). For brood rearing, one of the more important habitats is salt affected tundra on islands in river deltas (J. Shook, pers. comm.). Most North Slope breeders winter in western North America from British Columbia into California (Mowbray et al. 2000). Current Arctic Coastal Plain population is estimated at approximately 9,000 with an increasing trend (Larned et al. 2012).

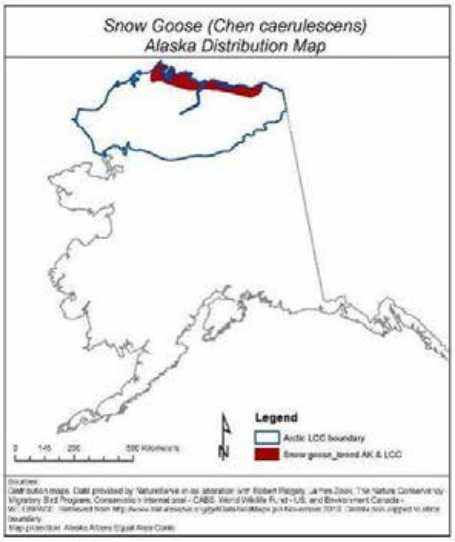
J. Liebezeit @ WCS

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America and other range descriptions (Bart et al. 2012, Johnson and Herter 1989).

Sea Level Rise & Natural Barriers: Because of this its restricted range along coastal areas in Arctic Alaska, this species was considered slightly vulnerable to both sea-level rise and to limitations in expansion of their range northward ("natural barriers" factor).

Physiological Hydro Niche: Snow Geese were scored as particularly vulnerable to changes in hydrologic niche because of their significant association with coastal habitats (in particular salt marsh), ponds, and wet tundra habitats for nesting, foraging, brood-rearing, molting, and avoiding predation. If substantial tundra drying occurs, this species could experience a considerable negative impact. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Disturbance Regime: Climate-mediated disturbances, most importantly increasing storms (Jones et al. 2009) on the coastal plain (including high winds) can back up water and cause the flooding of river deltas. This may destroy nests that are often less than a meter above sea level. Breeding densities could decline nearest the coast, but they may be able to successfully nest inland or redistribute to other colony areas on the coastal plain (J. Shook, pers. comm.).



Interactions with Other Species: In terms of interactions with other species, it is possible that red fox nest predation could increase as this predator's range expands northward from boreal regions (Pamperin et al. 2006). Geese would unlikely be able to defend nests as successfully as against the smaller arctic foxes. Also, climate changes may disrupt the regularity of the

Snow Goose (*Chen Caerulescens*)
Vulnerability: **Presumed Stable** **Confidence:** Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*	*			
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)					*		
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*	*		*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

lemming cycles (Post et al. 2009), thus exposing this species to greater nest predation pressure if lemmings become a less common food source for predators.

Phenological Response: Although long-term data sets for this species exist (e.g. Larned et al. 2012), the relationship between seasonal temperature / precipitation and phenological patterns in the Alaska portion of the Arctic LCC has not been examined.

In summary, while Snow Geese will likely experience some negative impacts from climate change this species appears, overall, to have enough versatility in life history traits and behaviors to remain "stable" at least during the timeframe of this assessment (to 2050).

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Brant (*Branta bernicla*)

Vulnerability: **Moderately Vulnerable** Confidence: Moderate

The Brant is a small goose well known in Alaska for the tens of thousands of individuals that molt in the Teshekpuk Lake area of the coastal plain during the late summer. In Arctic Alaska, this species typically nests within 8 km of the coast although in the National Petroleum Reserve – Alaska (NPR-A) can nest up to 30 km inland (Reed et al. 1998, D. Ward, pers. comm.). Brant often nest in colonies near the upper edge of salt marshes along sloping seacoasts or on estuarine deltas, although in areas where salt marshes are less common, they will be more dispersed, nesting near small ponds and freshwater marshes (Reed et al. 1998). Brant subsist on a vegetarian diet and during breeding primarily focus on just a few species of sedges and grasses (Reed et al. 1998). Alaskan breeders spend their winters along the Pacific Coast of North America as far down as Baja California (Reed et al 1998). Current Pacific Brant population (which includes the sizeable Y-K delta breeders) is estimated at approximately 125,000 (Arctic Goose Joint Venture 2008).

Range: For this assessment, we adjusted the NatureServe Map to more closely reflect the range map depicted in the Birds of North America account as the latter more accurately represented this species' range based on multiple accounts and expert opinion (Johnson and Herter 1989, Reed et al. 1998, D. Ward, pers. comm.).

Sea Level Rise: Because Brant rely on coastal areas for breeding, foraging, and especially molting/staging in the Arctic LCC area, they would most likely be negatively impacted by predicted sea level rise and a disturbance regime of increased storm surge frequency and salt water intrusion (IPCC 2007, Jones et al. 2009). Their ability to shift to nesting habitats that are less susceptible to such phenomena is possible as they are known to nest further inland in some places, albeit in lower numbers than near the coast (Reed et al. 1998).

Human Response to CC: All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact Brant, particularly near Teshekpuk Lake, however other sources of human activity related to climate change mitigation (e.g. wind farms) will be much less pervasive in the near future so would likely only slightly increase vulnerability.

Physiological Hydro Niche: Brant response to changing hydrological conditions could range from slight to greatly increased vulnerability (see table below) as they are reliant on coastal wetlands that are periodically inundated by salt water and nesting areas could be negatively impacted directly through potential tundra drying and indirectly as some nest predators may be able to more readily access nesting sites previously surrounded by water. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Brant (*Branta bernicla*)

Vulnerability: **Moderately Vulnerable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise				*			
B2a. Natural barriers				*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)						*	
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*	*		
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*	*				
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility			*	*			
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Dietary Versatility: Brant rely on just a few wetland plant species for forage (*Carex subspatheca* and *Puccinellia phryganodes*). Although they do eat other plants, it is possible that a significant reduction in availability of these species (via tundra drying or other events) could negatively impact Brant populations.

Interactions with Other Species: Brant are known to sometimes nest in the territory of predatory birds for protection, particularly Russian populations (Summers et al. 1987). However; it is unknown how a changing climate would alter this behavior and if it would confer a positive or negative outcome toward nesting success.

Phenological Response: There are long-term data sets on Brant in northern Alaska and they do indicate that timing of nesting has advanced about 10 days since the 1970s (D. Ward, pers. comm.). Although this provides some evidence that Brant can keep pace with climate changes, it is unknown how they can adjust to the changing phenology of the plant species they depend on for forage.

In summary, the accumulation of potential sources of vulnerability, particularly with regard to this species' heavy reliance on coastal and wetland habitats for breeding, foraging, and molting, resulted in this species ranking as moderately vulnerable in all three climate change projections we considered.

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Cackling/Canada Goose (*Branta hutchinsii / canadensis*)

Vulnerability: **Presumed Stable** Confidence: High

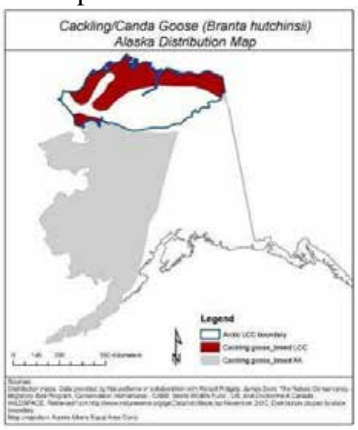
Cackling and Canada Geese were recently split into two species. The Cackling Goose *taverneri* subspecies is thought to be the dominant breeder on Alaska's Arctic Coastal Plain although some evidence suggests they may interbreed with Canada Goose *parvipes* subspecies (Mowbray et al. 2002). Coastal plain Cackling/Canada geese nest in moist sedge shrub tundra with brood rearing in wet sedge meadows, often near the coast (Mowbray et al. 2002). On the coastal plain their diet is dominated by *Carex* spp. (J. Hupp, pers. comm.). Arctic Alaskan populations winter primarily in w. Washington and Oregon as well as n. California (Mowbray et al. 2002). The Alaskan Arctic Coastal Plain population is estimated at ~8,000 with a stable population (Larned et al. 2012).

Range: We used the extant NatureServe map for the assessment as it matched the Birds of North America range description (Mowbray et al. 2002). It should be noted that most birds occur near Teshekpuk Lake (J. Hupp, pers. comm.).

Physiological Hydro Niche: Reliance on particular hydrologic conditions was ranked as the greatest potential source of vulnerability for the Cackling/Canada geese. This response was driven primarily by this species close association with moist/wet sedge communities and large lakes for both nesting and foraging. A drying trend could have negative impacts by reducing availability of suitable habitats. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Human Response to CC: All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact breeding and molting habitats, particularly near Teshekpuk Lake. However, combined sources of human activity related to climate change mitigation will likely be minimal and localized in the near future.

Physiological Thermal Niche: Because this species is distributed across a broad thermal range in North America they are likely not impacted or could benefit from warming temperatures, reducing stress related to early season cold temperatures.



Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Likewise, predicted increased coastal erosion and resulting salinization (Jones et al. 2009) could both negatively and positively affect nesting and staging birds by destroying and creating nesting, foraging, and molting habitats.

Dietary Versatility: Because this species complex relies so heavily on *Carex* spp. as a diet source, any reduction in this food source related to climate could have negative consequences.

Genetic Variation: Current mitochondrial DNA evidence suggests Cackling/Canada geese have

Cackling/Canada Goose (*Branta hutchinsii / canadensis*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*	*				
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*	*			
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*		*		
C5a. Genetic variation		*					
C5b. Genetic bottlenecks		*					
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

high genetic diversity (Scribner et al. 2003) and so would likely cope well with climate-mediated impacts that exert influence across their range.

Interactions with Other Species: In terms of "interactions with other species", it is possible that nest predation by red fox could increase as this species' range may expand northward moving in from boreal regions (Pamperin et al. 2006) and geese would not be able to defend nests as successfully as against the smaller arctic foxes. Also, climate changes may make lemming cycles less regular (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings no longer become periodically superabundant.

Phenological Repsonse: Arrival data collected on the Colville River Delta (J. Helmericks, unpub. data) are currently being analyzed. Even if their arrival dates have advanced (like other North Slope geese; D. Ward, pers. comm.) it is unknown if they can synchronize timing to changing schedules of other phenomena (e.g. spring green up timing).

In summary, this assessment suggests that Cackling/Canada Geese will likely be able to adapt to climate changes projected to occur in Arctic Alaska in the next 50 years.

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Northern Pintail (*Anas acuta*)

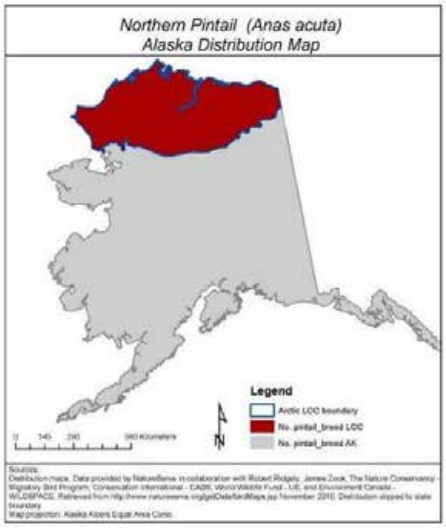
Vulnerability: **Presumed Stable** Confidence: Moderate

The Northern Pintail is the most common breeding dabbling duck in Arctic Alaska, with its core breeding area centered on the coastal plain. In Alaska this species nests on wet sedge (*Carex*) or grass meadows, sloughs, river banks, pond shores and in tidal habitats (Austin and Miller 1995). During the breeding season pintails consume mostly animal foods (aquatic invertebrates) although they switch to a largely vegetarian diet later in summer and fall (Austin and Miller 1995). Northern Pintails spend their winters primarily in the southern US and Mexico (Austin and Miller 1995). The North American pintail population is down from 6 million in the early 1970s to 2.6 million in 2005 (http://ak.audubon.org/species/norpin). However, aerial surveys suggest the pintail population on the Alaskan Arctic Coastal Plain has not shown a significant change since 1992, although there is substantial annual variation (J. Hupp, pers. comm.).

Range: We used the extant NatureServe map for the assessment as it matched other range map sources and descriptions (Johnson and Herter 1989, Austin and Miller 1995, Bart et al. 2012). However, it should be noted that this species less commonly nests in the Brooks Range and foothills (J. Hupp, pers. comm.).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Northern Pintails ranked neutral in most categories with the exception of physiological hydrologic niche for which they were evaluated to have a "slightly to greatly increased" vulnerability. This response was driven primarily by this species close association with shallow wetland habitats on the coastal plain. Effects of climate change (and projected drying trends) on wetland availability in northern Alaska are very poorly understood and current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP).Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. This uncertainty is reflected in the range of vulnerability scores in the table below.

Physical Habitat Restrictions: Pintails expansive breeding range and ability to utilize different wetland habitat types make them less sensitive to constraints posed by dispersal/movement barriers when responding to potential shifts in habitat availability.



Physiological Thermo Niche: Because this species breeding range also occurs much further south (e.g. prairie pothole region) they would likely be able to adapt physiologically to a warmer Arctic environment and perhaps could even benefit from it.

Disturbance Regime: Disturbance (e.g. large-scale thermokarst, disease outbreaks) and human mitigation or adaptation activities related to climate could impact this species. But these types of factors will likely be localized in impact or, in the case of thermokarst, could actually

Northern Pintail (*Anas acuta*)
Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation		*					
C5b. Genetic bottlenecks							*
C6. Phenological response			*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

increase viable habitat (Martin et al. 2009).
Dietary Versatility: Because of the high flexibility in pintail diet they would likely be able to cope with climate-mediated changes in prey base and could benefit from increased availability of aquatic invertebrates resulting from increased productivity of warming wetlands.
Genetic Variation: Northern Pintails have high genetic variation (Flint et al. 2009) and there is no evidence of recent genetic bottlenecks in the Alaska population so they would be likely to withstand any climate-mediated impacts (e.g. disease outbreaks) that would wipe out a less genetically diverse population.
Phenological Response: There is at least one long-term data set on arrival dates of Northern Pintails in Arctic Alaska that could shed some light on how this species phenology may be changing with climate (J. Hupp, pers. comm.), however, that data set has currently not been analyzed so it is unknown how this species will respond to changing biotic schedules.

In summary, this assessment suggests that Northern Pintails will likely be able to cope with climate and perhaps even benefit from associated habitat changes that may occur in Arctic Alaska during the 50 year timeline of this assessment.

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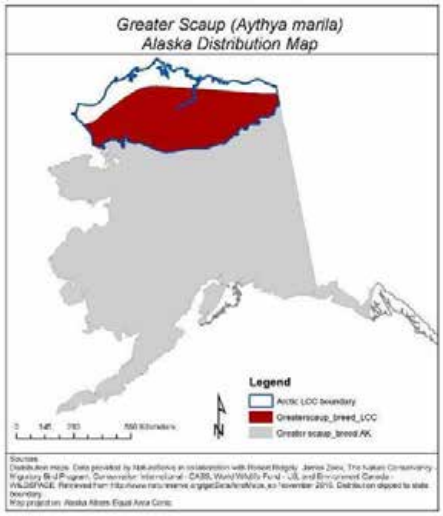
Greater Scaup (Aythya marila)

Vulnerability: **Presumed Stable** Confidence: High

The Greater Scaup is the only diving duck in the genus *Aythya* that has a circumpolar distribution. In Alaska this species has its highest nesting densities in the Yukon-Kuskokwim Delta but they also breed in Arctic Alaska throughout the Brooks Range, foothills and Arctic Coastal Plain. Its breeding habitat is typically characterized by relatively shallow (1–2 m) lakes and large ponds with low surrounding vegetation in extensive, largely treeless, wetlands (Kessel et al. 2002). Greater Scaup have an omnivorous diet but tend to focus on more protein-rich animal foods (mostly aquatic invertebrates) during the summer. This species winters primarily in marine waters of both the Atlantic and Pacific coasts (Kessel et al. 2002). Breeding ground population estimates for this species from 1978-2011 range from 434,000 – 642,000 and there is some evidence of regional declines (Kessel et al. 2002).

Range: We used the extant NatureServe map for this assessment as it closely matched other range map sources and descriptions (Johnson and Herter 1989, Kessel et al. 2002). However, it should be noted that this species does occasionally breed sporadically closer to the Arctic Ocean coastline and along the Dalton Highway (Kessel et al. 2002).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Greater Scaup ranked neutral in most categories although they were ranked with a greater than "slight increase" in vulnerability for "physiological hydrologic niche" and "interactions with other species". For the first category this response was driven by the scaup's requirement for wetlands and ponds rich in aquatic invertebrates for feeding during migration, nesting, and brood rearing. They need smaller wetlands, likely with abundant emergent vegetation for cover and feeding, particularly for brood rearing (Kessel et al. 2002). A tundra drying trend could limit wetland availability in northern Alaska. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). This uncertainty is reflected in the range of vulnerability severity scores in this category (see table below).



Interactions with Other Species: In terms of "interactions with other species", it is possible that red fox nest predation could increase as this species may become more numerous moving in from boreal regions (Pamperin et al. 2006) and scaup would not be able to defend nests as successfully as against the smaller arctic foxes. However this does not seem to be a problem for them in the southern portion of their range.

Disturbance Regime: Disturbances (e.g. large-scale thermokarst, disease outbreaks) and human

Greater Scaup (Aythya marila)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*		*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*					
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*		*		
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

mitigation activities related to climate could impact this species, but experts felt this to be unlikely as these types factors will likely be localized or, in the case of thermokarst, could potentially create habitat (Martin et al. 2009).

Physical Habitat Restrictions: The Greater Scaup's expansive breeding range into southern Alaska makes them less susceptible to constraints posed by natural barriers related to dispersal/movement issues. Because this species experiences much warmer conditions at interior Alaska breeding sites, they would likely have no problem adapting physiologically to a warmer Arctic environment and perhaps could expand their nesting presence in far northern Alaska.

Phenological Response: There are no long-term data sets on nesting or migration chronology for Greater Scaup for the North Slope (D. Safine, pers. comm.) and so it is currently unknown how they would respond to phenology changes.

In summary, this assessment suggests that Greater Scaup will likely be adaptable enough to cope with climate change and perhaps even benefit from associated habitat changes that may occur in Arctic Alaska, at least during the 50 year timeline of this assessment.

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Martin, P., J. Jenkins, F.J. Adams, M.T. Jorgenson, A.C. Matz, D.C. Payer, P.E. Reynolds, A.C. Tidwell, and J.R. Zelenak. 2009. Wildlife response to environmental Arctic change: Predicting future habitats of Arctic Alaska. Report of the Wildlife Response to Environmental Arctic Change (WildREACH), Predicting Future Habitats of Arctic Alaska Workshop, 17-18 November 2008. Fairbanks, Alaska, USFWS, 148 pages.

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Steller's Eider (*Polysticta stelleri*)

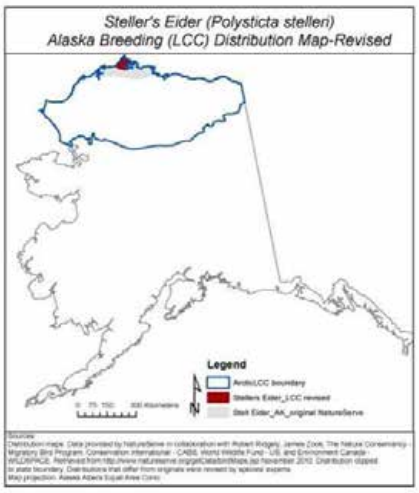
Vulnerability: **Moderately Vulnerable** Confidence: Moderate

The Steller's Eider, is the smallest of the four eiders and in many ways resembles dabbling ducks more than sea ducks. This species was listed as "threatened" in 1997 under the Endangered Species Act as it has virtually disappeared from historic breeding areas in the Yukon-Kuskokwim Delta, once the most populated breeding ground in Alaska. In Arctic Alaska, Steller's Eiders nest in polygonal tundra near the coast or up to 30km inland on sites with a complex of interconnected ponds (Fredrickson 2001). During the breeding season, their diet consists primarily of aquatic insects including chironomid and tipulid larvae (Fredrickson 2001). Alaskan breeders spend their winters along the Alaskan panhandle and the eastern Aleutian Islands (Fredrickson 2001). Current Arctic Coastal Plain population is estimated at <1000 individuals (Larned et al. 2012).

Range: We adjusted the NatureServe Map to more closely reflect a more restricted breeding range within the "Barrow Triangle" area. Over the past decades, breeding locations for this species have only been documented in this region (P. Martin, pers. comm.). Because of their restricted range near the coast, there is potentially little room for Steller's Eiders to relocate if climate-mediated changes result in habitat loss.

Natural Barriers: Increasing rates of shoreline erosion may result in relocation of infrastructure in the vicinity of Barrow which could adversely affect Steller's Eider breeding habitat. However, such impacts would be localized and presumably, adequate nesting and foraging habitat would remain.

Physiological Hydro Niche: Of all the factors used in the assessment those related to "hydrological niche" indicated the greatest possibility of significantly increasing vulnerability in this species (see table). Steller's eiders depend on shallow ponds for feeding and brood-rearing. Increased temperatures may alter prey base and/or dessication of these key habitats. The wide range in potential responses (see table) represents the significant uncertainty of such impacts. At present, information on how a warming climate will affect wetland primary productivity and aquatic insect prey base is speculative. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.



Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy good foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). In fact, anecdotal evidence suggests Steller's Eiders may benefit from a flush of productivity that accompanies sudden lake drainage (P. Martin, pers. comm.). Likewise, predicted increased coastal erosion and resulting

Steller's Eider (*Polysticta stelleri*)

Vulnerability: **Moderately Vulnerable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise				*			
B2a. Natural barriers				*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)						*	
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*		*		
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*	*		
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

salinization (Jones et al. 2009) could both negatively and positively affect post-breeding aggregations of staging birds by destroying and creating foraging habitat.

Interactions with Other Species: Steller's eider breeding success is strongly influenced by nest predation, and average nest success is higher when there is abundant lemming prey. Lemming cycles may become less regular (Post et al. 2009), potentially exposing eiders to greater nest predation.

Phenological Response: As of yet, the relationship between seasonal temperature / precipitation and phenology for this species in the Arctic LCC has not been studied.

In summary, the sources of potential vulnerability identified by this assessment, particularly with regard to this species heavy reliance on coastal and wetland habitats for breeding, foraging, and post-breeding activity and their small range in Arctic Alaska, yielded a moderately vulnerable result in all three climate change projections we considered.

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Spectacled Eider (*Somateria fischeri*)

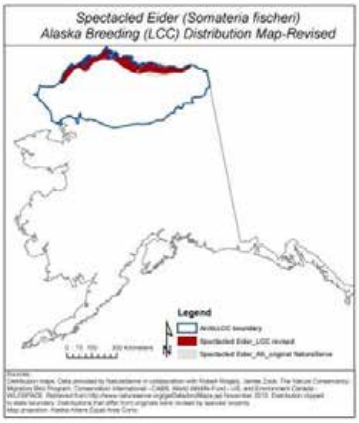
Vulnerability: **Presumed Stable** Confidence: Low

The Spectacled Eider is a medium-sized sea duck with males easily recognized by their striking "clown-like" head plumage. This species was listed as threatened in 1993 under the Endangered Species Act as it has suffered severe population declines in western Alaska. The Arctic Coastal Plain population may also be declining. In Arctic Alaska, breeding Spectacled Eiders use river deltas and wet tundra habitats, including drained-lake basins, flooded wetlands, and islets within a matrix of thaw lakes for both nesting and foraging (Petersen et al. 2000). During the breeding season, their diet consists primarily of both adult and larval aquatic insects (Petersen et al. 2000). Alaskan breeders spend their winters offshore in the Bering Sea, often amassed in small openings in the pack ice (Petersen et al. 2000). Current Arctic Coastal Plain population is estimated at 6-8,000 (http://seaduckjv.org/infoseries/spei_sppfactsheet.pdf).

Range: We adjusted the NatureServe Map to more closely reflect recent satellite telemetry studies indicating that most Spectacled Eiders in Arctic Alaska nest within 20 km of the coast (M. Sexson, pers. comm.). Because of their reliance on nesting habitats near the coast, their ability to shift to new habitats is restricted.

Human Response to CC: All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact this species. At the same time, impounded water created by a road network could provide additional foraging habitat (J. Liebezeit, pers. obs.). Overall, human activity in response to climate change will likely be localized in the near future so would only slightly increase vulnerability.

Physiological Hydro Niche: The greatest potential source of vulnerability for Spectacled Eiders was with respect to "physiological hydrologic niche" category, in which scores ranged from "neutral" to "greatly increased" vulnerability. This range reflects uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the eider (less or greater vulnerability). If substantial tundra drying occurs, this species could experience a considerable negative impact as they are highly dependent on wet tundra habitats for nesting and foraging (Petersen et al. 2000). Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.



Disturbance Regime: In terms of disturbance, projected increases in winter precipitation and surface temperatures (ACIA 2005) will likely alter the amount, extent, and duration of flooding, potentially limiting nesting habitat. At the same time thermokarst could create new nesting and foraging habitats (Martin et al. 2009).

Interactions with Other Species: Spectacled eiders are known to sometimes nest in gull

Spectacled Eider (*Somateria fischeri*)

Vulnerability: **Presumed Stable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers				*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)					*		
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*	*		
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*					
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation				*			
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

territories supposedly to gain protection (Petersen et al. 2000). How a changing climate might alter this relationship is not known. It is possible that nest predation by red fox could increase as their population may be expanding in the arctic (Pamperin et al. 2006). Eiders may not be able to defend nests as successfully as against the smaller arctic foxes.

Genetic Variation: Spectacled Eiders are genetically homogenous across their range as a result of male dispersal (Scribner et al. 2001) and thus could be vulnerable to certain climate-mediated events in the near future (e.g. disease outbreaks).

Phenological Response: The relationship between seasonal temperature / precipitation and phenology for this species in the Arctic LCC has not yet been examined.

In summary, this assessment suggests the Spectacled Eider will remain stable in the face of a changing climate. However, it was ranked close to the cut-off for "moderately vulnerable" (see assessment results section) and worth continued attention as Arctic Alaska climatic conditions continue to change.

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King Eider (*Somateria spectabilis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

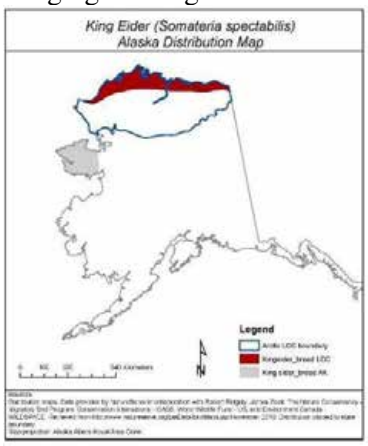
The King Eider, conspicuous for the male's elegant plumage, is a common nester on the Arctic Coastal Plain of Alaska. King Eiders typically nest in wet lowland tundra with many small ponds and pools, islands, and wet marshes. Dry tundra is also used when small lakes and ponds are available nearby as foraging areas (Powell and Suydam 2012). Unlike other eiders, this species is not as closely tied to coastal breeding habitats. During the breeding season, their diet is primarily omnivorous (Powell and Suydam 2012). Alaskan breeders spend their winters in marine environments mostly in the Bering Sea and along the Aleutians (Powell and Suydam 2012). Eider populations have declined since the 1970s (Powell and Suydam 2012). Current Arctic Coastal Plain population is estimated at approximately 15,000 (Larned et al. 2005).

Range: We used the extant NatureServe range map for this assessment as it closely matched the Birds of North America and other range descriptions. Because of their reliance on habitats relatively near the coast their ability to shift to new habitats is restricted.

Human Response to CC: All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact this species. At the same time, impounded water created by a road network could provide additional foraging habitat (J. Liebezeit, pers. obs.). Overall, human activity related to climate change mitigation will likely be localized in the near future so would only slightly increase vulnerability.

Physiological Hydro Niche: King Eiders showed the strongest "increased vulnerability" response in the "physiological hydrologic niche" category, ranging from "slightly" to "greatly increased" vulnerability. This range represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the eider. If substantial tundra drying occurs, this species could experience a negative impact as they are highly dependent on wet tundra habitats for nesting and foraging (Powell and Suydam 2000). Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment. Also, interaction with hydrologic processes is very poorly understood (Martin et al. 2009).

Disturbance Regime: Climate-mediated disturbance, namely thermokarst, could both create and destroy good foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Likewise, increased coastal erosion and resulting salinization (Jones et al. 2009) could both negatively and positively affect post-breeding aggregations of staging birds by destroying and creating foraging/molting habitat.



Interactions with Other Species: King Eiders are known to benefit from nesting in the vicinity of aggressive species, (e.g. Glaucous Gulls) but these interactions are not required for

King Eider (*Somateria spectabilis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*	*		
C5a. Genetic variation		*					
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*	*		*
D1. CC-related distribution response				*			*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

persistence (Bentzen et al. 2009. It is possible that red fox nest predation could increase as this species may become more numerous in the arctic (Pamperin et al. 2006) and eiders would not be able to defend nests as successfully as against the smaller arctic foxes.

Genetic Variation: King Eiders have relatively high genetic variation (Pearce et al. 2004) and so would potentially be able to cope well with climate driven changes.

Phenological Response: The relationship between seasonal temperature/precipitation and phenology for this species in the Arctic LCC has not yet been studied, so it is at best speculative to assert how King Eiders would respond to changing habitat phenology.

Related Distribution Response: Decline of birds from 1970s to 1990s is potentially explained by reduced carrying capacity of wintering habitats in the Bering Sea due to a regime shift towards warmer waters supporting a different and less energetically profitable benthic invertebrate community (Suydam et al. 2000).

In summary, despite some sources of vulnerability, King Eiders will likely remain "stable" and adjust to climate-mediated changes in their breeding range for the next 50 years.

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Common Eider (*Somateria mollissima*)

Vulnerability: **Highly Vulnerable** Confidence: Low

The Common Eider, a large sea duck, is more closely tied to marine environments than are many other sea ducks. On the Arctic Coastal Plain of Alaska this species nests primarily on barrier islands and peninsulas of the Arctic Coastal Plain (a small proportion of the total area) while in other parts of its range they select quite varied nesting sites (Goudie et al. 2000). Common eiders depend on a marine prey base, eating invertebrates (primarily mollusks and crustaceans) by diving to the sea floor. Alaskan breeders spend their winters nearby in the Bering Sea, Gulf of Alaska, and off Russia's Chukotka Peninsula (SDJV 2004). Current Arctic Coastal Plain population is estimated at approximately 2,000 (Dau and Bollinger 2009).

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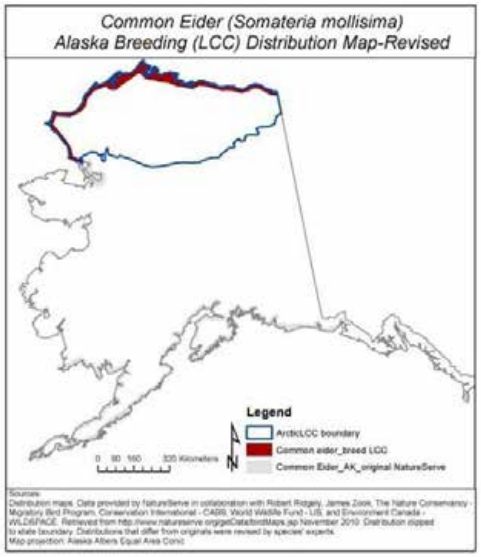
Range: We adjusted the NatureServe Map to more closely reflect the range map depicted in the Birds of North America account for this assessment as the latter more accurately represented this species' range based on multiple accounts and expert opinion (Johnson and Herter 1989, Goudie et al. 2000, C. Dau pers. comm.).

Sea Level Rise: Because of the Common Eiders' reliance on barrier islands and other coastal areas for nesting they would most likely be negatively impacted by predicted sea level rise and a disturbance regime of increased storm surge frequency (IPCC 2007, Jones et al. 2009). Their ability to shift to nesting habitats that are less susceptible to such phenomena is minimal as they rely on coastal habitats for breeding throughout their range (Goudie et al. 2000).

Human Response to CC: Hardening of the windward side of barrier islands (to prevent erosion on development platforms as off-shore activity increases) could benefit species by protecting islands from erosion, although increased human activity could also increase stress to incubating birds and young (C. Dau, pers. comm.).

Physiological Hydro Niche: The salinity regime encountered by Common Eiders affects breeding and survival. Climate change will likely affect ice conditions, sea levels, stability of fresh-water habitats, and other factors which would alter the salinity of essential aquatic habitats (Nystrom et al. 1988, C. Dau pers. comm.). These could have negative consequences.



Physical Habitat Restrictions: At other places (outside the Arctic LCC) throughout their breeding range Common Eiders utilize a variety of nesting habitat from tundra heath to boreal forest (Goudie et al. 2000). It is unknown if the Arctic Alaska populations, which seem to rely almost exclusively on barrier islands, have the capacity and adaptability to utilize different types of nesting habitat. In this assessment it was assumed they do not but this could be an area of future investigation.

Common Eider (*Somateria mollissima*)

Vulnerability: **Highly Vulnerable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC		*	*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*	*		*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Interactions with Other Species: Common Eiders are known to sometimes nest in the territory of predatory birds to gain protection which can sometimes increase nest success (Goudie et al. 2000). However; it is unknown how a changing climate would alter this behavior and if it would confer a positive or negative outcome.

Pheonological Response: Despite the existence of long-term data sets on Common Eiders in northern Alaska (Dau and Bollinger 2009) an assessment of phenology-related variables has not been a part of that effort so it is, at best, speculative to assert how this species will respond to changing biotic schedules.

In summary, the accumulation of potential sources of vulnerability, particularly with regard to barrier island nesting, resulted in a ranking of highly vulnerable for this species in two of the three climate change projections we considered.

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Long-tailed Duck (*Clangula hyemalis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

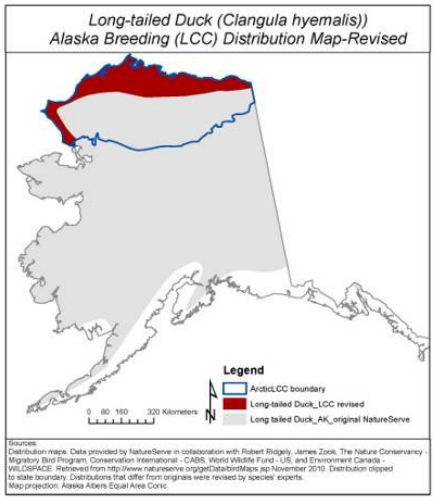
The Long-tailed Duck is one of the most common sea ducks in Arctic Alaska, and has a circumpolar distribution. They are known for their ability to dive to impressive depths (> 60 m) in search of food (Robertson and Savard 2002). In Arctic Alaska, this species typically nests in wet tundra near shallow *Carex* or *Arctophila*-dominated ponds, and braided streams (Robertson and Savard 2002). During the breeding season, their diet consists primarily of aquatic invertebrates although they will also take vegetative matter (Robertson and Savard 2002). During post-breeding molt, this species uses coastal lagoons and deep, open lakes (Robertson and Savard 2002). Long-tailed Ducks winter on both coasts of North America and on the Great Lakes (Robertson and Savard 2002). Current Arctic Coastal Plain population is estimated at approximately 44,000 with a stable trend across recent years (Larned et al. 2012).

Range: We modified the NatureServe range map for this assessment to more accurately reflect this species more coastally-oriented breeding range based on the Birds of North America (Robertson and Savard 2002) and other range descriptions (Bart et al. 2012, Johnson and Herter 1989).

Physiological Hydro Niche: Long-tailed Ducks were ranked as particularly vulnerable to changes in hydrologic niche because of their significant association with wet tundra and shallow pond habitats for nesting and foraging. If substantial tundra drying occurs, this species could experience a negative impact. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Physical Habitat Restrictions: Hardening of the windward side of barrier islands (to prevent erosion on development platforms as off-shore activity increases) could impact this species, although molting Long-tailed Ducks that currently use hardened sites around existing oilfields (e.g. West Dock) show little sign of impact (J. Reed, pers. comm.).

Disturbance Regimes: Climate-mediated disturbance processes, most importantly increasing storms and associated coastal erosion (Jones et al. 2009) could affect barrier island / lagoon systems, thus affecting the availability of molting sites for Long-tailed Ducks. These types of habitat features are relatively uncommon in the Arctic LCC and are particularly susceptible to such disturbances.



Interactions with Other Species: In terms of interactions with other species, it is possible climate changes may disrupt lemming cycles (Post et al. 2009) and thus could expose this species to greater nest predation pressure if lemmings are no longer a periodically superabundant food source for predators.

Long-tailed Duck (*Clangula hyemalis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions			*	*			
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: Although long-term data sets exist for this species (e.g. Larned et al. 2012), the relationship between seasonal temperature / precipitation and phenology for this species in the Arctic LCC has not been examined, so it is at best speculative on how they would respond to changing biotic schedules.

In summary, Long-tailed Ducks will likely experience some negative impacts from climate change. In particular, they may be most susceptible to coastal impacts during the molting period. Overall, though, this species appears to have enough versatility in life history traits and behaviors to remain "stable" with regard to climate change at least during the timeframe of this assessment (to 2050).

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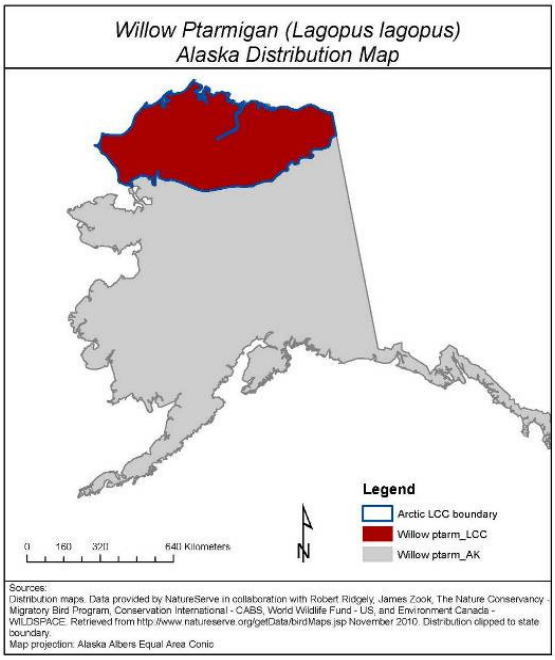
Willow Ptarmigan (*Lagopus lagopus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

The Willow Ptarmigan is an abundant and conspicuous breeding bird in Arctic Alaska and is one of the few birds that remain in the Arctic year-round. During the breeding season this species nests in tall shrub habitats as well as in well-drained tundra sites (Hannon et al. 1998). In early spring Willow Ptarmigan are willow bud specialists (constituting up to 80% of their diet); in summer the dietary breadth widens substantially to include insects, berries, equisetum, and leaves (Hannon et al. 1998). In Alaska, female Willow Ptarmigan may move as far south as the southern side of the Brooks Range in winter while males stay closer to the tundra breeding grounds (Irving et al. 1966). Global population estimate is 40 million (Rich et al. 2004).

K. Pietrzak

Range: We used the extant NatureServe range map for the assessment as it matched the Birds of North America (Hannon et al. 1998) and other range descriptions (Johnson and Herter 1989).
Physiological Thermal Niche: For most of the indirect exposure and sensitivity categories in this assessment, Willow Ptarmigan were scored with a neutral response (see table on next page). This species is associated with dense shrub patches, primarily in valley bottoms that are warmer on average than surrounding upland habitats suggesting this species may be sensitive to changes in localized thermal conditions.
Physiological Hydro Niche: Willow Ptarmigan are sensitive to changes in snow depth in the winter months due to their dependence on shrubs for cover from predators and for food. Furthermore, Willow Ptarmigan delay egg-laying in years with late spring snow melt and this may result in lower breeding success (Martin and Weibe 2004). Current precipitation models do predict increased snowfall in winter in Arctic Alaska (http://www.snap.uaf.edu/).
Biotic Habitat Dependence: In the winter and spring when snow cover is extensive, Willow Ptarmigan on the North Slope of Alaska depend primarily on one willow species, (*Salix alaxensis*), for food and cover. Any changes in the distribution of this one plant species could have a significant impact on this species. With shrub expansion taking place on the North Slope (Tape et al. 2006), it could provide expanded breeding habitat opportunities. However, in the long-term, as spruce and deciduous forest expand into shrub-dominated areas, Willow Ptarmigan habitat will likely be reduced.



Disturbance Regime: Disturbance events such as periodic flooding of riparian areas and deposition of sediment may benefit ptarmigan by enhancing habitat suitability for early-successional willows such as *S. alaxensis*. However, in the longer-term, the expected invasion of trees such as poplar (*Populus balsamifera*) in riparian floodplains would be detrimental to ptarmigan (Mann et al. 2010).

Willow Ptarmigan (*Lagopus lagopus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: Willow Ptarmigan appear to adjust their lay dates according to snow cover, which varies annually (Martin and Weibe 2004). No studies explicitly examining long-term climate change and ptarmigan phenology have been conducted (K. Christie, pers. comm.).

Genetic Variation: There is little information in the literature regarding degree of genetic variation or recent evolutionary bottlenecks for this species.

In summary, this assessment suggests that Willow Ptarmigan have enough flexibility in life history and in response to expected changes in environmental conditions to allow them to remain stable with regard to climate change, at least within the next 50 years.

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Rock Ptarmigan (*Lagopus mutus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

The Rock Ptarmigan is a common breeding bird in Arctic Alaska and, like the Willow Ptarmigan, is one of the few birds that remain in the Arctic year-round. This species typically breeds in habitats that include a mix of rocky outcrops, graminoid meadows, and small patches of *Salix* or *Betula* less than 1 m in height (Montgomerie and Holder 2008). Unlike the Willow Ptarmigan, this species is less dependent on shrubs associated with riparian areas. In summer, Rock Ptarmigan consume a variety of foods including *Dryas*, *Oxytropis*, and *Salix* leaves, insects, *Betula* and *Salix* catkins, and berries (Montgomerie and Holder 2008). This species winters mainly within the breeding range but withdraws from the northernmost regions (Montgomerie and Holder 2008). Global population estimate is >8 million (Rich et al. 2004).

Range: We used the extant Nature Serve range map for the assessment as it matched the Birds of North America (Montgomerie and Holder 2008) and other range descriptions (Johnson and Herter 1989).

Physiological Thermal Niche: For most of the indirect exposure and sensitivity categories in the assessment, Rock Ptarmigan were ranked with a neutral response (see table on next page). This species breeds in alpine and arctic tundra regions, and is associated with cooler, higher elevation thermal environments within the arctic LCC. The availability of these environments may decline as temperatures increase and shrubs and trees encroach on tundra habitats (Tape et al. 2006, Danby et al. 2007).

Physiological Hydro Niche: If winter precipitation were to increase as some models predict (http://www.snap.uaf. edu/), access to shrubs, and thus food and protection from predators would be reduced. It is important to note that in general, Rock Ptarmigan are less dependent on water driven environments (compared to Willow Ptarmigan).

Disturbance Regime: In general climate-mediated disturbance events are unlikely to have a significant impact on Rock Ptarmigan, although increased freezing rain events early and late in winter could lead to greater mortality (K. Christie, pers. comm.).

Biotic Habitat Dependence: In the winter and spring, Rock Ptarmigan occur in tall shrub patches associated with river and lake edges. At this time, dwarf birch (*Betula nana*) and willow (*Salix* spp.) are important for both food and cover. Conversely, Willow Ptarmigan exhibit a stronger dependence on just one plant species (i.e. *Salix alaxensis*).

Physical Habitat Restrictions: Unlike Willow Ptarmigan, Rock Ptarmigan tend to prefer more open tundra areas with short or sparse shrub cover for breeding (Montgomerie and Holder 2008), so they will likely not benefit as much from shrub expansion. Over the long-term, as tree-line advances, suitable habitat for this species will likely be reduced, causing range contraction to higher elevations and latitudes (Lloyd et al. 2002).

Rock Ptarmigan (*Lagopus mutus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime		*	*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation		*					
C5b. Genetic bottlenecks							*
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Genetic Variation: Significant genetic variation exists in North American populations of Rock Ptarmigan (Holder et al. 1999) and so they may be resilient responding to climate-mediated impacts at the population level.

Phenological Response: Timing of snow melt can influence breeding phenology and reproductive output for this species, which experiences decreased clutch size in years with late snow melt (Wilson and Martin 2010).

In summary, the flexibility in behavior and life history exhibited by the Rock Ptarmigan, in combination with a widespread distribution in the Arctic LCC, suggests they will likely remain stable under the current predictions of climate change within the 50 year timeframe of this assessment.

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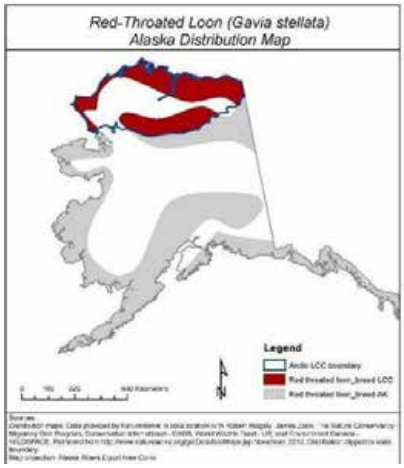
Red-throated Loon (*Gavia stellata*)

Vulnerability: **Presumed Stable** Confidence: Very High

The Red-throated Loon is the smallest of the world's five loon species. This species typically breeds in low wetlands in both tundra and forested terrain (Barr et al. 2000). They nest on pond edges, sometimes along very small ponds (<1 ha), particularly in parts of their range sympatric with Pacific Loons (Barr et al. 2000). Red-throated Loons are unique in that they regularly forage on fish away from their nesting ponds.In Arctic Alaska this often involves flights to the Arctic Ocean (Andres 1993). Like Yellow-billed Loons, the North American breeding population, north of 68° latitude, appear to winter primarily in East Asia from the western Kuril Islands to the Yellow Sea (J. Schmutz et al., unpublished data). In 1993, the Red-throated Loon population in Alaska was estimated at approximately 10,000 individuals (Groves et al. 1996) while more recent surveys indicated an estimated population size of 2-3,000 on the Arctic Coastal Plain of Alaska (Larned et al. 2012).

Range: We used the extant NatureServe map for the assessment as it matched other range map sources and descriptions (Johnson and Herter 1989, Barr et al. 2000).

Physiological Hyrdo Niche: Among the indirect exposure and sensitivity factors in the assessment, Red-throated Loon scored neutral in most categories (see table on next page). They were considered most vulnerable to climate change in the hydrological niche category ranging from "increased" to "greatly increased" primarily because of their reliance on small, shallow lakes (average area 0.4 ha, range 0.1 to 0.8 ha; Bergman and Derksen 1977) for nesting. Water dynamics in these lakes is dictated primarily by water balance (snow melt, precipitation, evaporation) rather than lateral expansion or drainage due to thermokarst thawing (Arp et al. 2011). Thus, the availability of suitable nesting lakes in the Arctic LCC will likely be related to spring snow melt input and the balance between precipitation and evaporation in summer maintaining sufficient water in this size class of lakes. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment.



Disturbance Regime: Shoreline stabilization is likely to occur in response to increasing storm frequency and erosion (Jones et al. 2009). But such impacts may be limited to Native Alaskan village sites and industrial facilities that are dispersed along the coastline and have relatively small human populations. Shoreline stabilization is unlikely to have a meaningful effect on loon foraging or post-breeding activity along the Arctic Ocean coastline.

Physical Habitat Restrictions: Red-throated Loons are not tied to any uncommon geological features in their Alaskan range for nesting or foraging.

Red-throated Loon (*Gavia stellata*)

Vulnerability: **Presumed Stable** Confidence: Very High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche					*	*	
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: With regard to nesting phenology, no time-series data exist for the Arctic LCC, but Red-throated Loons nesting on the Yukon-Kuskokwim Delta in Alaska have shown a trend of earlier average hatch date over the past 27 years (Fischer et al. 2009). Even if the North Slope population is able to adjust nesting to earlier spring phenology, it is unknown if they can adjust timing to the changing schedules of the other organisms on which they depend.

In summary, the results of this assessment suggest Red-throated Loons will likely be able to cope with climate and associated habitat changes predicted to occur in Arctic Alaska, at least during the next 50 years.

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Pacific Loon (*Gavia pacifica*)

Vulnerability**: Presumed Stable** Confidence: Moderate

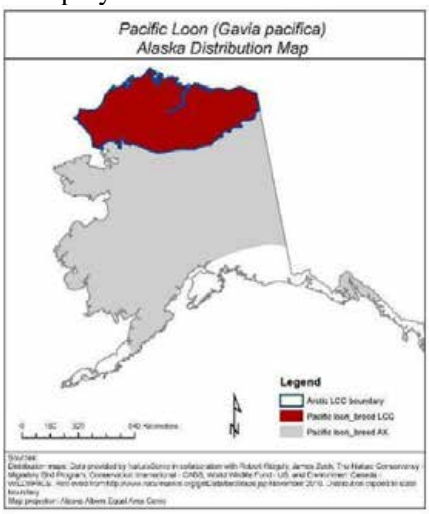
The Pacific Loon is the most common breeding loon in Arctic Alaska, nesting throughout much of the state (Russell 2002). This species typically breeds on lakes that are ≥1 ha in size in both boreal and tundra habitats. They are primarily piscivorous although they are known to commonly feed chicks invertebrates (D. Rizzolo and J. Schmutz, unpublished data). Many Pacific Loons spend their winters in offshore waters of the west coast of Canada and the U.S. (Russell 2002). The most recent Alaska population estimate is 100-125,000 individuals (Ruggles and Tankersley 1992) with ~ 69,500 on the Arctic Coastal Plain specifically (Groves et al. 1996).

Range: We used the extant NatureServe map for the assessment as it matched other range map sources and descriptions (Johnson and Herter 1989, Russell 2002).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Pacific Loons ranked neutral in most categories with the exception of physiological hydrologic niche for which they were evaluated to have a "slightly to greatly increased" vulnerability. This response was driven primarily by this species reliance on small water bodies (typically <1ha) for breeding and foraging. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment.

Physical Habitat Restrictions: Pacific Loons occur throughout Alaska in a variety of habitats including warmer boreal environs, so there is little reason to think they could not adapt physiologically to some degree of warming in the Arctic environment in the future. Also their adaptability to varied habitat types would enable them to cope with shrub or boreal zone encroachment (Tape et al. 2006) into tundra habitats.

Although small fish make up a significant part of the Pacific Loon diet, they also eat many invertebrates (e.g., caddis fly larvae, nostracods) and so, unlike some other loon species, exhibit enough flexibility in their diet that they would likely be able to adjust to climate-mediated changes in prey base.



Disturbance Regime: Climate-mediated disturbance, namely thermokarst, could both create and destroy lake habitats through ice wedge degradation and draining of thaw lakes (Martin et al. 2009). No other known climate-mediated disturbance events are likely to affect this species significantly in the timeframe of this assessment.

Pacific Loons do show some evidence of an inverse distribution relative to the much larger Yellow-billed Loon, which is probably driven by competitive exclusion. However, since Pacific Loons are so much more numerous, any population-level influence on abundance is probably insubstantial (J. Schmutz, pers. comm.)

Pacific Loon (*Gavia pacifica*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: Despite the existence of long-term data sets for loons in northern Alaska (Mallek et al. 2005) there is currently no assessment of phenology-related variables and, thus, it is not known how this species might respond to changing biotic schedules. However, Pacific Loon populations in Alaska have been relatively stable over the history of aerial abundance surveys (> 35 years; Groves et al. 1996).

In summary, the Pacific Loon will likely be able to adjust to climate and associated habitat changes predicted to occur in Arctic Alaska, at least during the 50 year timeline of this assessment.

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Yellow-billed Loon (*Gavia adamsii*)

Vulnerability: **Moderately Vulnerable** Confidence: Low

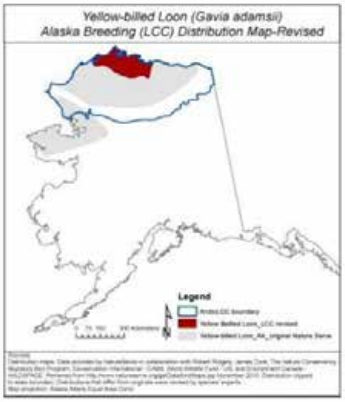
The Yellow-billed loon, the largest of the world's five loon species, and also the rarest, has one of the highest nesting densities in the world on the central Arctic Coastal Plain of Alaska (Earnst et al. 2005). In Alaska, this species typically breeds on the edges of relatively deep (>2 m), large (usu. >12 ha) fish-bearing lakes (http://alaska.fws.gov/). Little is known about their diet in Alaska, but they are believed to depend on several fish species, with cisco (*Coregonus* spp.) being the most important (J. Schmutz, pers. comm.). Although previously thought to winter off the coast of the Pacific Northwest, new evidence suggests the North American breeding population winters in East Asia from the western Kuril Islands to the Yellow Sea (J. Schmutz et al., unpublished data). Earnst et al. (2005) estimates that <1000 nesting pairs breed in n. Alaska.

Range: For this assessment, we modified the NatureServe map to more closely match the core breeding range of this species based on a recent study and expert opinion. In Arctic Alaska, Yellow-billed Loons principally occur in the large lake region of the National Petroleum Reserve - Alaska. Few nest east of the Colville River, west of the Meade River, or in the Brooks Range foothills (Earnst et al. 2005).

Physiological Hydro Niche: The Yellow-billed Loon scored as most vulnerable to climate change in the hydrological niche category ranging from "slightly" to "greatly increased". Since this species relies on large lakes for breeding a drying trend will not likely lead to loss of such lakes. In fact current patterns of permafrost melt indicate an increase in size of such lakes (Martin et al. 2009) yet recent evidence suggests a doubling of lake expansion results in a six fold increase in lake drainage (Grosse and Jones 2012). A drying trend or change in hydrology from increased thermokarst could limit fish colonization of lakes by restricting passage. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy lake habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009).

Human Response to CC: All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact this species by limiting fish passage due to insufficient bridge/culvert design associated with the road construction. At this point, there is little information to determine the significance of such a potential impact.



Physiological Thermal Niche: Yellow-billed Loons would unlikely be stressed thermally by an expected increase in temperature over the timeframe of this assessment. The rationale for this inference is simply based on the physical similarity to the congeneric Common Loon (*Gavia immer*), which appears essentially morphologically identical, yet breeds over a

Yellow-billed Loon (*Gavia adamsii*)

Vulnerability: **Moderately Vulnerable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)						*	
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*	*			
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation				*			
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

wider latitudinal gradient. It is possible that feather density is higher on Yellow-billed Loons, to deal with the colder water temperatures, which might cause heat stress if lake temperatures were substantially higher, but this is speculative.

Interactions with Other Species: Competition with Common Loons, more than habitat limitation, might be the more important climate threat for Yellow-billed Loons, if Common Loons expand northward (J. Schmutz, pers. comm.).

Dietary Versatility: Because Yellow-billed Loon diet may depend heavily on ciscos during the breeding season, they may have less flexibility in their diet compared to some other loon species. However, details of their diet are not well known.

Genetic Variation: This species is believed to have low genetic variability (A. McMillan, unpublished data) and so would be susceptible to climate-mediated impacts that stress them at the population level (e.g. disease outbreaks).

Phenological Response: Despite the existence of long-term data sets for loons in northern Alaska (Mallek et al. 2005), an assessment of phenology-related variables has not been a part of that effort, nor has not been examined, so it is currently unknown how this species will respond to changing biotic schedules.

In summary, the accumulation of potential sources of vulnerability, particularly with regard to this species dependence of fish-bearing lakes and their limited core range, yielded a result of "moderately vulnerable" for all three climate change projections we considered.

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Rough-legged Hawk (*Buteo lagopus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

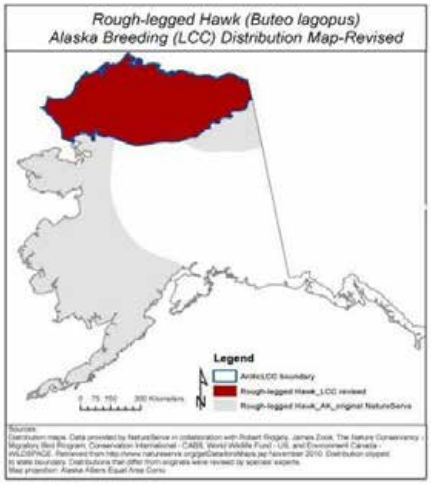
The Rough-legged Hawk is truly a hawk of the far north, with its breeding range largely restricted to arctic tundra and taiga habitats. In open tundra, this species typically places nests on steep outcroppings and cliff faces. Rough-legged Hawks rely on a diet of small mammals (mostly lemmings, voles) although a variety of birds are also eaten (Bechard and Swem 2002). On the coastal plain of Alaska they typically forage in open tundra and low-brush habitats (e.g. river floodplains) (Bechard and Swem 2002). Rough-legged Hawks spend their winters in southern Canada and throughout the lower 48 (Bechard and Swem 2002). The current global population is estimated at > 4 million (Rich et al. 2004).

Range: We modified the NatureServe range map for the assessment to include the entire Arctic LCC as suggested by the Birds of North America and other range descriptions (Bechard and Swem 2002, Johnson and Herter 1989).

Physical Habitat Restrictions: Among the indirect exposure and sensitivity factors in the CCVI (see table on next page), Rough-legged Hawks ranked neutral in most categories with the exception of "physical habitat restrictions" where they ranked "neutral" to "increased" vulnerability as this species is dependent on topographic relief (soil and rock bluffs, rock outcrops) for nest sites. However, they do occasionally nest on the ground or on human infrastructure (R. Ritchie, pers. comm.) showing some flexibility in nest site selection.

Physiological Thermal Niche: There is some anecdotal evidence that this species may prefer more southerly aspects in the Arctic LCC, particularly since they are free of snow sooner than north-facing bluffs/nesting areas (B. Ritchie, pers. comm.). However, it is unknown what temperature extremes (in either direction) would negatively impact reproductive success or preclude nesting.

Disturbance Regimes: In terms of disturbance regimes mediated by climate, increased fire (Racine et al. 2004) could change (improve) some foraging habitats, increasing accessibility to some taller brush or tussock tundra habitats, if foraging prey (microtine numbers) increase (B. Ritchie, pers. comm.).



Interactions with Other Species: Because they often rely on lemmings and voles as a food source, they may be affected by lemming population cycles. Climate change could increase the length of lemming population cycles and decrease maximum population densities (Ims and Fuglei 2005, Gilg et al. 2009). Currently there is no evidence to suggest that such climate-mediated changes in lemming abundance would negatively influence Rough-legged Hawk nest survivorship, distribution, and/or abundance. This species' more varied diet (compared to species that are much more closely

Rough-legged Hawk (*Buteo lagopus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*				
C2c. Disturbance regime		*	*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions			*	*	*		
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

tied to lemmings like Snowy Owl) suggest they would, in most cases, be able to compensate for such changes with little negative impact.

Phenological Response: There currently exists little or no information regarding the phenological constraints that would make this species more or less vulnerable to a warming climate.

In summary, the results of this assessment suggest Rough-legged Hawks will likely be able to adjust to climate and associated habitat changes predicted to occur in Arctic Alaska, at least during the next 50 years.

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Gyrfalcon (*Falco rusticolus*)

Vulnerability: **Highly Vulnerable** Confidence: Low

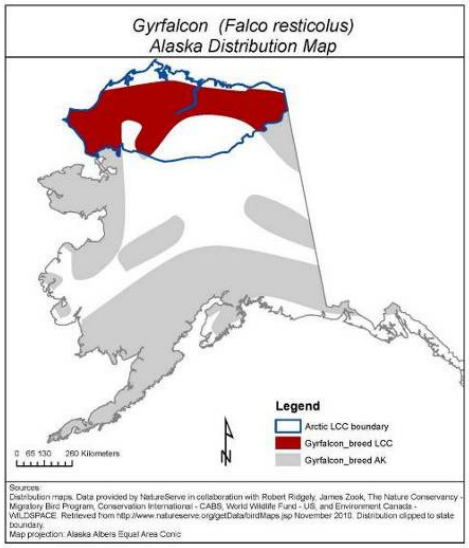
The Gyrfalcon, the largest falcon, is an iconic bird of the circumpolar arctic and subarctic. This species nests primarily on precipitous cliff faces and typically utilizes nests built by other species (particularly Common Raven, Golden Eagle, and Rough-legged Hawk) (Booms et al. 2008). Gyrfalcon main prey includes bird species ranging in size from passerines to geese while ptarmigan are the preferred prey. Although not well documented, in winter this species moves south throughout Canada and sometimes into the northern lower 48. Current population on the North Slope (*tundrius* subspecies) is estimated at 250 breeding pairs (USFWS 2000).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (Booms et al. 2008) and other sources (Johnson and Herter 1989).

The results of this assessment suggest that Gyrfalcon may be quite vulnerable to climate change due to factors mostly related to their narrow ecological niche that includes a specialized diet and nesting requirements (see table on next page).

Biotic Habitat Dependence: In late winter and early spring when females are producing eggs, the species is completely dependent on one species of ptarmigan (either Willow or Rock Ptarmigan depending on the region). Some ptarmigan populations, in turn, exhibit cyclical changes in numbers (Mossop and Hayes 1994) which could be altered due to climate change.

Physical Habitat Restrictions: Gyrfalcons select cliff wall nest sites which, for the most part, are rare microsites in the Arctic LCC. The rareness of these sites is further exacerbated by the fact that this species regularly uses stick nests made by other bird species; as such sites may provide higher nest success or other advantages (T. Booms, pers. comm.). Gyrfalcons also have at least some sensitivity to thermal conditions, evidenced by the fact that they do not breed below 55 degrees latitude. It is possible that warmer temperatures (particularly at nest sites on south-facing slopes) could influence nesting site preference.



Disturbance Regime: In terms of climate-mediated disturbances, Gyrfalcons require dry or "normal" spring conditions to successfully hatch young. An increase in spring storms would likely reduce nest success. In addition, this species is known to be highly susceptible to a wide variety of pathogens. The introduction of a new pathogen to the current regime could have drastic effects on survival (T. Booms, pers. comm.). Spread of shrub habitats northward (Tape et al. 2006) will likely reduce available upland tundra and open land foraging habitats.

Phenological Response: Gyrfalcons have relatively low genetic variation (Johnson et al. 2009) making them susceptible to climate-mediated impacts that stress them at the population level (e.g. disease outbreaks).

A 30 year dataset from the Yukon shows

Gyrfalcon (*Falco rusticolus*)

Vulnerability: **Highly Vulnerable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime			*	*	*		
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions				*	*		
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility					*		
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation				*			*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*	*	*		*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

that Gyrfalcons are nesting 20 days later and have declined by 40% in occupancy. Ptarmigan have apparently stopped cycling in this study area, possibly caused by climate change. This is likely creating a phenological mismatch linked to the later nesting (D. Mossop, unpublished data). A recent modeling effort indicates that the future Gyrfalcon range in Alaska could decrease substantially (Booms et al. 2011).

In summary, the accumulation of sources of potential vulnerability, particularly with regard to specialization in diet, nesting patterns and new modeling studies suggest this species is highly vulnerable to climate changes in the Arctic LCC.

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Peregrine Falcon (*Falco peregrinus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

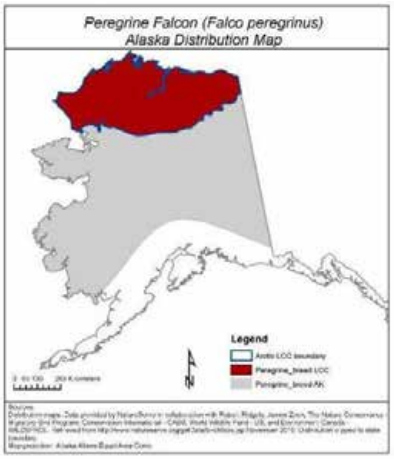
The Peregrine Falcon is one of the most ubiquitous bird species with a breeding distribution ranging from tundra to the tropics. In Arctic Alaska this bird's breeding stronghold is found in major river systems where cliff ledges abound and serve as preferred nesting sites. Peregrine Falcons prey on a wide variety of bird species ranging from small passerines to medium-sized ducks and will also take small mammals (White et al. 2002). This species travels widely and Arctic-breeding Peregrine Falcons make some of the longest migrations of any bird species. The North American subspecies (*tundrius*) winters in Central and South America (White et al. 2002). The global population is estimated at ~1.2 million individuals (BirdLife International 2012).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (White et al. 2002) and other sources (Johnson and Herter 1989). It is important to note that breeding is most dense along rivers, especially through the Brooks Range foothills (B. Ritchie, Pers. comm.).

Human Response to CC: Power lines associated with more all-weather roads (necessitated by a warming climate and shortened ice road season) for energy extraction activities could result in more collision fatalities; although their hunting styles and flight behaviors should reduce the potential for this (B. Ritchie, pers. comm.).

Physiological Thermal Niche: Because this species has a widely distributed breeding range across a broad thermal gradient in North America and elsewhere, negative effects of warming are unlikely. This species could actually benefit from warming temperatures, reducing stress related to early season cold temperatures.

Physiological Hydro Niche: Peregrine Falcons use a range of wet to dry habitats as foraging grounds. Wetter habitats can be particularly important during key times of the breeding season and during post-breeding. A tundra drying trend could have some negative effects, but this species would likely be able to effectively utilize drier habitats. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment.



Disturbance Regime: In terms of climate-mediated disturbance, increased fire frequency (Racine and Jandt 2008) may both create and destroy favorable hunting habitat. Similarly, thermokarst, through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009) could both create and reduce nesting sites on deep lakes and wetland foraging sites.

Physical Habitat Restrictions: Although Peregrine Falcons primarily rely on relatively limited nesting sites in the Arctic LCC (e.g. cliff ledges, riparian cliffs, nests built by other species), they also exhibit flexibility using dirt bluffs, eroding banks, and recently, oil field and

Peregrine Falcon (*Falco peregrinus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*			
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*	*	*			
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation			*				
C5b. Genetic bottlenecks							*
C6. Phenological response			*				*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

other human infrastructure for nest substrates (B. Ritchie, pers. comm.).

Genetic Variation: Peregrine Falcons have average genetic variation (White and Boyce 1988), reducing susceptibility to climate-mediated impacts that stress them at the population level (e.g. disease outbreaks) compared to species with lower genetic variation.

Phenological Response: Although there has been some long-term monitoring of nesting Peregrine Falcons in Arctic Alaska (Swem and Matz 2011), effects on phenological factors in response to changing climate have not been examined.

In summary, despite some identified vulnerabilities this assessment suggests that Peregrine Falcons will likely be able to adjust to the climate changes predicted to occur in Arctic Alaska in the next 50 years.

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Black-bellied Plover (*Pluvialis squatarola*)

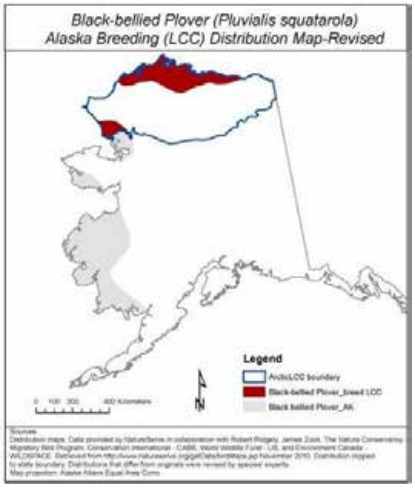
Vulnerability: **Presumed Stable** Confidence: Moderate

The Black-bellied Plover breeds regularly in Arctic Alaska with the highest numbers concentrated in the central portion of the Arctic Coastal Plain (Johnson et al. 2007). In general, this species tends to choose dry habitats for nesting such as dry heath tundra, exposed ridges, and river banks. They will occasionally nest in wetter tundra habitats but tend to select drier microsites (Paulson 1995). Black-bellied Plovers search for invertebrate prey visually on open tundra during the breeding season. This species winters along the coastlines of North America from southern Canada to Middle America (Paulson 1995). Current Alaska population estimate (*P. s. squatarola*) is 50,000 with a declining population trend (Morrison et al. 2006).

Range: We modified the NatureServe range map by expanding the breeding range slightly to the west in the Arctic Coastal Plain based on recent findings (Bart et al. 2012).

Physiological Hydro Niche: Among the factors (see table on next page), Black-bellied Plover ranked "neutral" in many categories. Scores for physical hydrological niche ranged from "decreased to increased vulnerability." This range represents uncertainty both in the direction and intensity of change in arctic hydrology, as well as in the effect this will have on the plover (less or greater vulnerability). If significant tundra drying occurs, this species could experience loss of preferred wet foraging habitat (Bart et al. 2012), although they commonly utilize drier foraging habitats (Paulson 1995). Because they often nest in drier tundra, they may actually benefit from large-scale tundra drying. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. Complex hydrological processes could ameliorate or exacerbate a drying trend (Martin et al. 2009).

Historical Hydro Niche: Conversion of ice roads to all-weather roads, could impact hydrology at local and regional scales (Jorgensen et al. 2010). These changes to hydrology can affect the shallow tundra wetlands in which Black-bellied Plovers forage, reducing water levels, soil moisture and invertebrate abundance.



Disturbance Regime: Climate-mediated thermokarst, could both create and destroy nesting and foraging habitats (Martin et al. 2009).

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Post et al. 2009) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Dietary Versatility: Plovers have a flexible diet and current evidence suggests they take advantage of a wide variety of prey (Paulson 1995) so they would likely not face any negative impacts from a changing prey base.

Black-bellied Plover (*Pluvialis squatarola*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*	*			
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche		*	*	*	*		
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence							
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				*
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: The timing of breeding in this species is closely tied to snow melt at some sites (Smith et al. 2010) and so they may or may not be vulnerable to climate changes that alter snow melt patterns.

In summary, Black-bellied Plovers have enough versatility in their life history traits and behaviors on the breeding grounds that will likely enable them to cope and their populations to remain "stable" with regard to climate change at least during the timeframe of this assessment (to 2050).

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American Golden-plover (*Pluvialis dominica*)

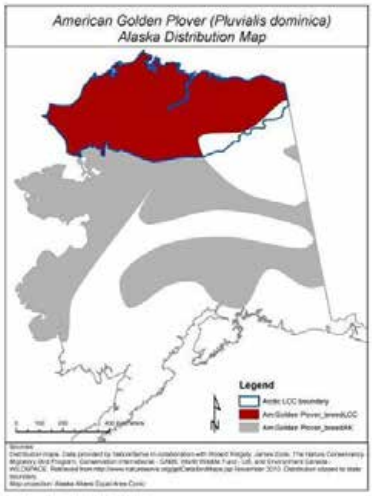
Vulnerability: **Presumed Stable** Confidence: Moderate

The American Golden-plover is a conspicuous breeding bird in Arctic Alaska with slightly higher density in the Brooks Range foothills compared to the coastal plain (Johnson et al. 2007). In general, this species tends to nest in upland dry habitats, quite often near wetland areas (Johnson and Connors 1996). Like other plovers, American Golden-plovers search for invertebrate prey visually and forage in a mix of wet to dry tundra during the breeding season. This species winters primarily in the southern portion of South America (Johnson and Connors 1996). Current North American population estimate is 200,000 with a declining trend (Morrison et al. 2006).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (Johnson and Connors 1996) and other range descriptions (Johnson and Herter 1989, Johnson et al. 2007).

Physiological Thermal Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), American Golden-plover ranked "neutral", in many categories. In the physiological hydrologic niche category there was broad range of scores from neutral to increased vulnerability. This range represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the plover. If significant tundra drying occurs, this species could experience loss of wet foraging habitat, although they commonly utilize a mix of both dry and wet foraging habitats (Johnson and Connors 1996). Because they typically nest in drier tundra, they may actually benefit from large-scale tundra drying. Current projections of annual potential evavapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor was not heavily weighted in the assessment.

Disturbance Regime: Disturbance processes, such as climate-mediated thermokarst could both create and destroy nesting and foraging habitats. Fire frequency in the foothills is likely to increase (Racine and Jandt 2008), reducing soil moisture and potentially diminishing availability of invertebrate prey. Fires could also reduce nesting site availability (Martin et al. 2009). In the foreseeable future, fire will likely only affect a small portion of the landscape and thus not significantly impact plover habitat.



Interactions with Other Species: Climate changes may reduce the amplitude of lemming cycles making them less available as alternative prey (Ims and Fuglei 2005) and thus could expose this species to greater nest predation.

Dietary versatility: Plovers have a flexible diet and current evidence suggests they take advantage of a wide variety of prey (Johnson and Connors 1996) so they would likely not face any negative impacts from a changing prey base.

Phenological Response: Although not demonstrated in American Golden-plovers, there is evidence suggesting shorebirds are able to

American Golden-plover (*Pluvialis dominica*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation				*			*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

shift their nest initiation dates in response to climate warming (J. Liebezeit and S. Zack, unpublished comm.). However, it is unknown if they can synchronize timing to match potentially changing schedules of invertebrate prey.

Genetic Variation: Shorebird species are believed to have low genetic variation (Baker and Stauch 1988) and thus potentially would be more vulnerable to certain climate-mediated events in the near future (e.g. disease outbreaks).

In summary, American Golden-plovers have enough versatility in their life history traits and behaviors on the breeding grounds that will likely enable them to cope and remain "stable" with regard to climate change at least during the timeframe of this assessment (to 2050).

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Whimbrel (*Numenius phaeopus*)

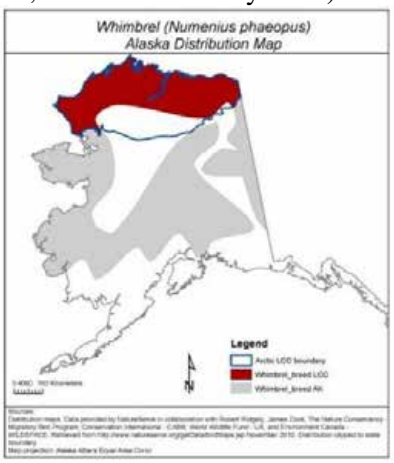
Vulnerability: **Presumed Stable** Confidence: High

The Whimbrel is one of the larger breeding shorebirds in Arctic Alaska, occurring in both taiga and tundra habitats. In Arctic Alaska, this species nests in a variety of tundra habitats ranging from lowland wet polygonal to well-drained moist upland tundra, sometimes with significant shrub cover (Skeel and Mallory 1996). During the breeding season, Whimbrel will visually search for prey in wet to dry tundra habitats. This species winters along North American coastlines, mainly from the southern U.S. to South America (Skeel and Mallory 1996). Current North American population estimate is 66,000 (Morrison et al. 2006).

Range: We used the extant NatureServe range map for this assessment as it closely matched that of the Birds of North America (Skeel and Mallory 1996). However, it should be noted recent studies from Alaskan Arctic have indicated Whimbrel distribution is centered in the Brooks Range foothills and that they are largely absent in wet sedge dominated habitat closer to the Arctic Ocean coastline (Johnson et al. 2007, Bart et al. 2012).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Whimbrel scored "neutral" in many categories. In the physiological hydrologic niche category there was broad range of scores from slightly decreased to increased vulnerability. This range represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the Whimbrel (less or greater vulnerability). Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. Also, complex hydrological processes could ameliorate or exacerbate the drying trend (Martin et al. 2009).

Biotic Habitat Dependence: The uncertainty also reflects this species' relatively flexible nesting and foraging behavior. Although they tend to occupy more well-drained sites in general, they do commonly utilize a mix of both dry and wet foraging habitats and will nest in wet tundra as well (although tend to select drier microsites; Skeel and Mallory 1996).



Disturbance Regime: Climate-mediated disturbance processes, such as thermokarst, could both create and destroy nesting and foraging habitats. Fire frequency is likely to increase (Racine et al. 2004), potentially diminishing availability of invertebrate prey. Fires could also reduce nest site availability. In the foreseeable future, fire will likely only affect a small portion of the landscape and thus not significantly impact Whimbrel habitat.

Interactions with Other Species:
Climate changes may reduce the amplitude of lemming cycles making them less available as alternative prey (Ims and Fuglei 2005) and thus could expose this species to greater nest predation.

Dietary Versatility: This species has a flexible diet and current evidence suggests they take advantage of a wide variety of prey (Skeel and

Whimbrel (*Numenius phaeopus*)
Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*	*		
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response			*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Mallory 1996) so they would likely not face any negative impacts from a changing prey base.

Phenological Response: Although not demonstrated in Whimbrel, there is evidence suggesting some shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to other organisms changing schedules that they depend on (e.g. invertebrate prey).

In summary, Whimbrel appear to have enough versatility in their life history traits and behaviors on the breeding grounds that will likely enable them to cope and remain "stable" with regard to climate change at least during the timeframe of this assessment (to 2050).

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Bar-tailed Godwit (*Limosa lapponica*)

Vulnerability: **Presumed Stable** Confidence: High

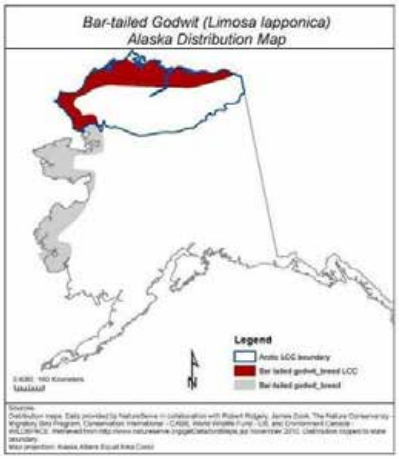
The Bar-tailed Godwit completes one of the most incredible journeys of any bird species, traveling non-stop across the Pacific Ocean from Alaska to Australia and New Zealand during its fall migration. In Arctic Alaska, this species is found most commonly west of the Colville River and is particularly frequent in the Brooks Range foothills (Johnson et al. 2007). On the North Slope, Bar-tailed Godwits nest in moist tussock tundra near wetlands to wet sedge meadows (McCaffery and Gill 2001). They typically forage in shallow, flooded areas on insects but will eat berries upon arrival to breeding grounds (McCaffery and Gill 2001). Current population estimate for North American breeders (*baueri* subspecies) is 90,000 with a declining trend (Morrison et al. 2006).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (McCaffery and Gill 2001) and other sources (Bart et al. 2012, Johnson et al. 2007).

Physiological Hydrologic Niche: Conversion of ice roads to all-weather roads, a possible consequence of reduced suitability of winter snow and ice conditions, could impact hydrology at local and regional scales. Shallow tundra wetlands can be adversely affected by road construction and potentially impact availability of invertebrate prey. The extent of such activities will likely be localized.

Physiological Thermal Niche: Compared to other arctic shorebirds, Bar-tailed Godwits breed over a relatively wide latitudinal gradient both near and far from marine shorelines, thus there is no evidence to suggest that they have any thermal sensitivity during nesting. They could actually benefit from warmer temperatures at the northern terminus of their breeding range via reduction in cold stress.

Physical Habitat Restrictions: Although Bar-tailed Godwits do exploit a range of upland to wet tundra habitats for nesting, they depend on water-dominated habitats for foraging during both breeding and post-breeding and so may be negatively impacted by a net drying trend. Because of their flexible habitat use they may be able to better adjust to utilizing drier habitats compared to other shorebird species. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor was not heavily weighted in the assessment.



Disturbance Regime: Disturbance processes, specifically thermokarst-mediated changes on the landscape, could both destroy and create new nesting and foraging habitat (Martin et al. 2009). More frequent tundra fires (Racine and Jandt 2008) could reduce nesting and foraging habitat although tundra fires will likely be a localized phenomena in the near future.

Interactions with Other Species:
Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Bar-tailed Godwit (*Limosa lapponica*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: There is evidence suggesting some shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data; D. Ward, pers. comm.). However, currently there is no examination of this with Bar-tailed Godwits.

In summary, Bar-tailed Godwits appear to have enough versatility in their life history attributes to enable them to compensate for changes and remain "stable" with regard to climate change at least during the timeframe of this assessment (next 50 years).

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Ruddy Turnstone (*Arenaria interpres*)

Vulnerability: **Moderately Vulnerable** Confidence: Low

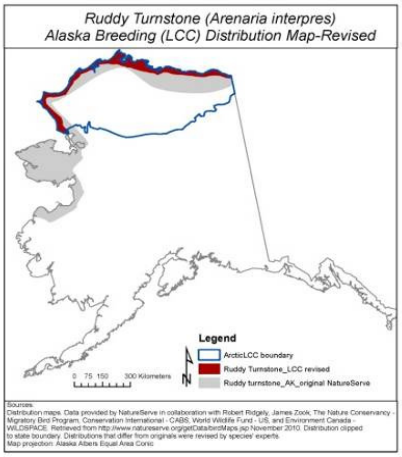
The Ruddy Turnstone, named after its habit of turning over stones and other objects in search of prey, occurs throughout the circumpolar arctic. In Alaska, this species typically nests in barren halophytic, sparsely vegetated sites (Bart et al. 2012, Nettleship 2000), usually near the coast or along rivers, and rarely inland (Johnson et al. 2007). During the breeding season, Ruddy Turnstones feed primarily on dipteran insects obtained in dry to wet habitats near ponds and streams and often along pond margins (Nettleship 2000). This species winters along both coasts of North America in the west from northern California down into South America (Nettleship 2000). Current population estimate for Alaska is 20,000 (Morrison et al. 2006) and for the North Slope is likely <10,000 (Bart et al. 2012).

Range: We modified the Nature Serve range map for the assessment to better match the more coastally oriented breeding range depicted in the Birds of North America account (Nettleship 2000) as well as accounts described from other sources (Johnson et al. 2007; P. Bruner, pers. comm.). This species is generally patchily distributed along the coast and near major river corridors. It appears to be quite rare in western Arctic Alaska (Johnson et al. 2007).

Sea Level Rise & Natural Barriers: Because of this species' restricted range along low-lying coastal areas in Arctic Alaska they were ranked as being slightly vulnerable to both sea-level rise and to limitations in expansion of their range northward ("natural barriers" factor).

Human Response to CC: Conversion of ice roads to all-weather roads, a possible consequence of reduced suitability of winter snow and ice conditions, could impact hydrology at local and regional scales. Shallow tundra wetlands can be adversely affected by road construction and potentially impact availability of invertebrate prey or other factors. The extent of such activities will likely be localized.

Physiological Thermal Niche: Ruddy Turnstones have a stronger association with both coastal and high arctic breeding habitats compared to many other Arctic Alaskan shorebirds suggesting they may have higher sensitivity to warming temperatures.



Physiological Hydro Niche: Ruddy Turnstones forage near water bodies and are dependent on the emergence of aquatic insects during the breeding season (Nettleship 2000). In dry years, they may forgo nesting, apparently due to limited prey supply (P. Bruner, pers. comm.). If tundra drying occurs, slight changes in moisture regime could have substantial impacts on tundra wetlands. Current projections of annual evapotranspiration suggest negligible atmospheric drying for the foreseeable future (TWS and SNAP). Thus moisture balance, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Disturbance Regime: Because they often nest coastally or near rivers, Ruddy Turnstones are

Ruddy Turnstone (*Arenaria interpres*)

Vulnerability: **Moderately Vulnerable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*	*			
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime		*	*	*	*		
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*	*				
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

particularly susceptible to flooding events which will likely increase as storm frequency and severity in the arctic increases (Jones et al. 2009). Other climate-mediated disturbance processes, such as thermokarst, could both create and destroy nesting and foraging habitats.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Phenological Response: Although not demonstrated in turnstones, there is evidence suggesting some shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data; D. Ward, pers. comm.). However, it is unknown if they can adjust timing to the changing schedules of the other organisms on which they depend (e.g. invertebrate prey).

In summary, this species' dependence on coastal and riverine habitats combined with other sources of vulnerability yielded a ranking of "moderately vulnerable" in this assessment.

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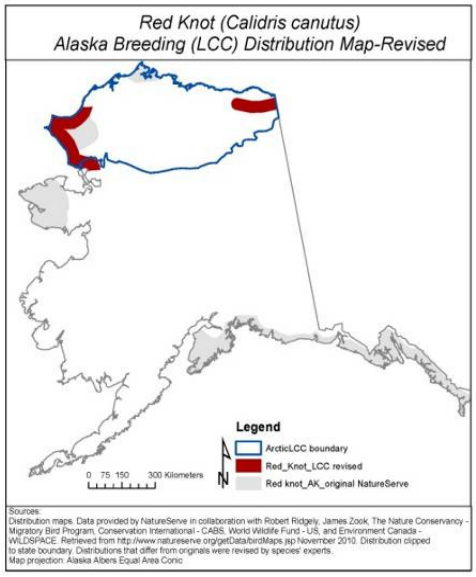
Red Knot (*Calidris canutus*)
Vulnerability: **Presumed Stable** Confidence: High

The Red Knot, *roselaari* subspecies, is a relatively uncommon breeding shorebird in Arctic Alaska. They typically nest in coastal alpine habitats, preferring sparsely vegetated and broad alpine ridgelines and dome tops (Harrington 2001, J. Johnson, pers. comm.). There is little information on breeding season diet in this species however; field observations suggest a varied diet from insects to plant materials (e.g., lichens, leaves, berries) (Harrington 2001). During May, knots occur in coastal lagoons adjacent to suitable nesting habitats. These lagoons apparently serve as foraging and resting sites preceding dispersal to nesting areas (J. Johnson, pers. comm.). This subspecies winters at sites along the Pacific Coast from California down into Central America. Current population estimate for *roselaari* is 20,000 (Morrison et al. 2006) although newer estimates place it at approximately 17,000 (J. Lyons, unpublished data).

Range: We modified the NatureServe breeding range map based on new evidence and expert opinion (J. Johnson, unpublished data). We removed the Barrow breeding area as there is no recent evidence of breeding there. We constrained the western portion of their breeding range to within 50km of the coast based on their association with coastal alpine habitats and recent surveys (J. Johnson, unpublished data). Finally, we included breeding range in the northeastern Brooks Range within the Arctic Refuge as there is strong suspicion of nesting there (J. Johnson, pers. comm.).

Physiologic Thermo Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Red Knots ranked neutral in most categories. This species is associated with cold-adapted alpine habitats and so it may be sensitive to changes in thermal conditions (i.e. warming) that are likely to occur in this region (http://www.snap.uaf.edu/).

Physical Habitat Restrictions: Although Red Knots nest in relatively arid habitats some individuals (>50%) that nest near the coast forage in coastal habitats throughout the breeding season. Also, just prior to breeding they depend on coastal lagoons for foraging and resting which may provide a temporal buffer for knots that arrive when inland sites are still covered by snow (J. Johnson, pers. comm.). Like other shorebirds, Red Knots utilize coastal habitats post-breeding as well (J. Johnson, unpublished data, Taylor et al. 2010). Loss or alteration of coastal lagoons as a result of climate-mediated erosion and overwash from increased storm frequency (Jones et al. 2009) would likely have an adverse effect on knots.



Dietary Versatility: Red Knots have an omnivorous diet and current evidence suggests they can take advantage of a wide variety of prey and so would likely not be impacted by changes in prey base associated with climate change.

Red Knot (*Calidris canutus*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*	*				
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey. In addition, this species will communally feed and flock with other shorebirds during breeding and migration and will join other shorebird species in mobbing potential predators during the nesting season (Harrington 2001) but it is unknown if these behaviors increase species persistence.

Phenological Response: Although not demonstrated in Red Knots, there is evidence suggesting shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to other organisms changing schedules that they depend on (e.g. invertebrate prey).

In summary, Red Knots will likely experience some negative impacts from climate change however these will be slight and, overall, they have enough versatility in their life history traits and behaviors and remain "stable" with regard to climate change at least during the timeframe of this assessment (to 2050).

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Semipalmated Sandpiper (*Calidris pusilla*)

Vulnerability: **Presumed Stable** Confidence: High

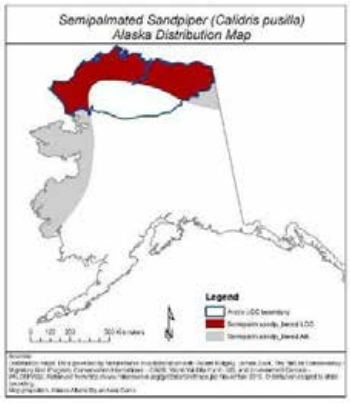
The Semipalmated Sandpiper is likely the most abundant breeding shorebird on the Arctic Coastal Plain of Alaska, with the highest densities occurring in the western portion of the coastal plain (Johnson et al. 2007). In Arctic Alaska, this species nests in a range of upland dry to moist and wet tundra habitats near water and typically focus their foraging along marsh and pond edges (Gratto-Trevor 1992). The current North American population estimate is 2 million (Morrison et al. 2006). While the Alaska breeding population appears to be stable, there is evidence that eastern Semipalmated Sandpiper populations are declining (Andres et al. 2012).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (Gratto-Trevor 1992) and other sources (Johnson et al. 2007, Bart et al. 2012).

Physical Habitat Restrictions: Among the indirect exposure and sensitivity factors (see table on next page), Semipalmated Sandpipers scored "neutral", in many categories. Although this species breeds primarily on the coastal plain in the Arctic LCC assessment area, they do occur well inland and so sea level rise impacts will likely be minimal and their ability to shift range (e.g. in response to habitat changes) will not be significantly compromised.

Physiological Hydro Niche: Although this species relies on water-dominated habitats for foraging, they often utilize moist to dry tundra for nesting. For this reason, the physiological hydrologic niche category was scored only as "slightly increased" vulnerability. Significant tundra drying could certainly have an impact on their foraging habitats. However, current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy good foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes. Likewise, increased coastal erosion and resulting salinization (Jones et al. 2009) could both negatively and positively affect post-breeding staging birds by destroying and creating foraging habitat.



Dietary Versatility: Semipalmated Sandpipers have a flexible diet and evidence suggests they take advantage of a wide variety of invertebrate prey (Gratto-Trevor 1992) so they would likely not face negative impacts from a changing prey base.

Interactions with Other Species: In terms of dependence on interspecific interactions, this species will communally feed and flock with other shorebirds during post- breeding staging (Taylor et al. 2010), but it is unknown if these behaviors increase species persistence. Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Semipalmated Sandpiper (*Calidris pusilla*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation			*				
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Genetic Variation: Little is known about Semipalmated Sandpiper genetics although, in general, many shorebird species are believed to have low genetic variation (Baker and Stauch 1988) and thus potentially would be more vulnerable to certain climate-mediated events in the near future (e.g. disease outbreaks). However, at this time, there is no support for low genetic variation for this species.
Phenological Response: There is evidence suggesting that this species is able to track phenological changes associated with a warming climate at least with respect to nest initiation (J. Liebezeit and S. Zack unpublished data, D. Ward, pers. comm.). However, it is unknown if they can synchronize timing with other organisms they depend on (e.g. invertebrate prey).

In summary, despite some potential sources of vulnerability, Semipalmated Sandpipers will likely be able to compensate for most and remain "stable" with regard to climate change at least during the timeframe considered by this assessment.

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Western Sandpiper (*Calidris mauri*)

Vulnerability: **Presumed Stable** Confidence: Low

The Western Sandpiper is one of the most abundant sandpipers in the western hemisphere. In Alaska, the core of its breeding population is in the Yukon-Kuskokwim River Delta. It also breeds less commonly in the western portion of the North Slope (Johnson et al. 2007). This species nests in well-drained moist to upland tundra habitats dominated by dwarf shrubs and tussock grasses (Wilson 1994). During the breeding season Western Sandpipers typically forage on aquatic insects in wet tundra habitats and along pond edges near nesting areas, but occasionally forage on terrestrial arthropods as well (Wilson 1994). This species winters along the west coast of North America from California to Peru (Wilson 1994). Current population estimate for North America is 3.5 million with a declining trend (Morrison et al. 2006).

Range: We modified the NatureServe range map to more closely match the Birds of North America map and evidence from recent studies that suggest greater usage of inland sites in the western portion of the coastal plain (Bart et al. 2012, Johnson et al. 2007).

Physiological Hydro Niche: Because Western Sandpipers use wet tundra habitats to some degree, primarily for foraging during both the breeding season and during post-breeding staging they were scored as "neutral-to-increased" vulnerability in the "physiological hydrologic niche" category (see table). Drying of wet tundra habitats could reduce invertebrate availability. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential for "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Human Response to CC: Shoreline armoring related to climate change mitigation could reduce the availability of staging habitats this species uses prior to fall migration. However, shoreline armoring would be limited to existing communities or infrastructure, which is limited in extent at present and thus impacts would be slight.

Physiological Thermal Niche: The heart of the Western Sandpiper breeding range is in the sub-arctic and so presumably, as arctic temperatures rise, themal conditions could become more amenable for expansion of their breeding range into more of the coastal plain potentially increasing competition with the closely related Semipalmated Sandpipers.

Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy lake habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Increased fire frequency (Racine and Jandt 2008) could reduce habitat suitability required by the species for nesting, although for the timeline of this assessment fires will likely be localized phenomenon. Increased coastal erosion and resulting salinization (Jones et al. 2009) could impacts post-breeding staging birds.

Interactions with Other Species: In terms of interspecies interactions, this species will communally feed and flock with other shorebirds during post-breeding staging (Taylor et al. 2010), but it is unknown if these behaviors increase species persistence. Climate change

Western Sandpiper (*Calidris mauri*)

Vulnerability: **Presumed Stable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation				*			
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Phenological Response: There is evidence suggesting some shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to other organisms changing schedules that they depend on (e.g. invert. prey).

In summary, while a few potential sources of climate-related vulnerability were identified for this species, the assessment presumes that Western Sandpiper will be stable in this region at least for the next few decades.

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White-rumped Sandpiper (*Calidris fuscicollis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

The White-rumped Sandpiper is a small shorebird that is a relatively rare breeder in Arctic Alaska. They nest in coastal wetlands between Barrow and Cape Halkett on the Arctic Coastal Plain of Alaska (Bart et al. 2012). In eastern Canada this species is similarly associated with coastal wetlands (Smith et al. 2007), but may also use moist tundra or even dwarf shrub tundra for nesting (Parmelee 1992). White-rumped Sandpipers have one of the longest migrations of any bird species and winter primarily in southern South America east of the Andes (Parmelee 1992). Current estimate of the North American population is 1.12 million with a declining trend (Morrison et al. 2006).

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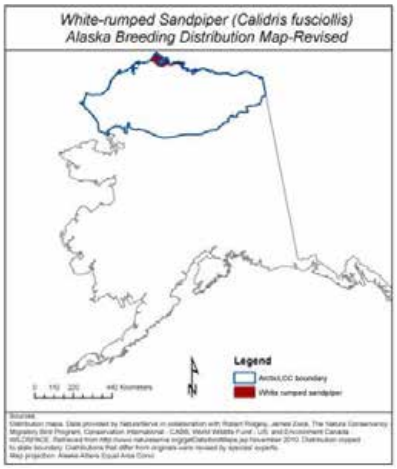
Range: We modified the NatureServe range map for this assessment, restricting this species breeding range to the region around Barrow. We based this adjustment on recent studies that suggest the Birds of North America range is no longer accurate (Johnson et al. 2007, Bart et al. 2012).

Sea Level Rise & Natural Barriers: Because of this species' restricted range along low lying coastal areas on the coastal plain they were ranked as being "slightly vulnerable" to both sea-level rise and to limitations in expansion of their range northward ("natural barriers" factor).

Human Response to CC: Conversion of ice roads to all-weather roads, a possible consequence of reduced suitability of winter snow and ice conditions, could impact hydrology at local and regional scales. Shallow tundra wetlands can be adversely affected by road construction and potentially impact availability of invertebrate prey. The extent of such activities will likely be localized.

Physiological Thermal Niche: White-rumped Sandpipers select concealed nest sites, sheltered from the wind (Smith et al. 2007) indicating they may have some sensitivity to changing thermal conditions.

Physiological Hydro Niche: Because this species depends heavily on coastal tundra habitats, hydrological niche was their greatest potential source of vulnerability. The range of scores represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the sandpiper. Slight changes in moisture regime or active layer depth can have substantial impacts on tundra wetlands, because they are generally shallow. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.



Disturbance Regime: Disturbances, specifically coastal erosion and increased coastal flooding from increased storms (Jones et al. 2009) may negatively impact both breeding and post-breeding White-rumped Sandpipers. However, such coastal disturbance events, as well as thermokarst-mediated changes on the landscape, could create new nesting and foraging habitat.

White-rumped Sandpiper (*Calidris fuscicollis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise				*			
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*	*			
C2bi. Historical hydro niche (GIS)						*	
C2bii. Physiological hydro niche		*		*	*		
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Interactions with Other Species: In terms of dependence on interspecific interactions, this species will communally feed and flock with other shorebirds during post-breeding staging (Taylor et al. 2010) but it is unknown if these behaviors increase species persistence. Climate change may reduce the amplitude of lemming cycles (Post et al. 2009) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

In summary, White-rumped Sandpipers will likely experience some negative impacts from climate change, however they appear to have enough versatility in their life history traits and behaviors to remain "stable" with regard to climate change at least during the timeframe of this assessment (to 2050).

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Baird's Sandpiper (*Calidris bairdii*)

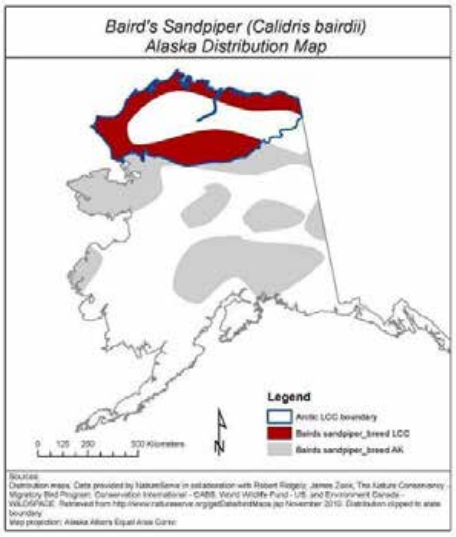
Vulnerability: **Presumed Stable** Confidence: High

The Baird's Sandpiper is an uncommon breeding bird in Arctic Alaska using both coastal and montane regions. This species typically nests in upland, well-drained, exposed tundra, generally avoiding wet tundra although will sometimes nest in wet prairie meadows near lakes (Marconi & Salvadori 2008). Like other sandpipers, Baird's Sandpipers feed almost entirely on insects during the breeding season adjusting to seasonal shifts in primary prey items (Moskoff and Montgomerie 2002). This species is a long-distance migrant and winters throughout the southern cone of South America. Current population estimate is 300,000 (Morrison et al. 2006).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (Moskoff and Montgomerie 2002) and other sources (Johnson and Herter 1989). However, it should be noted that the breeding range may be more restricted than previously thought because of their preference for well-drained stony ridges and riparian nesting habitat (Johnson et al. 2007).

Physiological Thermal Niche: Among the indirect exposure and sensitivity factors in this assessment (see table on next page), Baird's Sandpiper ranked "neutral", in many categories. For three categories they ranked as "neutral to slightly increased" vulnerability. This species, particularly in Arctic Canada, nests in relatively higher latitude sites therefore it is possible that they are associated with a colder thermal environment; however this pattern is less discernable in Alaska.

Physiological Hydro Niche: At a site in Canada, Marconi and Salvadori (2008) suggest that Baird's may nest preferentially in wet prairie meadow, however previous observations at the same site suggested that Baird's generally nest in drier shrubby areas (Lepage et al. 1998) as generally appears to be the case in Alaska. This suggests that a tundra drying trend could have some negative impact on this species but they will most likely be able to adjust to drier nesting sites. They do depend on water-dominated habitats for foraging during both breeding and post-breeding so this may be more important in terms of a tundra drying impacts. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.



Interactions with other Species: Changes in lemming cycling could negatively impact this species indirectly through increased nest predation if lemming population booms become rarer (Ims and Fuglei 2005). However, there is currently no evidence that Baird's are affected by lemming cycles.

Phenological Response: Baird's were ranked from "slightly decreased" to "increased"

Baird's Sandpiper (*Calidris bairdii*)
Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC		*	*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*	*		*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

vulnerability to phenology changes. At present, it is unknown how this species will respond. A mismatch in timing would likely be negative for nesting (Schekkeman and Tulp 2008) or they may be able to track changes and take advantage of the positive benefits of earlier nesting.

Disturbance Regime: Disturbance processes, specifically thermokarst-mediated changes on the landscape could both destroy and create new nesting and foraging habitat. More tundra fires could theoretically increase nesting habitat by speeding up shrub invasion.

In summary, Baird's Sandpipers appear to have enough versatility in their life history attributes to enable them to compensate for changes and remain "stable" with regard to climate change at least during the timeframe of this assessment (next 50 years).

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Pectoral Sandpiper (*Calidris melanotos*)

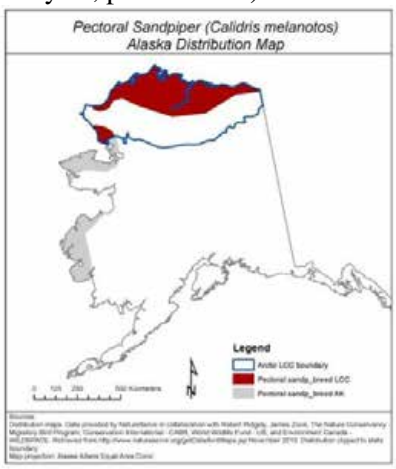
Vulnerability: **Presumed Stable** Confidence: High

The Pectoral Sandpiper is one of the most abundant breeding birds on the Arctic Coastal Plain of Alaska. They typically have low nest site fidelity which is likely related to their promiscuous mating strategy, thus nest densities are highly variable from year to year at a given site (Holmes and Pitelka 1998). In Arctic Alaska, primary breeding habitat includes low-lying ponds in a mix of marshy to hummocky tundra and nests are typically placed in slightly raised or better drained sites (Holmes and Pitelka 1998). Pectoral Sandpipers spend their winters primarily in southern South America (Holmes and Pitelka 1998). The current North American population estimate is 500,000 and they are believed to be declining (Morrison et al. 2006).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America (Holmes and Pitelka 1998). It should be noted that in Alaska the highest densities occur in the western portion of the coastal plain (Johnson et al. 2007).

Physiologic Hydro Niche: Net loss of nesting and foraging habitat related to drying tundra is likely to be the most important source of vulnerability for this species (see table on next page). Wet / moist coastal tundra habitats in the Arctic LCC may decrease in extent if changes in summer temperature and soil active layer depth create a generally drier summer environment in the Arctic. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. Increasing shrubs and paludification may also decrease sedge/wet meadow tundra extent (Martin et al. 2009).

Physical Habitat Restrictions: Shoreline armoring related to climate change mitigation could reduce the availability of brackish water staging habitats that this species sometimes uses prior to fall migration. However, shoreline armoring would be focused on existing communities or infrastructure, which is limited in extent at present. Overall, pectoral sandpipers tend to stopover/stage infrequently at coastal areas (most birds tend to feed in tundra habitats prior to fall migration), so this limits their exposure to coastal land use changes as well (A. Taylor, pers. comm.).



Disturbance Regime: Climate-mediated disturbance, namely thermokarst, could both create and destroy foraging and nesting habitats through both ice wedge degradation and draining of thaw lakes. Likewise, increased coastal erosion and resulting salinization (Jones et al. 2009) could both negatively and positively affect post-breeding aggregations of staging birds by destroying and creating foraging habitat.

Interactions with Other Species: In terms of dependence on interspecific interactions, this species will communally feed and flock with other shorebirds during post- breeding staging (Taylor et al. 2010) but it is unknown if these behaviors increase species persistence. Pectoral sandpiper nest survivorship is often higher in

Pectoral Sandpiper (*Calidris melanotos*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*	*			
C2bii. Physiological hydro niche				*	*		
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

boom lemming years (J. Liebezeit, unpublished data). Lemming cycles are predicted to become rarer (Ims and Fuglei 2005) and could potentially expose this species to greater nest predation pressure.

Phenological Response: There is evidence suggesting that this species is able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to changes in the schedules of other organisms that they depend on (e.g. invertebrate prey).

In summary, despite the potential negative effects of tundra drying, Pectoral Sandpipers will likely be able to compensate for such changes and remain "stable" with regard to climate change at least during the timeframe of this assessment.

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Dunlin (*Calidris alpina*)

Vulnerability: **Presumed Stable** Confidence: High

The Dunlin (*arcticola* subspecies) is a common breeding bird in Arctic Alaska from the area surrounding Barrow to the east. The *pacifica* subspecies also occurs within the Arctic LCC assessment area in the region around Cape Lisburne and Cape Krusenstern. Dunlin use a wide variety of breeding habitats found in the northern sub-arctic and arctic. On the Arctic Coastal Plain of Alaska, *C. a. arcticola* breed in moist-wet tundra, often in areas with ponds, polygons, and strangmoor landforms (Warnock and Gill 1996). The *arcticola* subspecies winters in Asia while *pacifica* winters along the west coast of North America. Current population estimate is 1.3 million (*arcticola*: 750,000, *pacifica*: 500,000; Morrison et al. 2006) with a declining trend.

Range: We used the extant Nature Serve range map for the assessment as it closely matched that of the Birds of North America (Warnock and Gill 1996) and other sources (Johnson and Herter 1989, Johnson et al. 2007, Bart et al. 2012).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Dunlin ranked "neutral", in many categories. Only in the physiological hydrologic niche category was there a clear scoring of increased vulnerability. The range from "slightly increased" to "greatly increased" vulnerability represents uncertainty in the severity of such an impact. If significant tundra drying occurs this species could experience a considerable negative impact as they often utilize wet tundra habitats for nesting and foraging (particularly the *arcticola* subspecies; Warnock and Gill 1996). Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. Dunlin do commonly nest and forage in moist tundra (rather than wet tundra) during the breeding season so it is possible they could adjust to drier habitats. The geospatial component of the assessment picked up Dunlin as being slightly vulnerable to sea-level rise.

Dietary Versatility: Dunlin have a flexible diet and current evidence suggests they take advantage of a wide variety of prey (Warnock and Gill 1996) so they would likely not face any negative impacts from a changing prey base.

Interactions with Other Species: In terms of dependence on interspecific interactions, this species will communally feed and flock with other shorebirds during post-breeding staging (Taylor et al. 2010) but it is unknown if these behaviors increase species persistence. Also, climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Genetic Variation: Little is known about Dunlin genetics although, in general, many shorebird species are believed to have low genetic variation (Baker and Stauch 1988) and thus

Dunlin (*Calidris alpina*)
Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise				*			
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

potentially more vulnerability to certain climate-mediated events (e.g. disease outbreaks). However, at this time, there is little evidence to support such occurrences in the near future.

Phenological Response: Although there is evidence suggesting that some shorebird species are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack unpublished data; D. Ward, pers. comm.) there is no such evidence for Dunlin specifically at this time.

In summary, despite potential negative response to changes in tundra conditions, , Dunlin will likely be able to remain "stable" with regard to climate change, at least during the timeframe of this assessment (next 50 years).

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Stilt Sandpiper (*Calidris himantopus*)

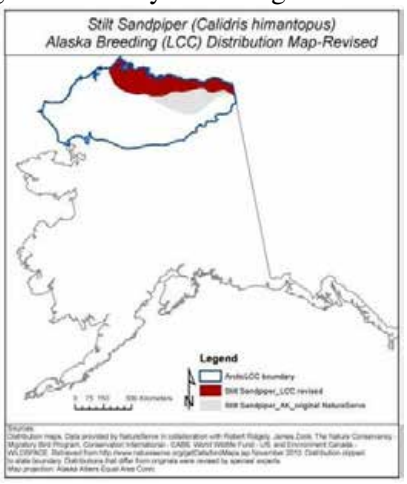
Vulnerability: **Presumed Stable** Confidence: Low

The Stilt Sandpiper is an uncommon to common breeding shorebird on the Arctic Coastal Plain of Alaska that typically nests near the coast from the Canadian border to the Barrow area (Johnson et al. 2007, Klima and Jehl 2012). Highest known breeding densities occur in Arctic Canada where they often nest in taiga and boreal habitats. In Alaska, they prefer nesting in wet, poorly drained tundra and forage mainly in marshes, pools, damp pond margins, and on shorelines of drying ponds during the breeding season (Klima and Jehl 2012). Stilt Sandpipers primarily migrate through the central North American Flyway toward core wintering areas throughout South America. Current population estimate is 820,000 and stable (Morrison et al. 2006).

Range: We modified the NatureServe map based on recent studies (Johnson et al. 2007, Bart et al. 2012) and the Birds of North America account descriptions (Klima and Jehl (2012).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Stilt Sandpipers scored neutral in most categories with the exception of "physiological hydrologic niche", for which they were deemed to be potentially sensitive to a tundra drying impact. While in Alaska this species is known to primarily nest in wetter tundra habitats (e.g. strangmoor), in Canada it often nests in drier tundra and taiga habitats (Klima and Jehl 2012), indicating that the species may be able to adapt to drying conditions. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Natural Barriers: Natural barriers are likely not an issue for this species although their proclivities for nesting near the coast leaves them little option for shifting their range northward. Again their flexibility in nesting habitat as demonstrated by Canadian populations may signal flexibility in nesting habitat use.



Disturbance Regime: In terms of disturbance regimes, this species could be impacted by habitat degradation along the coast (from more severe storms and subsequent overwash and erosion; Jones et al. 2009), which they utilize post-breeding for fueling up before migration (although their use of coastal habitats during post-breeding is minimal compared to other shorebird species, Taylor et al. 2010). More tundra fires (Racine et al. 2004) could theoretically reduce nesting and foraging habitat, but such fires are relegated to inland areas so they would likely not be impacting current Stilt habitats in Alaska in the foreseeable future.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Stilt Sandpiper (*Calidris himantopus*)

Vulnerability: **Presumed Stable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*	*			
C2bi. Historical hydro niche (GIS)		*					
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Also, this species will communally feed and flock with other shorebirds during breeding and migration and will join other shorebird species in mobbing potential predators during the nesting season (particularly just after hatch; Kilma and Jehl 2012), but it unknown if these behaviors increase species persistence.

In summary, Stilt Sandpipers have enough versatility in their life history traits and behaviors on the breeding grounds to likely allow them to adjust to changing climate conditions and remain "stable" at least during the timeframe of this assessment (to 2050).

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Buff-breasted Sandpiper (*Tryngites subruficollis*)

Vulnerability: **Moderately Vulnerable** Confidence: Moderate

The Buff-breasted Sandpiper is known for its dramatic lekking displays and breeds near arctic coastlines from central Alaska into Canada (Lanctot and Laredo 1994). This species nests in a variety of habitats ranging from dry sedge tussock tundra to wet sedge-graminoid meadows and strangmoor (Lanctot and Laredo 1994). Buff-breasted Sandpipers typically forage in areas of dry, elevated tundra with sparse vegetation primarily consuming terrestrial arthropods (Lanctot and Laredo 1994). This species is one of the few shorebirds that do not show a seasonal shift toward lowland, wet sites during brood-rearing (Jones 1980, R. Lanctot, unpublished data). Buff-breasted Sandpipers spend winters on the pampas of South America. Current population estimate in North America is 30-56,000 with a declining trend (Lanctot et al. 2010, Morrison et al. 2006).

Range: We modified the NatureServe range map to more closely match the more restricted and coastally oriented breeding range depicted in the Birds of North America account (Lanctot and Laredo 1994) and as described in more recent assessments (Johnson et al. 2007; Bart et al. 2012). Within its range, this species is sparsely distributed (R. Lanctot, pers. comm.).

Sea Level Rise: Because this species' range is restricted to coastal areas in Arctic Alaska, they were ranked as being slightly vulnerable to both sea-level rise and to limitations in expansion of their range northward.

Physiological Hydro Niche: Because Buff-breasted Sandpipers use wet tundra habitats to some degree for nesting, foraging, and brood-rearing (though less than many other shorebirds) they were ranked as "neutral-to-increased" vulnerability in the "physiological hydrologic niche" category (see table). Current annual moisture balance predictions suggest negligible increases in drying for the foreseeable future (TWS and SNAP). Thus moisture balance, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. However, historical hydrological niche was ranked as "greatly increased" as they have historically experienced low variation in average precipitation across their relatively small Alaska breeding range, suggesting sensitivity to increased variation.

Disturbance Regime: Climate-mediated disturbances, namely thermokarst, could both create and destroy lake habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Increased fire frequency could reduce habitat suitability required by the species for nesting, although for the purpose of this assessment fires were considered to have only localized effects.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Genetic Variation: Shorebird species are believed to have low genetic variation (Baker and Stauch 1988) making them potentially more vulnerable to certain climate-mediated events in the near future (e.g. disease outbreaks).

Buff-breasted Sandpiper (*Tryngites subruficollis*)

Vulnerability: **Moderately Vulnerable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise				*			
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)						*	
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation				*			*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability,GI=Greatly increase vulnerability.

Phenological Response: There is evidence suggesting some shorebirds are able to track changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to shifting schedules of organisms they rely on (e.g. invertebrate prey).

In summary, this species' combination of potential sources of vulnerability provided a ranking of "moderately vulnerable".

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Long-billed Dowitcher (*Limnodromus scolopaceus*)

Vulnerability: **Presumed Stable** Confidence: Low

The Long-billed Dowitcher is a medium-sized shorebird that commonly breeds on the Arctic Coastal Plain of Alaska. This species nests in higher densities in the western portion of the coastal plain compared to the east (Johnson et al. 2007). They prefer wet grassy meadows for nesting often showing an affinity for sedge-willow, wet meadow or sedge marsh along drainages or near ponds (Takekawa and Warnock 2000). Long-billed Dowitchers generally migrate west of the Mississippi River and winter primarily along the Pacific and Gulf Coasts of North America into Mexico (Takekawa and Warnock 2000). Current population estimate of the North American population is 400,000 (Morrison et al. 2006).

Range: We used the extant NatureServe range map for the assessment as it closely matched that of the Birds of North America as well as other range descriptions (Johnson et al. 2007, Bart et al. 2012).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Long-billed Dowitchers ranked "neutral", in many categories. In the physiological hydrologic niche category, the ranking ranged from neutral to greatly increased vulnerability. This range represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on dowitchers. Significant tundra drying could have a considerable negative effect, given that this species primarily depends on wet tundra habitats for nesting and foraging in Alaska, as well as in other parts of their range (Takekawa and Warnock 2000). Current models for the Alaskan Arctic generally project a greater potential drying in the western coastal plain (http://www.snap.uaf.edu/), which is also where Long-billed Dowitchers' have highest nest densities (Johnson et al. 2007). Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Disturbance Regime: Disturbance regimes, specifically coastal erosion and increased coastal flooding (Jones et al. 2009) have the possibility of negatively impacting both breeding and post-breeding dowitchers. However, such coastal disturbance, as well as thermokarst-mediated changes on the landscape, could create new nesting and foraging habitat. As a case in point, along the coast, dowitchers are often associated with salt ponds (Taylor et al. 2010) and thus could benefit from salt water intrusion from storm events. More tundra fires (Racine et al. 2004) could theoretically reduce nesting and foraging habitat but tundra fires are relegated to inland areas at this point so they would likely not significantly impact dowitcher habitats in Alaska soon.

Dietary Versatility: This species has an omnivorous diet and current evidence suggests they take advantage of a wide variety of prey

Long-billed Dowitcher (*Limnodromus scolopaceus*)

Vulnerability: **Presumed Stable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche			*	*	*	*	
C2c. Disturbance regime		*	*	*	*		
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

(Takekawa and Warnock 2000) so they would likely not face any negative impacts from a changing prey base.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey. Also, this species will communally feed and flock with other shorebirds during breeding and migration, as well as join other shorebird species in mobbing potential predators during the nesting season (Takekawa and Warnock 2000). It is unknown if these behaviors increase species persistence.

In summary, despite some vulnerability, overall, Long-billed Dowitchers will likely be able to compensate for climate-changes and remain "stable" at least during the timeframe of this assessment (next 50 years).

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Red-necked Phalarope (*Phalaropus lobatus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

The Red-necked Phalarope commonly breeds in both the Brooks Range foothills and Arctic Coastal Plain of Alaska. In Alaska, this species typically nests in wet tundra near water's edge. It differs from the Red Phalarope in that it breeds further inland and at higher elevations (Rubega et al. 2000). Like other phalaropes, this species depends on aquatic food sources for much of its diet (Rubega et al. 2000). Red-necked Phalaropes spend winter at sea in tropical waters in large numbers off the west coast of South America (Rubega et al. 2000). Current North American population estimate is 2.5 million with a declining trend (Morrison et al. 2006).

Range: We modified the NatureServe range map for the assessment to more closely match that of the Birds of North America (Rubega et al. 2000) and other habitat descriptions (Bart et al. 2012). It should be noted that this species occurs more abundantly at inland wet tundra sites more than along the immediate coast (Johnson et al. 2007).

Physiologic Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), the greatest potential source of vulnerability for Red-necked Phalaropes was in the "physiological hydrologic niche" category. Scores for physical hydrological niche ranged from "slightly" to "greatly increased "vulnerability. This range represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the phalarope. If substantial tundra drying occurs this species could experience a considerable negative impact as they primarily depend on wet tundra habitats for nesting and foraging in Alaska (Rubega et al. 2000). Currently it is unknown how adaptable this species would be in utilizing drier habitats for nesting. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Human Response to CC: Shoreline armoring by humans in response to climate change could reduce the availability of stopover or staging habitats this species uses prior to fall migration. However, shoreline armoring would be limited to existing communities or infrastructure, which is limited in extent at present.

Physical Habitat Restrictions: During post-breeding, Red Phalaropes will often use the leeward side of barrier islands for foraging (Taylor et al. 2010). These types of habitat features are relatively uncommon and are vulnerable to disturbance. Coastal erosion and overwash, in particular, have the potential to negatively impact post-breeding phalaropes. Other disturbances, such as thermokarst-mediated changes on the landscape, could both create and destroy nesting and foraging habitats. More tundra fires could theoretically reduce nesting and foraging habitat but tundra fires are relegated to inland areas and are presently highly localized so they would likely not significantly

Red-necked Phalarope (*Phalaropus lobatus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions			*	*			
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

impact current phalarope habitats in Alaska in the near future.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could expose this species to greater nest predation pressure if lemmings become less available as alternative prey.

Genetic Variation: Little is known about Red-necked Phalarope genetics although, in general, many shorebird species are believed to have low genetic variation (Baker and Stauch 1988).

Phenological Response: Although not demonstrated in phalaropes, there is evidence suggesting shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to other organisms changing schedules that they depend on (e.g. invertebrate prey).

In summary, although ranked as "stable" in this assessment, this species' high dependence on wet habitats for nesting, foraging, and post-breeding activities, combined with other vulnerabilities may make it vulnerable if geomophological changes linked to permafrost ultimately lead to drier conditions.

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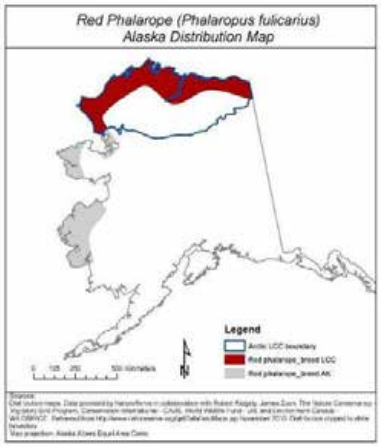
Red Phalarope (*Phalaropus fulicarius*)
Vulnerability: **Moderately Vulnerable** Confidence: Low

The Red Phalarope commonly breeds on the Arctic Coastal Plain of Alaska, but is more abundant west of the Colville River primarily near the coast (Johnson et al. 2007). In Alaska, this species almost exclusively nests in wet/moist polygonal or marshy tundra and are dependent on aquatic food sources for much of their diet (Tracy et al. 2002). Red Phalaropes are the most pelagic of the three phalarope species and spend most of their winters in subtropical and tropical seas near areas of nutrient upwelling (Tracy et al. 2002). Current population estimate of the North American population is 1.25 million with a suspected declining trend (Morrison et al. 2006).

Range: We used the extant Nature Serve range map for the assessment as it closely matched that of the Birds of North America (Tracy et al. 2002) as well other range descriptions (Johnson et al. 2007, Bart et al. 2012).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), the greatest potential source of vulnerability for Red Phalaropes was in the "physiological hydrologic niche" category. Scores for physical hydrological niche ranged from "slightly" to "greatly increased "vulnerability. This range represents uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on the phalarope. If substantial tundra drying occurs this species could experience a considerable negative impact as they primarily depend on wet tundra habitats for nesting and foraging in Alaska as well as in other parts of their range (Tracy et al. 2002). It is unknown how adaptable this species would be in utilizing drier habitats for nesting. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment.

Physiological Thermal Niche: Red Phalarope were also scored as having a "slight increase" in vulnerability with respect to physiological thermal niche because they tend to breed closer to the coast which is cooler than interior habitats where the same breeding and foraging habitat types are available. It is possible, phalaropes are responding to some other factor, rather than thermal conditions, in their coastal restriction.



Disturbance Regime: During post-breeding, Red Phalaropes will often use the leeward side of barrier islands for foraging (Taylor et al. 2010). These types of habitat features are relatively uncommon and are vulnerable to disturbances. In particular, coastal erosion and overwash (Jones et al. 2009) related to more frequent and severe storms may negatively impact post-breeding phalaropes. Other disturbance processes, such as thermokarst-mediated changes on the landscape, could both create and destroy nesting and foraging habitats.

Interactions with Other Species: Climate change may reduce the amplitude of lemming cycles (Ims and Fuglei 2005) and thus could

Red Phalarope (*Phalaropus fulicarius*)

Vulnerability: **Moderately Vulnerable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions			*	*			
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

expose this species to greater nest predation pressure if lemmings become less available as alternative prey. In addition, this species will communally feed and flock with other shorebirds during post- breeding staging (Taylor et al. 2010) but it is unknown if these behaviors increase species persistence.

Phenological Response: There is evidence suggesting some shorebirds are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data; D. Ward, pers. comm.). However, it is unknown if they can synchronize timing to other organisms changing schedules that they depend on (e.g. invertebrate prey).

In summary, as a result of the combined potential sources of vulnerability, Red Pharalope was considered "moderately vulnerable" to climate change in this assessment.

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Glaucous Gull (*Larus hyperboreus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

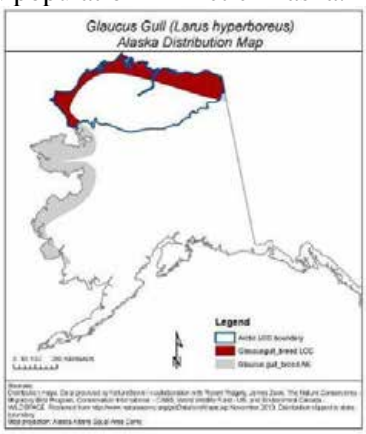
The Glaucous Gull is a large gull with a circumpolar distribution. In Alaska, it is the most common gull along Arctic Ocean coastal areas. Like other gulls, this generalist species has benefited from the presence of humans in the arctic and readily utilizes human-subsidized food resources (e.g. edible garbage, roadkills; Day 1998). Glaucous Gulls take advantage of a wide variety of natural prey as well and are a noted nest predator. Alaskan populations of this species winter in the Pribilof and Aleutian islands of Alaska and in decreasing numbers down to coastal Oregon and California (Denlinger 2006). The global population is estimated at 340,000-2,400,000 (Wetlands International 2006).

Range: We used the extant NatureServe range map for this assessment as it closely matched the Birds of North America (Gilchrist 2001) and other range descriptions (Johnson and Herter 1989).

Physical Habitat Restrictions: Among the indirect exposure and sensitivity factors (see table on next page), Glaucous Gull ranked neutral in most categories with the exception of physiological hydrologic niche for which they were evaluated to have a "neutral to greatly increased" vulnerability. This response was driven primarily by their common use of small islands in shallow ponds and lakes for nesting to escape fox and bear predation (Gilchrist 2001). If tundra lakes drain due to permafrost melting and/or if less surface water is available, Glaucous Gulls could become limited by nesting habitat or at least experience years of low nesting success more frequently as predation rates could increase.

Physiological Hydro Niche: The wide range in responses in this category captures the significant uncertainty both in the direction and intensity of change in Arctic hydrology, as well as in the effect this will have on gulls. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Human Response to CC: Increased human activity and infrastructure associated with climate change mitigation could benefit Glaucous Gulls as witnessed by the influence of current human developments in the region (Day 1998). Glaucous Gull reproductive success is often higher in human developed areas in the Arctic (Weiser and Powell 2010). Melting sea ice will likely allow for additional offshore drilling and new shipping routes – both of which have the potential to benefit Glaucous Gulls if they provide a new at-sea source of food (garbage). This could improve subadult / nonbreeding survival rates and result in an increased population in Arctic Alaska.



Physiological Thermal Niche: Glaucous Gulls are coastally oriented (the coast being cooler than inland areas). The lakes/ponds on which they nest are also quite cold with water

Glaucous Gull (*Larus hyperboreus*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC		*	*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*	*	*	
C2c. Disturbance regime			*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

temperatures barely above 0° C for most of the summer. Glaucous Gulls are thermoneutral to 2° C (Gabrielsen and Mehlum 1989) so it is not surprising that these cold-adapted birds would be uncomfortable in warm weather. This could potentially change their distribution if local temperatures increase although it is unlikely that summer coastal temperatures would change so much as to eliminate them from arctic Alaska.

Phenological Response: Currently, there are no long-term data sets to provide sufficient information on Glaucous Gull phenological response to climate change in the arctic and so it is unknown how they will respond to changing phenologies.

In summary, this vulnerability assessment suggests that Glaucous Gulls will remain stable in the region with regard to climate change impacts and potentially even benefit from a warming climate.

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Sabine's Gull (*Xema sabini*)

Vulnerability: **Presumed Stable** Confidence: Very High

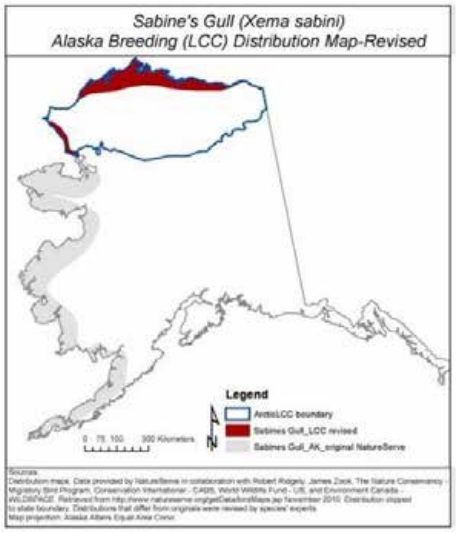
A gull of the Subarctic and Arctic, the Sabine's Gull, with its distinctive plumage, commonly nests in the Alaskan Arctic, often in association with Arctic Terns (*Sterna paradisaea*). This species typically nests near fresh water in swampy low-lying tundra, in tidal marshes, and on small coastal islands (Day et al. 2001). During the breeding season, aquatic insects and other invertebrates are their most important food items (Day et al. 2001). Sabine's Gulls spend their winters offshore primarily in subtropical and tropical coastal upwelling zones (Day et al. 2001). The northern Alaska population estimate is rarely surveyed extensively. Two surveys in 1996 indicate a population somewhere between 6,000 and 10,000 (Day et al. 2001).

Range: For the CCVI, we adjusted the NatureServe Map to reflect the range map depicted in the Birds of North America account as the latter more accurately represented this species' range based on multiple accounts and expert opinion (Johnson and Herter 1989, Day et al. 2001, Bart et al. 2012, I. Stenhouse, pers. comm.).

Physiological Hydro Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Sabine's Gull ranked neutral in most categories with the exception of physiological hydrologic niche, for which they were evaluated to have a "slightly to greatly increased" vulnerability. This response was driven primarily by this species reliance on small water bodies for foraging and for selecting nest sites (Stenhouse et al. 2005). Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment. Any potential drying trend could also be offset by changes in surface hydrology that create more nesting and foraging habitat (Martin et al. 2009).

Physical Habitat Restrictions: Sabine's Gulls are not associated with any uncommon geological features.

Dietary Versatility: They have relatively high dietary versatility, allowing flexibility in response to any climate-mediated changes that would affect these aspects of this species life history.



Interactions with Other Species: Sabine's Gulls are described as nesting only in association with Arctic Terns in some places (i.e. Greenland). In other areas, however, such as eastern Canadian Arctic and in Arctic Alaska, the association with Arctic Terns is less strict. The interaction between these species may be related to combined nest defense however it is unknown if such an association would be impacted by climate change or result in any net benefit or impact (I. Stenhouse, pers. comm.).

Sabine's Gull (*Xema sabini*)

Vulnerability: **Presumed Stable** Confidence: Very High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche					*	*	
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: Little is known about Sabine's Gull genetics and there are currently no long-term data sets for this species that indicate a change in phenology.

In summary, the results suggests Sabine's Gull will likely be able to adjust to climate and associated habitat changes predicted to occur in Arctic Alaska, at least during the 50 year timeline of this assessment.

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Arctic Tern (*Sterna paradisaea*)

Vulnerability: **Presumed Stable** **Stable Confidence:** Moderate

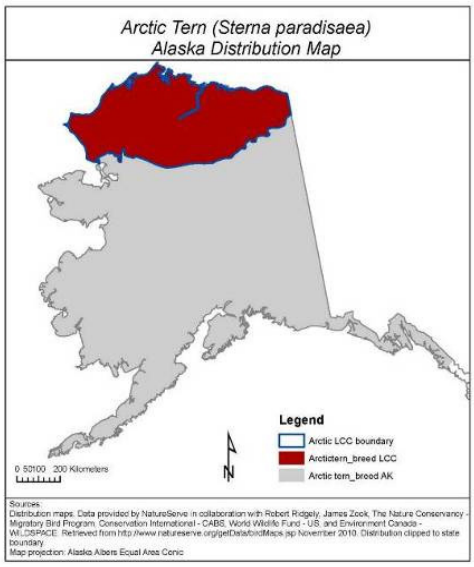
The Arctic Tern completes annual epic migrations from pole to pole covering at least 40,000 km on their round-trip journeys. They breed throughout Arctic Alaska from boreal to tundra habitats and have their highest nesting densities inland (Lensink 1984). Arctic Terns typically choose nest sites on open ground near water and often on small islands in ponds and lakes (Hatch 2002). Arctic terns consume a wide variety of fish and invertebrate prey, fish are particularly important during the breeding season for feeding young (Hatch 2002). This species spends their winters (austral summers) in offshore waters near Antarctica (Hatch 2002). Alaskan Arctic Coastal Plain population estimates from 2011 range from 7-12,000 (Larned et al. 2012).

Range: We used the extant Nature Serve map for the assessment as it matched other range map sources and descriptions (Johnson and Herter 1989, Hatch 2002).

Physiological Hydrologic Niche: Among the indirect exposure and sensitivity factors in the assessment (see table on next page), Arctic Terns ranked neutral in most categories with the exception of physiological hydrologic niche for which they were evaluated to have a "slightly to greatly increased" vulnerability. This response was driven primarily by this species reliance on wetland and shallow water bodies for breeding and foraging. An arctic drying trend could result in loss of small water bodies. However, this drying trend could be offset by changes in surface hydrology that create more nesting and foraging habitat (Martin et al. 2009). Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor was not heavily weighted in the assessment.

Physiological Thermal Niche: Arctic Terns occur throughout Alaska in a variety of habitats including warmer boreal environs so there is no plausible reason to think they could not adapt physiologically to a warmer Arctic environment in the foreseeable future.

Dietary Versatility: Although small fish make up a significant part of the Arctic Tern, they also eat many invertebrates and so exhibit enough flexibility in their diet that they would likely be able to cope with climate-mediated changes in prey base.



Disturbance Regime: Climate-mediated disturbance processes, namely thermokarst, could both create and destroy lake habitats through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009). Loss of both coastal and inland nesting and foraging habitats by coastal erosion, and an increase in sea and riverine levels could have negative impacts although in the foreseeable future these impacts will likely be localized.

Phenological Response: Despite the existence of long-term data sets for Arctic Terns in

Arctic Tern (*Sterna paradisaea*)

Vulnerability: **Presumed Stable** **Stable Confidence:** Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime		*	*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

northern Alaska (Larned et al. 2012) an assessment of phenology-related variables has not been a part of that effort or has not been examined so it is currently unknown how this species will respond to changing biotic schedules.

Interactions with Other Species: Fox nest predation could increase as the availability of "island" nesting sites could be more limited if shallower ponds dry out from a region-wide tundra drying trend.

In summary, the results of this vulnerability assessment indicate that the Arctic Tern will likely be adaptable enough to cope with climate change and associated habitat changes predicted to occur in Arctic Alaska, at least during the 50 year timeline of this assessment.

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Pomarine Jaeger (*Stercorarius pomarinus*)

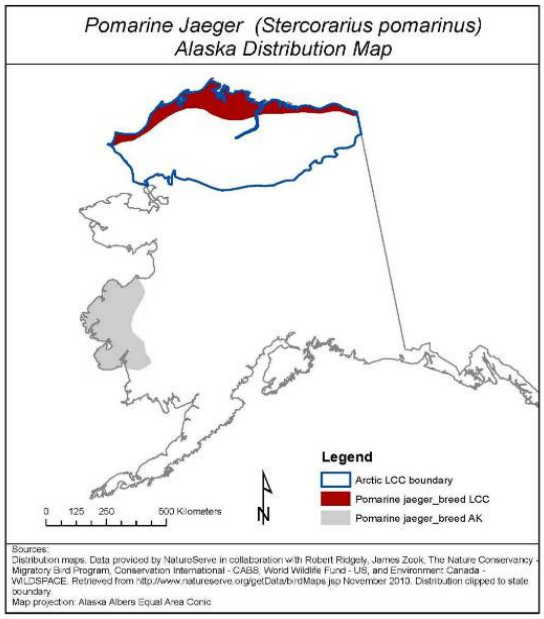
Vulnerability: **Moderately vulnerable** Confidence: Low

The Pomarine Jaeger, the largest of the three jaegers, prowls the arctic tundra subsisting on a diet composed almost entirely of brown lemmings (*Lemmus trimucronatus*). This species presumably nests only in years when lemmings are abundant (Wiley and Lee 2000). Their breeding range in Alaska is relatively close to the coast, typically nesting in wet tundra habitats, the same habitats as those utilized by their favorite prey. Pomarine Jaegers may forgo breeding in low lemming years and prematurely return to their tropical and sub-tropical pelagic wintering grounds (Wiley and Lee 2000). Current global population estimate is 250,000 – 3 million individuals (BirdLife International 2012).

Range: For the assessment, we used a range map modified from the NatureServe map that more closely approximated the range depicted in the Birds of North America species account (Wiley and Lee 2000). We also included an inland breeding range extension in the Teshekpuk Lake region (J. Liebezeit, unpublished data).

Interactions with Other Species: In the assessment, Pomarine Jaegers were ranked as particularly vulnerable ("increased" or "greatly increased") to climate change impacts for three categories which are tied to their dependence on their main source of food - brown lemmings (see table below). They have low dietary versatility and their "interaction" with brown lemmings in terms of being dependent on their cyclical population booms could potentially make them vulnerable to climate change. In fact, there is some concern that climate change could disrupt lemming cycles (Ims and Fuglei 2005). The resulting repercussion on Pomarine Jaegers is unknown but could be detrimental.

Physiologic Hydro Niche: Because Pomarine jaegers nest in wet habitats the physiological hydrologic niche category also scored highly because of the potential for a drying trend in the arctic which could result in a net loss of wet tundra habitats. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment. This species' "preference" for wet habitats may be more related to being close to their prey base rather than to a physiological need. Unfortunately, little is known about their nesting habitat requirements or their flexibility in nest site selection (Wiley and Lee 2000).



Pomarine Jaeger (*Stercorarius pomarinus*)

Vulnerability: **Moderately vulnerable** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*	*			
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)				*			
C2bii. Physiological hydro niche				*	*	*	
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility				*	*		
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*	*		
C5a. Genetic variation							*
C5b. Genetic bottlenecks							
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Physical Habitat Restrictions: Because this species often breeds relatively close to the coast they could be constrained in nesting habitat by the natural barrier of the Arctic Ocean if climate change results in a net loss of wet tundra habitats (and the associated lemmings) on the coastal plain.

Phenological Response: Currently there is insufficient information on how or if specific climate-mediated disturbance regimes will impact this species. Certainly, disturbances that would impact lemming populations (e.g. increasing snow depth) would, in turn, likely impact Pomarine Jaegers.

In summary, the combined dependence of Pomarine Jaegers on one primary food source, brown lemmings (which themselves, could be vulnerable to a warming climate), use of coastal areas, reliance on wet habitats, and other factors, resulted in a "moderately vulnerable" ranking for this species in this assessment.

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Parasitic Jaeger (*Stercorarius parasiticus*)

Vulnerability: **Presumed Stable** Confidence: High

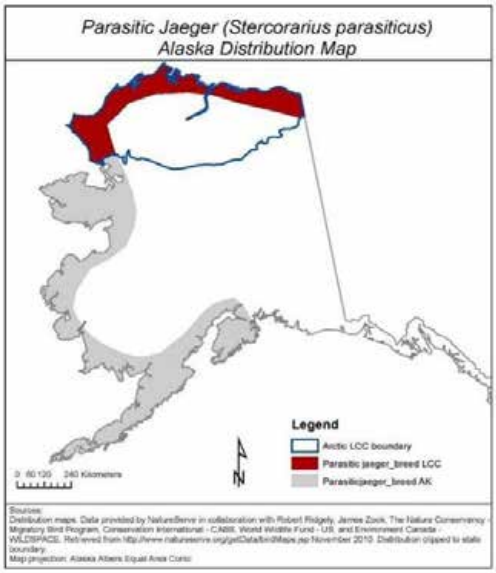
The Parasitic Jaeger, unlike the two other jaegers (the Long-tailed and Pomarine Jaegers), has a varied diet and is not closely tied to lemmings as a food source (Wiley and Lee 1999). This species utilizes both low-lying marshy tundra and drier tussock-heath tundra for nesting sites (Wiley and Lee 1999). Parastic Jaegers often hunt for fledgling and adult birds and are believed to be an important nest predator (Wiley and Lee 1999). Like the other jaeger species, Parasitic Jaegers winter in offshore tropical and sub-tropical oceans. The current global population estimate is 500,000 - 10,000,000 (BirdLife International 2012). There is no Alaska population estimate available.

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America and other range descriptions (Johnson and Herter 1989, Bart et al. 2012).

Physiological Hydro Niche: For most of the indirect exposure and sensitivity categories in the assessment, Parasitic Jaegers were ranked with a neutral response (see table on next page). Only in one category (Physiological hydro niche), was this species ranked with the potential for increased vulnerability as a drying trend in the arctic could negatively impact this species. Parasitic Jaegers breed and hunt in tundra habitats ranging the full spectrum from wet to dry. So, while they may be impacted in the wetter habitats by a drying trend, it is uncertain whether that would have an overall negative effect on the species. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.

Disturbance Regimes: Climate-related shifts in disturbance regimes (e.g. greater storm severity [Jones et al. 2009], disease outbreaks) and climate change mitigation and adaptation activities in the region will likely not occur at a large enough scale to impact Parasitic Jaeger populations in Alaska.

Dietary Versatility: Unlike the other jaeger species, the varied and flexible diet of Parasitic Jaegers may enable it to cope with any climate-mediated changes in prey base (Ims and Fuglei 2005).



Phenological Response & Genetic variation: There currently exists little or no information regarding the genetic or phenological traits that

Parasitic Jaeger (*Stercorarius parasiticus*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

would make Parasitic Jaegers more or less vulnerable to a warming climate.

In summary, this assessment suggests that Parasitic Jaegers may be the most resilient of jaeger species in coping with potential impacts associated with climate change and within this context will likely remain stable, at least during the time frame of this assessment.

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Long-tailed Jaeger (*Stercorarius longicaudus*)

Vulnerability: **Presumed Stable** Confidence: High

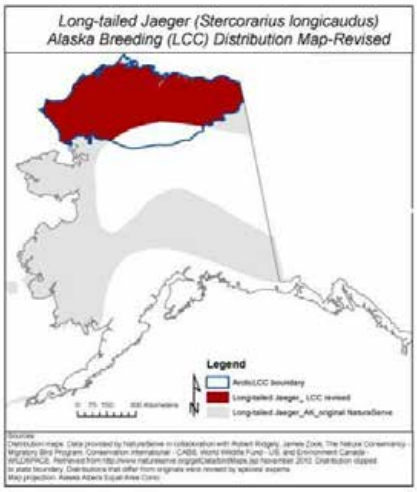
The Long-tailed Jaeger, the most sleek and graceful of the three jaegers, is a common bird in Arctic Alaska. Similar to the larger Pomarine Jaeger, this species diet consists primarily of lemmings and voles, however, unlike the Pomarine Jaeger, Long-tailed Jaegers can withstand cyclical rodent crashes as they can readily switch to other food sources (Wiley and Lee 1998). The Long-tailed Jaegers breeding range in Alaska extends more deeply into the interior than either the Pomarine or Parasitic Jaeger and typically nests in drier upland tundra (Wiley and Lee 1998). The current global population estimate is >150,000 – 5,000,000 (BirdLife International 2012). There is no Alaska population estimate available.

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America (Wiley and Lee 1998) and other range descriptions (Johnson and Herter 1989, Bart et al. 2012).

For most of the indirect exposure and sensitivity categories in the assessment, Long-tailed Jaegers were ranked with a neutral response (see table on next page). Only in one category (Physiological hydro niche), was this species ranked with the potential for significant vulnerability to climate change as wetter tundra habitats may be impacted by a drying trend.

Physiological Hydro Niche: Long-tailed Jaegers use wet tundra habitats for foraging, particularly non-breeding individuals that congregate around edges of ponds or swamps where arthropods are numerous (Wiley and Lee 1998). Also sometimes they will nest near water bodies. However, in general, they tend to nest and hunt more often in drier tundra. Therefore, any tundra drying will likely have a minimal impact. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP), and its interaction with hydrologic processes is very poorly understood (Martin et al. 2009). Thus atmospheric moisture, as an exposure factor was not heavily weighted in the assessment.

Human Response to CC: Long-tailed Jaegers (mostly non-breeders) do utilize coastal habitats during the breeding season to some extent. Human response to climate change related to the extension of levees and coastline hardening may occur but the extent of these activities will be localized and thus unlikely to significantly impact Long-tailed Jaeger populations.



Disturbance Regime: In terms of disturbance regime, the expected increase in storm intensity could result in deeper snow cover (Martin et al. 2009). Early arriving jaegers could have difficulty foraging for their key lemming and vole prey. However, because of their ability to switch to other prey, this will likely not be a significant problem for them. Unlike, Pomarine Jaeger's dependency on lemmings the Long-tailed Jaeger will likely be able to cope with climate-mediated changes in lemming abundance and cycling (Ims and Fuglei 2005).

Long-tailed Jaeger (*Stercorarius longicaudus*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility				*			
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Physiological Thermal Niche: Long-tailed Jaegers breeding range extends farther into the interior than the other Jaegers, suggesting they can withstand higher temperatures and thus possess greater thermal tolerance.

Phenological Response: There currently exists little or no information regarding the genetic or phenological traits that would make Long-tailed Jaegers more or less vulnerable to changing climate conditions.

In summary, although Long-tailed Jaegers may experience some negative impacts from climate change, overall their use of varied nesting and foraging habitats, their dietary versatility, and large geographic range will likely enable this species to remain stable for the near future.

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Snowy Owl (*Bubo scandiacus*)

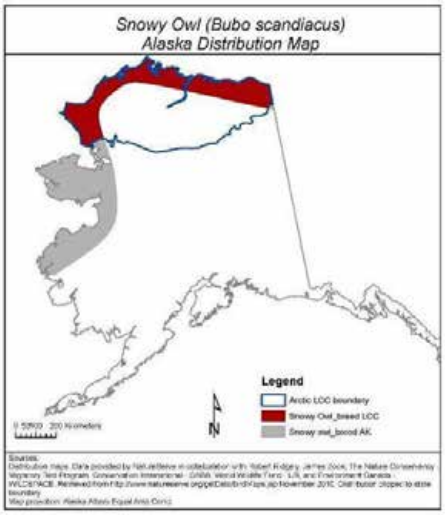
Vulnerability: **Presumed Stable** Confidence: High

The Snowy Owl, a conspicuous and majestic bird of the circumpolar arctic, is an efficient hunter of small mammals in tundra environs. In years of high lemming numbers they will focus on this abundant food source but will readily switch to a wide variety of other prey when lemmings are scarce (Parmelee 1992). Their breeding range in Alaska is generally restricted to the Arctic Coastal Plain, typically nesting in more upland tundra habitats, although they often, though not exclusively, forage in wetter tundra (Parmelee 1992). Snowy Owls are unpredictable migrants and will sometimes "invade" portions of southern Canada and the northern contiguous US, in winters when lemmings are scarce in the Arctic. The current global population is estimated at 300,000 (Rich et al. 2004).

Range: We used the extant Nature Serve range map for the assessment as it closely matched the Birds of North America (Parmelee 1992) and other range descriptions (Johnson and Herter 1989).

Interactions with Other Species: Snowy owl nesting seems to be tied to some degree to lemming population booms, so reductions in brown lemmings or less frequent population booms (through habitat change and/or increased icing events; see Ims and Fuglei 2005) could impact nest survivorship of snowy owls, distribution, and abundance. Thus, in this assessment, related categories ("dietary versatility", "species interaction") were ranked as "slightly increased" vulnerability. However, Snowy Owl's ability to switch to a variety of other prey sources suggest that it may be able to compensate for such changes with little negative effect.

Physiological Hydro Niche: Similarly, although Snowy Owls do utilize wet tundra habitats for foraging, sometimes extensively, they exploit drier tundra habitats as well, typically nesting in drier upland tundra. Because of this, they are unlikely to be significantly affected by a tundra drying trend in the arctic which could result in a net loss of wet tundra habitats. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus moisture balance, as an exposure factor (most influential on the "hydrological niche" sensitivity category), was not heavily weighted in the assessment.



Disturbance Regime: In terms of climate-mediated disturbances, deeper snow and subsequent flooding in early spring could reduce hunting success. Additionally, increased fires (Racine et al. 2004) could reduce available hunting and nesting areas but it is likely this would not result in significant impacts as the effects of these disturbances would be localized. However, over time (probably >50 years to be significant) increased fires could accelerate shrubification (Tape et al. 2006) reducing habitat quality.

Snowy Owl (*Bubo scandiacus*)
Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*	*			
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*			
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Physiological Thermal Niche: While habitat and prey are available further south, Snowy owl breeding range in the Arctic LCC is restricted along a 50-100km band along the Alaskan coastline, where temperatures are cooler compared to inland in the summer, suggesting a potential thermal sensitivity.

Phenological Response: There is at least one long-term data set in Arctic Alaska that could shed some light on how this species phenology may be changing with climate (D. Holt, pers. comm.). To date, though, it has not been analyzed so it is unknown how this species is or will respond to changing biotic schedules.

In summary, Snowy Owls certainly have some life history traits that potential make them vulnerable to climate change. However, within the time frame of this assessment this species will likely be able to cope with impacts associated with a changing climate and remain stable.

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Short-eared Owl (*Asio flammeus*)

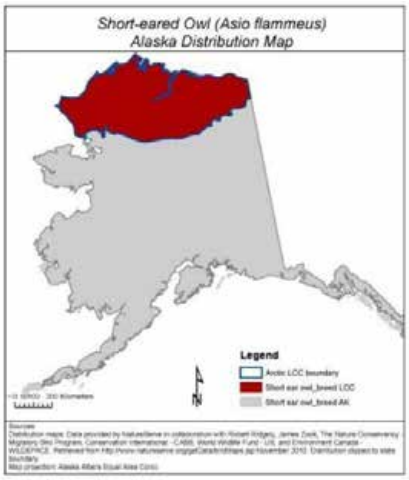
Vulnerability: **Presumed Stable** Confidence: High

The Short-eared Owl occurs widely throughout North America. An owl of open country, they nest on the ground inhabiting marshes, grasslands, and tundra throughout their range. Like Snowy Owls, Short-eared owl population dynamics are linked to cycles in their primary prey - small mammals (Holt and Leasure 1993). In the Alaskan Arctic, they typically nest on drier tundra sites, usually with enough vegetation to conceal incubating females. They often forage in wet tundra habitats, though not exclusively (Holt and Leasure 1993). Short-eared Owls migrate to wintering grounds in the lower 48 and northern Mexico (Holt and Leasure 1993). The current global population is estimated at 2 million (Rich et al. 2004).

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America and other range descriptions (Johnson and Herter 1989, Holt and Leasure 1993).

Interactions with Other Species: Like the Snowy owl, Short-eared Owl successful reproduction seems to be tied to some degree to lemming population cycles (Holt and Leasure 1993). Climate change has increased the length of lemming population cycles and decreases maximum population densities (Ims and Fuglei 2005, Gilg et al. 2009) which could negatively influence Short-eared Owl nest survivorship, distribution, and abundance. However, their ability to switch to a variety of other prey sources suggest they would, in most cases, be able to compensate for such changes with little negative impact.

Physiological Hydro Niche: Although Short-eared Owls do utilize wet tundra habitats for foraging, sometimes extensively, they exploit drier tundra habitats as well and they typically nest in drier upland tundra. Because of this, they are unlikely to be significantly affected by tundra drying events in the arctic, which could result in a net loss of wet tundra habitats. However, current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP).



Disturbance Regimes: Deeper snow and subsequent flooding in early spring could reduce hunting success. Fires and resulting shrubification (Tape et al. 2006) may reduce available hunting and nesting areas, but it is unlikely this would result in significant impacts, as the percentage of ground affected would be minimal. Thermokarst will likely change upland tundra habitats to new vegetation communities (Martin et al. 2009) but it is unknown how these new communities may or may not be suitable for Short-eared Owls.

Interspecies Interactions: Increased freeze/thaw and icing events could eliminate rodent cycles and keep their populations relatively low (Gilg et al. 2009).

Human Response to CC: Increasing power lines associated with a wider-ranging road network or other human activities in response to climate change could cause direct mortality, but the extent of such infrastructure will likely be minimal in the near future.

Short-eared Owl (*Asio flammeus*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*	*			
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*			
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*	*	*		
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response			*				*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Physiological Thermal Niche: Because Short-eared Owls breed over a wide latitudinal gradient, there is no evidence to suggest that they have any thermal sensitivity during nesting. They could actually benefit from warmer temperatures at the northern terminus of their breeding range via reduction in cold stress.

Phenological Response &Genetic Variation: There currently exists little or no information regarding the genetic or phenological traits that would make this species more or less vulnerable to a warming climate.

In summary, while Short-eared Owls have some life history traits that potentially make them vulnerable to climate change, within the time frame of this assessment this species will likely be able to cope with impacts associated with a changing climate and remain stable.

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Common Raven (*Corvus corax*)

Vulnerability: **Presumed Stable** Confidence: Moderate

The Common Raven is wide-ranging throughout much of North America utilizing a variety of habitats from deserts in the southwestern U.S. to tundra habitats in Arctic Alaska (Boarman and Heinrich 2000). Historically, this species did not nest in the northern portion of the Arctic Coastal Plain of Alaska but with the growing human presence in the region, particularly from oil development activities, they have been able to utilize human structures for nesting (Johnson and Herter 1989, Day 1998). Ravens are a generalist species and take advantage of a wide variety of prey and are a noted nest predator. Although some individuals may move south in the winter, many remain on the coastal plain (Johnson and Herter 1989). The global population is estimated at 16 million (Rich et al. 2004).

J. Liebezeit @ WCS

Range: We adjusted the NatureServe map to match the Birds of North America range map for this assessment as it more accurately represented this species' range based on other accounts and personal observations (Johnson and Herter 1989, S. Backensto, J. Liebezeit, pers. obs.) The Nature Serve map did not include the raven range extending to the Arctic Ocean coastline.

Based on the assessment ravens are likely to be slightly less vulnerable in five categories and slightly more vulnerable in two, but overall climate change impacts will have little impact ("neutral") on this species (see table on next page).

Human Response to CC: Increased human activity and infrastructure associated with climate change mitigation could benefit ravens as witnessed by the influence of current human developments in the region on raven populations. However, in the next 50 years, there likely will be no significant development of this type in Arctic Alaska so it would only have nominal influence on ravens.

Physiological Thermal Niche: Ravens use warm thermal environments created by oil processing facilities to roost and some breeding pairs in the oil fields place their nests on heated structures. On the Colville river, nests oriented to southerly aspects are common (S. Backensto, pers. comm.). No studies have indicated if these behaviors actually benefit ravens (e.g. increase nest survivorship). Despite this, these behaviors suggest they may benefit from a warming climate by reducing the physiological stress of cold temperatures during key parts of their lifecycle.

Physiological Hydro Niche: Ravens can withstand dramatic extremes in moisture regime tolerances as is exhibited by the fact that they are equally at home in the Mojave Desert as they are in the wet Pacific Northwest. Therefore, a drier or wetter arctic will unlikely have a negative impact on this species.

Dietary Versatility: The ravens' varied diet and ability to exploit human food subsidies could

Common Raven (*Corvus corax*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC		*	*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*				
C2c. Disturbance regime			*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions			*	*			
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*					
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

benefit this species as the climate warms, human activity in the region increases, and the food base changes.

Physical Habitat Restrictions: Despite raven use of human structures for nesting on the coastal plain, overall, nesting sites are still quite limited since they depend on relatively uncommon geologic features (e.g. cliffs, river banks). This paucity of adequate breeding sites will still be a key limiting factor for this species.

Genetic Variation: Although genetic studies on Alaskan raven populations have not been completed, they do tend to have high genetic variation (Webb et al. 2011) and thus would be less susceptible to disease and other disturbance events.

Phenological Response: Currently, there are no long term data sets to provide sufficient information on raven phenological response to climate change in the Arctic and so it is unknown how they will respond to changing biotic schedules.

In summary, the generalist nature of this species, combined with their high adaptability and expansive range suggests ravens will remain stable in the region with regard to climate change impacts during the 50 year timeline of this assessment.

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American Tree Sparrow (*Spizella arborea*)

Vulnerability: **Increase Likely** Confidence: Moderate

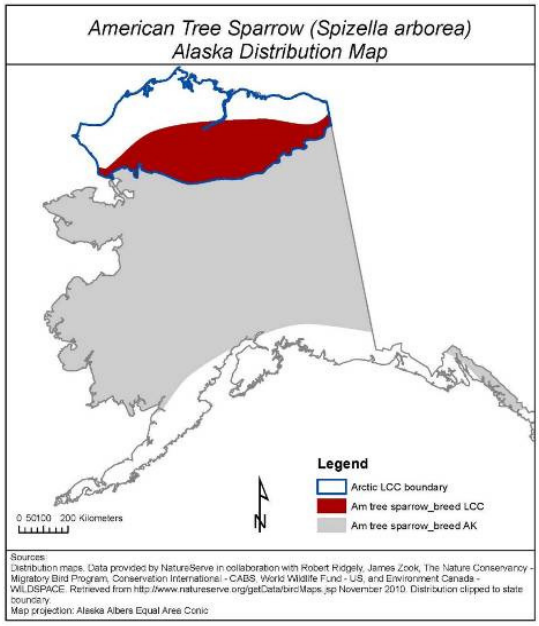
The American Tree Sparrow is a common breeding bird of boreal and tundra dominated habitats in northern Canada and Alaska. This species breeds in open scrubby areas; willow, birch, and alder thickets, stunted spruce, open tundra with scattered shrubs, often near lakes or bogs (Naugler 1993). In summer American Tree Sparrows consume a wide variety of animal prey (primarily both larval and adult insects). Alaskan birds are short-distance migrants and winter in temperate North America (Naugler 1993). This species' population is very large (>10 million) although the overall population has undergone a small (statistically insignificant) decrease over the last 40 years in North America (Butcher and Niven 2007).

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America (Naugler 1993) and other range descriptions (Johnson and Herter 1989).

For most of the sensitivity categories in the assessment, American Tree Sparrows were ranked with a neutral response (see table on next page) and for five categories, they ranked as potentially having decreased vulnerability. As shrubby and boreal habitats increase on the North Slope (Tape et al. 2006), American Tree Sparrows will be able to exploit new areas and potentially expand their breeding range further northward.

Human Response to Climate Change: In their lower 48 wintering range, this species is known to adapt well to human-dominated environments and are a frequent bird in suburban settings (Naugler 1993). Because of this, any increase in human presence (e.g. activities associated with climate change mitigation) will likely have no negatively impact on this species.

Physiological Thermal Niche: Because this species tolerates warm temperatures at breeding sites in the Alaskan interior and further south, it is unlikely that a warming climate will compromise this species' physiological ability to adapt thermally. Warming could actually facilitate northern expansion of their range.



Physiological Hydrologic Niche: American Tree Sparrow breeding territories are generally found near water, such as bogs, lakes or riparian areas, and so it is possible that an arctic drying trend could negatively impact this species. However, a drying trend is more likely to affect shallow ponds and emergent tundra which are less likely to be utilized by this riparian-oriented species. Current projections of annual potential evavapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP) and so wet habitats may only be minimally impacted.

American Tree Sparrow (*Spizella arborea*)

Vulnerability: **Increase Likely** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*			
C2c. Disturbance regime		*	*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions			*				
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*				*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: One common breeding passerine, the Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data), but it is unknown whether this result can be generalized. During a 20-year period (1992-2011) American Tree Sparrows have shown no significant shift in earlier or later departure dates from the Alaska Bird Observatory's banding station in Fairbanks, Alaska (S. Guers, unpublished data). However, there are apparently no other long-term datasets for this species' breeding or migration activities and so little else is known regarding phenology in this species (S. Guers, pers. comm.).

In general, this vulnerability assessment suggests that American Tree Sparrows will likely increase, potentially expanding their breeding range in Arctic Alaska under the current predictions of climate change.

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Savannah Sparrow (*Passerculus sandwichensis*)

Vulnerability: **Increase Likely** Confidence: Very High

The Savannah Sparrow has a widespread breeding range across North America from the southern U.S. to Arctic Alaska. This species will breed in open habitats ranging from meadows, cultivated fields, grazed pastures, roadsides, coastal grasslands and tundra (Wheelwright and Rising 2008). On the coastal plain of Arctic Alaska, tundra nesting habitat is often associated with stream/river drainages, nesting on the ground often hidden under low shrubs (Wheelwright and Rising 2008). During the breeding season they forage in a wide range of habitats on a variety of insect prey although seeds and other vegetative matter are also consumed (Wheelwright and Rising 2008). Savannah Sparrows are short-distance migrants and winter in the southern U.S. and Mexico (Wheelwright and Rising 2008). The North American population trend is currently stable (Wheelwright and Rising 2008).

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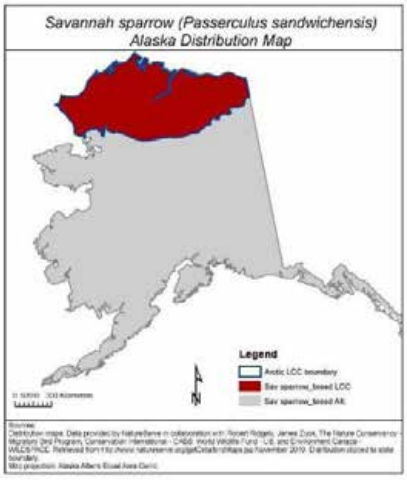
Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America and other range descriptions (Johnson and Herter 1989, Wheelwright and Rising 2008).

For most of the indirect exposure and sensitivity categories in the assessment, Savannah Sparrows were scored with a neutral response (see table on next page). For five categories their traits were considered to decrease vulnerability.

Human Responses to CC: Across their range Savannah Sparrows have generally benefited from human activity, and their densities over the past century are probably greater than at any time in the past because of this species' dependence on human-modified open habitats (e.g. fields, hay fields, cropland) (Wheelwright and Rising 2008). Based on this pattern, human responses to climate change in the Arctic LCC will likely either have no impact or potentially benefit this species.

Physiological Thermal Niche: As they are at the northern extreme of their breeding range in Arctic Alaska, Savannah Sparrows may actually benefit from a warmer climate, particularly during the nestling stage when their thermoregulatory capacity is compromised and cold snaps can be frequent and potentially lethal (Barry 1962) early in the breeding season. At some point, ambient temperatures may exceed a critical point in their ability to adjust physiologically, however the magnitude of climate warming estimated for the next 50 years is likely not great enough for this to be an issue (Martin et al. 2009).



Physiological Hydro Niche: Savannah Sparrows are not known to be closely associated with aquatic/wetland habitats or moisture regimes although they do often use habitats along riparian stretches on the coastal plain (J. Liebezeit, unpublished data.). Reduction in invertebrate communities from net drying affect could negatively affect foraging success during the breeding season but current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the

Savannah Sparrow (*Passerculus sandwichensis*)

Vulnerability: **Increase Likely** Confidence: Very High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC		*	*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*	*		
C2c. Disturbance regime			*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation		*					
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response			*				

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

foreseeable future (TWS and SNAP). Also this species could potentially switch to less aquatic-dependent prey as they have a broad diet (Wheelwright and Rising 2008).

Genetic Diversity: Savannah Sparrows exhibit high genetic diversity (Zink et al. 2005) and would thus likely be more resilient to disease and other disturbance events than species with lower genetic diversity.

Phenological Response: One common breeding passerine, the Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data), but it is unknown whether this result can be generalized. During a 20-year period (1992-2011) Savannah Sparrows have shown no significant shift in earlier or later departure dates from the Alaska Bird Observatory's banding station in Fairbanks, Alaska (S. Guers, unpublished data). Little else is known regarding phenology in this species (S. Guers, pers. comm.).

In general, this assessment suggests that Savannah Sparrows exhibit high flexibility in habitat use and behavior and so will likely increase under current predictions of climate change.

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White-crowned Sparrow (*Zonotrichia leucophrys*)

Vulnerability: **Increase Likely** Confidence: High

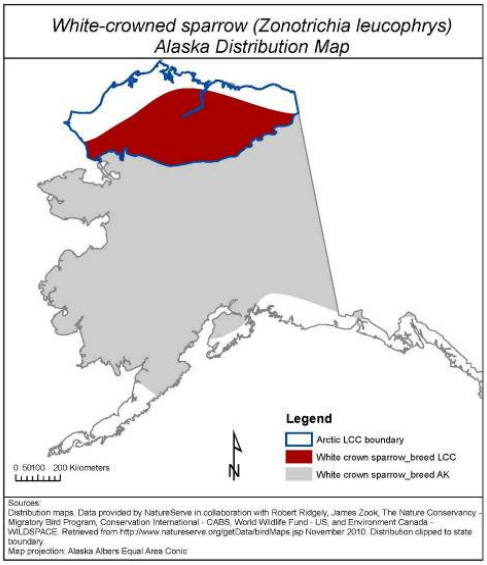
The White-crowned Sparrow is a common breeding bird from the Pacific Coast in the Lower 48 to the northern extent of its range in Arctic Alaska (Chilton et al. 1995). The Gambel's subspecies, the breeder in Alaska, is most commonly associated with shrubby riparian habitats that run through both boreal and tundra environs. White-crowned Sparrows consume a wide variety of plant and animal prey and during the breeding season feed their young a strict diet of insect and other animal prey. Alaskan birds are short-distance migrants and winter in temperate North America (Chilton et al. 1995). Overall White-crowned Sparrow populations appear to be stable (Chilton et al. 1995).

Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America (Chilton et al. 1995) and other range descriptions (Johnson and Herter 1989).

For most of the indirect exposure and sensitivity categories in the assessment, White-crowned Sparrows were scored as neutral (see table on next page), and for five categories, they ranked as potentially having decreased vulnerability. As shrubby and boreal habitats increase on the North Slope (Tape et al. 2006), White-crowned Sparrows will be able to exploit new areas and potentially expand their breeding range further northward (Martin et al. 2009).

Human Response to CC: In their Lower 48 wintering range, this species is known to adapt well to human-dominated environments and are a frequent bird in suburban settings. Because of this, any increase in human presence (e.g. activities in response to climate change) will likely have no negative impact on this species, and could, in fact, be beneficial through increasing habitat patchiness and heterogeneity.

Physiological Thermal Niche: Because this species tolerates warm temperatures at breeding sites in the Alaskan interior and further south, it is unlikely that a warming climate will compromise its physiological ability to adapt thermally. Warming could actually facilitate northern expansion of their range by reducing cold stress, particularly during the nesting period.



Physiological Hydro Niche: White-crowned Sparrow breeding territories are generally found near a source of water (standing or running), and so it is possible that a drying trend could negatively impact this species. However, a drying trend would more likely affect shallow ponds and emergent tundra which are less likely to be utilized by this riparian-oriented species. Also, it is important to point out that current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP).

White-crowned Sparrow (*Zonotrichia leucophrys*)

Vulnerability: **Increase Likely** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC		*	*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*			
C2c. Disturbance regime			*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation			*				
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response:
One common breeding passerine, the Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data), but it is unknown whether this result can be generalized. For White-crowned Sparrows, there are long-term data sets available from bird banding stations in Fairbanks (Alaska Bird Observatory), Tok (Tetlin National Wildlife Refuge), and near Denali National Park (Alaska Bird Observatory) that include spring arrival dates and fall departure dates. Unfortunately, these data have not been examined or the year-to-year variation makes it difficult to see trends (S. Sharbaugh, pers. comm.).

In general, this assessment suggests that White-crowned Sparrows will likely increase and expand their breeding range in Arctic Alaska under the current projections of climate change.

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The Wilderness Society (TWS) and Scenarios Network for Alaska Planning (SNAP), Projected (2001-2099: A1B scenario) monthly total potential evapotranspiration from 5 AR4 GCMs that perform best across Alaska and the Arctic, utilizing 2km downscaled temperature as model inputs. http://www.snap.uaf.edu/data.php.

Lapland Longspur (*Calcarius lapponicus*)

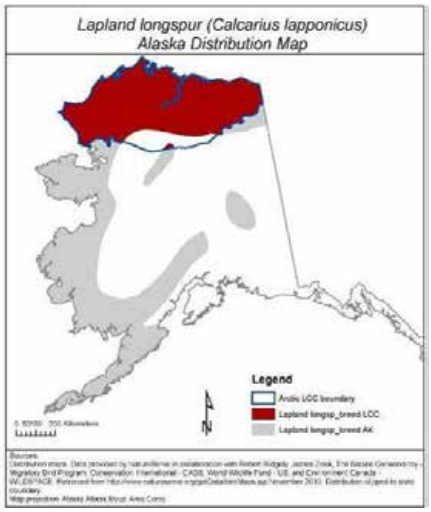
Vulnerability: **Increase Likely** Confidence: Moderate

The Lapland Longspur is the most abundant passerine breeder on the North Slope of Alaska. This species is most commonly associated with the Arctic Coastal Plain, but also nests in alpine habitats in the interior Brooks Range. High nesting densities have been found throughout the Alaskan coastal plain (Custer and Pitelka 1977, Liebezeit et al. 2011) with nesting sites often in dry/moist tundra near tussocks and less frequently in wetter tundra habitats (Hussell and Montgomerie 2002). During the breeding season they typically forage in a wide range of habitats on a variety of invertebrates but also consume seeds and other vegetative matter (Hussell and Montgomerie 2002). Alaskan Lapland Longspurs are short-distance migrants and are believed to winter in temperate North America. Current North American population estimate is 40-50 million.

Range: We used the extant NatureServe range map for this assessment as it closely matched the Birds of North America and other range maps (Hussell and Montgomerie 2002, Bart et al. 2012).

For most of the indirect exposure and sensitivity categories in the assessment, Lapland Longspurs were ranked with a neutral response (see table on next page). For five categories, longspurs were ranked as potentially having decreased vulnerability. For two categories ("habitat restrictions" and "biotic dispersal potential") this ranking is a reflection of this species ubiquitous range across the assessment area and flexible usage of habitats for both nesting and foraging.

Physiological Thermo Niche: Longspurs may actually benefit from a warmer physiological thermal niche, particularly during the nestling stage when their thermo-regulatory capacity is compromised and cold snaps can be frequent and potentially lethal (Barry 1962) early in the breeding season. At some point, ambient temperatures may exceed a critical tipping point in longspur ability to adjust physiologically, however summer climate warming estimates in the next 50 years are probably not drastic enough for this to be an issue (Martin et al. 2009).



Phenological Response: Some evidence indicates that Lapland Longspurs are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data) suggesting they may be able to compensate for a warming climate, at least in terms of nest timing. However their ability to cope with decoupling of nest initiation and other events is unknown.

Physiological Hydro Niche: In terms of hydrological niche, longspurs may experience some detrimental impact as they do have some level of dependency on wetter habitats. They would unlikely be significantly affected. In fact, a drying trend could expand preferred habitat. It is important to note that current moisture

Lapland Longspur (*Calcarius lapponicus*)

Vulnerability: **Increase Likely** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*	*		
C2c. Disturbance regime			*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility			*				
C4d. Biotic dispersal dependence		*	*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

balance predictions suggest, at best, negligible drying for the foreseeable future (TWS and SNAP). Thus moisture balance, as an exposure factor was not heavily weighted in the assessment.

Disturbance regime: Unlike many of the shorebirds and waterfowl species, longspurs are not dependent on shoreline habitats and so would likely not be significantly impacted by rising sea level or coastal disturbance events.

Overall, this assessment suggests that Lapland Longspus could benefit and possibly increase under the current predictions of climate change during the timeframe of this assessment.

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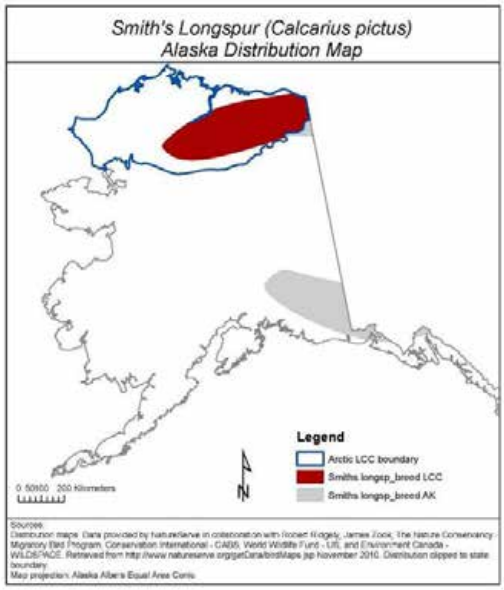
Smith's Longspur (*Calcarius pictus*)

Vulnerability: **Presumed Stable** Confidence: Very High

The Smith's Longspur is a relatively understudied passerine breeder on the North Slope of Alaska. In this region, they are most commonly associated with the Brooks Range foothills where they are found in broad valleys and low passes (S. Kendall, pers. comm.). Smith's Longspurs are known for their polygynandrous mating system which is unusual in passerines. In arctic Alaska, this species nests on open tundra, from upland hummocky terrain (Briskie 2009) to wet meadow habitats (Johnson and Herter 1989). During the breeding season they forage on a variety of invertebrates but also consume seeds and other vegetation (Briskie 2009). Smith's Longspurs are short-distance migrants and winter in the U.S. Midwest. Current population estimate is unknown but the trend is believed to be stable (BirdLife International 2012).

Range: We used the extant NatureServe range map for the assessment as it closely matched that described in the Birds of North America (Briskie 2009) and other range descriptions (Johnson and Herter 1989).

Physiological Hydro Niche: Smith's Longspurs were ranked as potentially most vulnerable to climate change in the physiological hydrological niche although the range from "neutral" to "increased" vulnerability selected in these categories reflects uncertainty in the severity of impact (see table on next page). This species relies to some degree on wet tundra habitats for foraging and nesting. They also tend to nest in association with rivers and streams and may utilize riparian areas for foraging more than is currently documented (S. Kendall, pers. comm.). Reduction in invertebrate communities and habitat loss from a net drying affect could negatively impact foraging success and nest site availability during the breeding season. But current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Also, this species could switch to less aquatic-dependent prey as they apparently have a broad diet (Briskie 2009).



Disturbance Regime: An increase in fires (Racine and Jandt 2008) would likely degrade Smith's Longspur breeding habitat, but impacts are mostly unknown and likely would be localized (S. Kendall, pers. comm.). The current regime of infrequent fires in tundra habitat allows for the growth of dwarf and tall/low shrubs which are habitats utilized by this species. Increased flooding in streams and rivers could affect riparian habitat but it is unknown how these events might impact Smith's Longspur use of these habitats.

Genetic Variation: There is little information in the literature regarding genetic variation or recent evolutionary bottlenecks for this species.

Smith's Longspur (*Calcarius pictus*)

Vulnerability: **Presumed Stable** Confidence: Very High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*				
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche			*	*	*		
C2c. Disturbance regime			*	*			
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response: Although some evidence indicates that their relative, the Lapland Longspur, is able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack unpublished data) this has not been documented for Smith's Longspurs. Their ability to cope with decoupling of nest initiation and other phenological events (Tulp and Schekkerman 2008), on which they are dependent, is also unknown.

In summary, this assessment suggests that Smith's Longspurs have enough flexibility to remain stable under the current predictions of climate change within the 50 year timeframe of this assessment.

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Snow Bunting (*Plectrophenax nivalis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

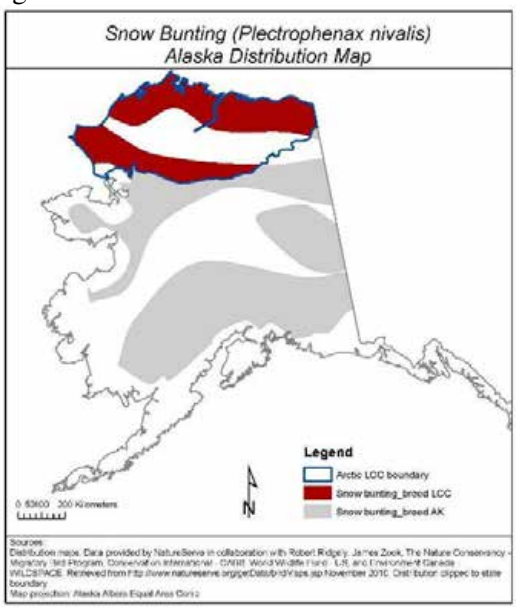
The Snow Bunting is one of the first birds to return to their Arctic breeding grounds, with males arriving in early April. This species occurs throughout the circumpolar arctic and, as a cavity-nester, will use human-made nest sites (e.g. barrels, buildings, pipelines) as readily as natural ones (rock cavities, under boulders, cliff faces; Lyon and Montgomerie 1995). Snow Buntings consume a wide variety of both plant (e.g. seeds, plant buds) and animal prey (invertebrates). Their wintering range is centered in the northern continental US and southern Canada although it extends north into the low arctic in some places (Lyon and Montgomerie 1995). Current global population estimate is 40 million (Rich et al. 2004).

Range: We used the extant NatureServe range map for the CCVI as it matched the Birds of North America and other range descriptions (Johnson and Herter 1989).

Human Response to CC: Increased human activity and infrastructure associated with human response to climate change could benefit Snow Buntings by providing increased artificial nesting habitat, as they are known to readily take advantage of human infrastructure (Lyon and Montgomerie 1995, J. Liebezeit, pers. obs.). Because it is unlikely that there will be significant development of this type in Arctic Alaska, the influence on this species would be nominal.

Physiological Thermal Niche: Changes in thermal and hydrological niche will likely not offer a significant benefit or disadvantage for this species. Increasing temperatures could make some nesting sites "too hot" while, in others cases provide warmer conditions beneficial for raising altricial young.

Physiological Hydro Niche: Snow buntings will utilize wet tundra for foraging but are not tied strongly to water-dominated habitats (Lyon and Montgomerie 1995) and so any tundra drying in Arctic Alaska (see Martin et al. 2009) is not likely to have a strong negative or positive affect on this species. Current projections of annual potential evapotranspiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Thus atmospheric moisture, as an exposure factor, was not heavily weighted in the assessment.



Dietary Versatility: The Snow Bunting's varied omnivorous diet will likely be beneficial to this species as the climate warms, human activity in the region increases, and the food base changes.

Physical Habitat Restrictions: Despite bunting use of human structures for nesting, nesting sites on the coastal plain are still quite limited since they depend on relatively uncommon geologic features (e.g. cliffs, rock outcrops). This paucity of adequate breeding sites on the coastal plain will likely continue to be a limiting factor for this species.

Snow Bunting (*Plectrophenax nivalis*)

Vulnerability: **Presumed Stable** Confidence: Moderate

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC	*		*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*			
C2c. Disturbance regime			*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions				*			
C4a. Biotic habitat dependence			*				
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks							*
C6. Phenological response		*	*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Genetic Varitation: There are currently no Snow Bunting studies that add insight into how climate change impacts would influence their population genetics.

Phenological Response: There are also no long-term data sets to provide sufficient information on how Snow Buntings will respond to changing arctic phenology.

In summary, this vulnerability assessment suggests that Snow Buntings are relatively flexible in most sensitivity factors and have an expansive enough breeding range to adjust to climate changes and remain stable (and potentially even benefit) in the region over the next 50 years.

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Common Redpoll (*Acanthis flammea*)

Vulnerability: **Increase Likely** Confidence: Low

The Common Redpoll is an abundant finch of northern regions around the world. Redpolls occur throughout Alaska, thriving in habitats ranging from boreal to tundra across a wide elevation gradient (Knox and Lowther 2000). This species nests in trees when available. In tundra habitats, they nest in willows (primarily along riparian areas) or on the ground (Knox and Lowther 2000, J. Liebezeit, unpublished data). While primarily a seed eater, in summer this species consumes arthropods to feed young (Knox and Lowther 2000). Common Redpolls winter as far north as the Brooks Range but will wander further south in irruptive years when seed-crop production fails (Knox and Lowther 2000). While their global population numbers in the millions, they are believed to be experiencing an overall population decline (Rich et al. 2004).

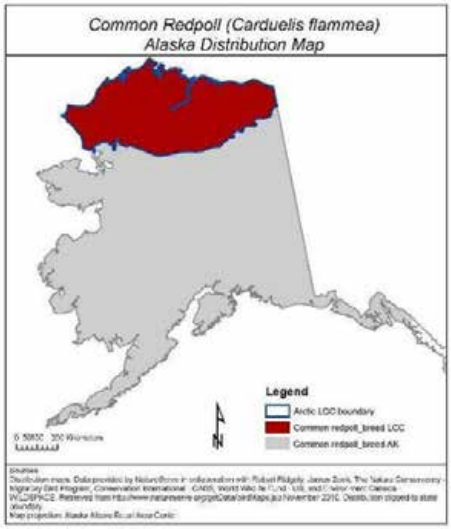
Range: We used the extant NatureServe range map for this assessment as it closely matched the Birds of North America (Knox and Lowther 2000) and other range descriptions (Johnson and Herter 1989).

For most of the indirect exposure and sensitivity categories in the assessment, Common Redpolls were ranked with a neutral response (see table on next page).

Physiological thermal niche: This species shows no close association with a particular thermal environment. Early work has shown that their upper thermal limit is ~38ºC and can withstand temperatures as low as -51ºC (Brooks 1968, S. Sharbaugh, pers. comm.). As such, they would likely be able to withstand a warming climate for years to come although little is known about thermal conditions necessary for successful hatch and fledging of their altricial young.

Physiological hydro niche: Common Redpolls are not known to be closely associated with aquatic/wetland habitats or moisture regimes (Knox and Lowther 2000) though they do often use willow habitats along riparian stretches on the coastal plain (J. Liebezeit, unpublished data.). Reduction in invertebrate communities from net drying could negatively affect foraging success during the breeding season. Current projections of annual potential evapo-transpiration suggest negligible atmospheric-driven drying for the foreseeable future (TWS and SNAP). Also, this species could potentially switch to less aquatic-dependent prey as they have a broad diet (Knox and Lowther 2000).

Disturbance Regime: As shrubby and boreal habitats increase on the North Slope (Tape et al. 2006), Common Redpolls will be able to exploit new areas and potentially nest in higher densities on the coastal plain. An increase in fire frequency could speed up the advance of shrubification (Racine et al. 2004).



Phenological Response: One common breeding passerine, the Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data), but it is unknown whether this result can be generalized. However there are apparently

Common Redpoll (*Acanthis flammea*)

Vulnerability: **Increase Likely** Confidence: Low

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche		*	*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*			
C2c. Disturbance regime		*	*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

no long-term datasets for Common Redpoll breeding or migration activities and so little is known regarding phenology in this species (S. Sharbaugh, pers. comm.).

In general, this assessment suggests that Common Redpolls will likely increase in Arctic Alaska under the current projections of climate change. They would likely take advantage of new shrubby nesting habitats and have enough flexibility, both physiologically and behaviorally, to cope with expected climate changes over the next 50 years in Arctic Alaska.

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Hoary Redpoll (*Acanthis hornemanni*)

Vulnerability: **Presumed Stable** Confidence: High

The Hoary Redpoll, closely related and often difficult to distinguish from the Common Redpoll, is a common finch of the circumpolar arctic. In Alaska their range is largely sympatric with the Common Redpoll although they tend to be more common further north. Like the Common Redpoll, they utilize both forested and tundra habitats although they tend to utilize tundra habitats more extensively (Knox and Lowther 2000). In Arctic Alaska tundra, this species nests in willows (primarily along riparian areas) or on the ground in shrubby areas (Knox and Lowther 2000, J. Liebezeit, unpublished data). While primarily a seed eater, in summer this species consumes arthropods to feed young (Knox and Lowther 2000). Hoary Redpolls often winter within their breeding range but will wander further south in irruptive years when seed-crop production fails (Knox and Lowther 2000). Their overall population estimate is unknown.

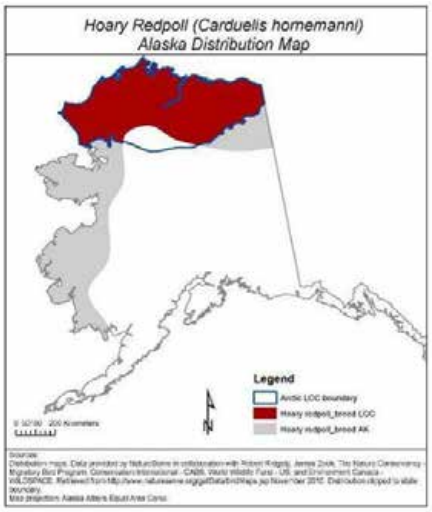
Range: We used the extant NatureServe range map for the assessment as it closely matched the Birds of North America and other range descriptions (Johnson and Herter 1989, Knox and Lowther 2000).

For most of the indirect exposure and sensitivity categories in the assessment, Hoary Redpolls were ranked with a neutral response (see table on next page).

Physiological Thermo Niche: This species shows no close association with a particular thermal environment. Early work has shown that their upper thermal limit is ~38ºC and can withstand temperatures as low as -57ºC (Brooks 1968, S. Sharbaugh, pers. obs.). As such, they would likely be able to withstand a warming climate although little is known about thermal conditions necessary for successful hatch and fledging of their altricial young. They tend to nest further north in greater numbers than Common Redpoll, which suggests some affinity for colder temperatures although this behavior could be related to a factor(s) unrelated to thermal conditions.

Physiological Hydro Niche: Hoary Redpolls are not known to be closely associated with aquatic/wetland habitats or moisture regimes although they do rely on willow habitats along riparian stretches on the coastal plain (Knox and Lowther 2000, J. Liebezeit, unpublished data) more than Common Redpolls which will often choose willows in more upland tundra (Knox and Lowther 2000).

Dietary Versatility: Reduction in invertebrate communities from net drying affect could negatively affect foraging success during the breeding season but current predictions for changes in atmospheric drying are neglibile (TWS and SNAP). Also, this species could potentially switch to less aquatic-dependent prey as they have a broad diet (Knox and Lowther 2000).



Disturbance Regime: As shrubby and boreal habitats increase on the North Slope (Tape et al. 2006), Hoary Redpolls will be able to exploit new areas and potentially nest in higher densities on the coastal plain. An increase in fire frequency could speed up the advance of shrubification (Racine et al. 2004).

Hoary Redpoll (*Acanthis hornemanni*)

Vulnerability: **Presumed Stable** Confidence: High

Vulnerability Factors	D	SD	N	SI	I	GI	Unknown or N/A
B1. Sea level rise			*				
B2a. Natural barriers			*				
B2b. Anthropogenic barriers			*				
B3. Human response to CC			*				
C1. Dispersal/Movement			*				
C2ai. Historical thermal niche (GIS)			*				
C2aii. Physiological thermal niche			*	*			
C2bi. Historical hydro niche (GIS)			*				
C2bii. Physiological hydro niche		*	*	*			
C2c. Disturbance regime		*	*				
C2d. Ice & Snow habitats			*				
C3. Physical habitat restrictions		*					
C4a. Biotic habitat dependence			*	*			
C4b. Dietary versatility		*	*				
C4d. Biotic dispersal dependence			*				
C4e. Interactions with other species			*				
C5a. Genetic variation							*
C5b. Genetic bottlenecks			*				
C6. Phenological response			*	*			*
D1. CC-related distribution response							*

D=Decrease vulnerability, SD=Somewhat decrease vulnerability, N=Neutral effect, SI=Slightly increase vulnerability, I=Increase vulnerability, GI=Greatly increase vulnerability.

Phenological Response:

One common breeding passerine, the Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data), but it is unknown whether this result can be generalized. However, there are apparently no long-term datasets for Hoary Redpoll breeding or migration activities and so little is known regarding phenology in this species (S. Sharbaugh, pers. comm.).

In general, this assessment suggests that Hoary Redpolls will likely remain stable in Arctic Alaska under the current projections of climate change. Though within the "presumed stable" category, assessment results suggest they do lean toward the "increase likely" category as they could take advantage of new shrubby nesting habitats and have enough flexibility, both physiologically and behaviorally, to cope with expected climate changes over the next 50 years in Arctic Alaska.

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Appendix C

Summary of the Climate Change Vulnerability Assessments For Winter Range and Passage Migration

Shorebirds are long distant migrants and only spend a short part of their lives on the breeding grounds. At migration stopover points and on the wintering grounds they inevitably encounter climate change stressors that may be quite different than on the breeding grounds. For this reason, we conducted separate climate change vulnerability assessments for 17 shorebird species[1] (Table AB.1) focused on their wintering grounds and key passage migration areas. The intent was to provide a climate change vulnerability ranking combining all three portions of their lifecycle for an overall vulnerability score spanning their entire annual range. The results of the additional assessments are preliminary since shorebird usage of stopover and wintering areas (particularly in South America and Asia) is poorly known, and reviewers recommended major modifications to our method for evaluating vulnerability during passage migration that were too significant to address within the timeframe of the current project. Here we offer a brief summary of the pilot effort.

Winter Range Vulnerability Assessment: Methods and Results

Methods: We assessed the vulnerability of the 17 shorebird species in their wintering grounds using the NatureServe Climate Change Vulnerability Index tool (CCVI Version 2.1, Young et al. 2010) as we did for the breeding grounds assessment. We engaged experts from within and outside the United States to score the sensitivity factors. Overall, the methods were nearly identical to those described previously (see Methods in main body of the report). The key differences included:

- The assessment was based on the entire winter range of each species. The ranges were often quite large, commonly capturing significant climate variability (e.g., Figure AB.1). For species that winter in the Western Hemisphere, we used winter ranges offered through NatureServe as a starting point. For species wintering in the Austral-Asian flyway, GIS shapefiles were initially sought through the USGS Alaska Science Center Avian Influenza Research program (http://alaska.usgs.gov/science/biology/avian_influenza/index.php). Edits to the initial range maps for both the Western Hemisphere and Austral-Asian flyway were made based on comments or alternate sources suggested by experts who completed the sensitivity surveys. Initial range maps were also compared with GIS shapefiles published by Bird Life International, but this source was not used as a basis for altering maps (http://www.birdlife.org/datazone).

- We used Climate Wizard's 50-km resolution climate projection data exclusively, as it was the only readily accessible climate data available for all the continents (www.climatewizardcustom.org/).

[1] The same 17 included in the breeding season assessment

- Only one scenario of future climate was considered for each species, which was the ensemble output of the16 general circulation models (GCMs) from the IPCC report (IPCC 2007).
- There were no readily available data for the climate change effects on the pelagic winter ranges of both phalarope species. Geospatial data of historical changes in ocean temperature and acidification were used as proxies (Halpern et al. 2008- http://www.nceas.ucsb.edu/globalmarine).

Table AB.1. Seventeen shorebird species considered in the vulnerability assessment.

Common Name	Scientific Name
Black-bellied Plover	*Pluvialis squatarola*
American Golden-plover	*Pluvialis dominica*
Whimbrel	*Numenius phaeopus*
Bar-tailed Godwit	*Limosa lapponica*
Ruddy Turnstone	*Arenaria interpres*
Red Knot	*Calidris canutus*
Semipalmated Sandpiper	*Calidris pusilla*
Western Sandpiper	*Calidris mauri*
White-rumped Sandpiper	*Calidris fuscicollis*
Baird's Sandpiper	*Calidris bairdii*
Pectoral Sandpiper	*Calidris melanotos*
Dunlin	*Calidris alpina*
Stilt Sandpiper	*Calidris himantopus*
Buff-breasted Sandpiper	*Tryngites subruficollis*
Long-billed Dowitcher	*Limnodromus scolopaceus*
Red-necked Phalarope	*Phalaropus lobatus*
Red Phalarope	*Phalaropus fulicarius*

Figure AB.1. An example of a range map used in the winter range assessment.

Results: The results of the assessment indicate that 5 of the 17 species we considered were highly (Long-billed Dowitcher, Black-bellied Plover) or moderately (Western Sandpiper, Semipalmated Sandpiper, and Dunlin) vulnerable to climate change in their winter ranges (Figure AB.2). The sensitivities or indirect exposure factors contributing to the vulnerability of these species included dependencies on physiological hydrological niche, sea level rise impacts, changes to key disturbance regimes, and impacts by human activities in response to climate change. The life history and other information provided for the remaining 12 species suggest that with respect to climate-mediated changes, they will be able to “remain stable”.

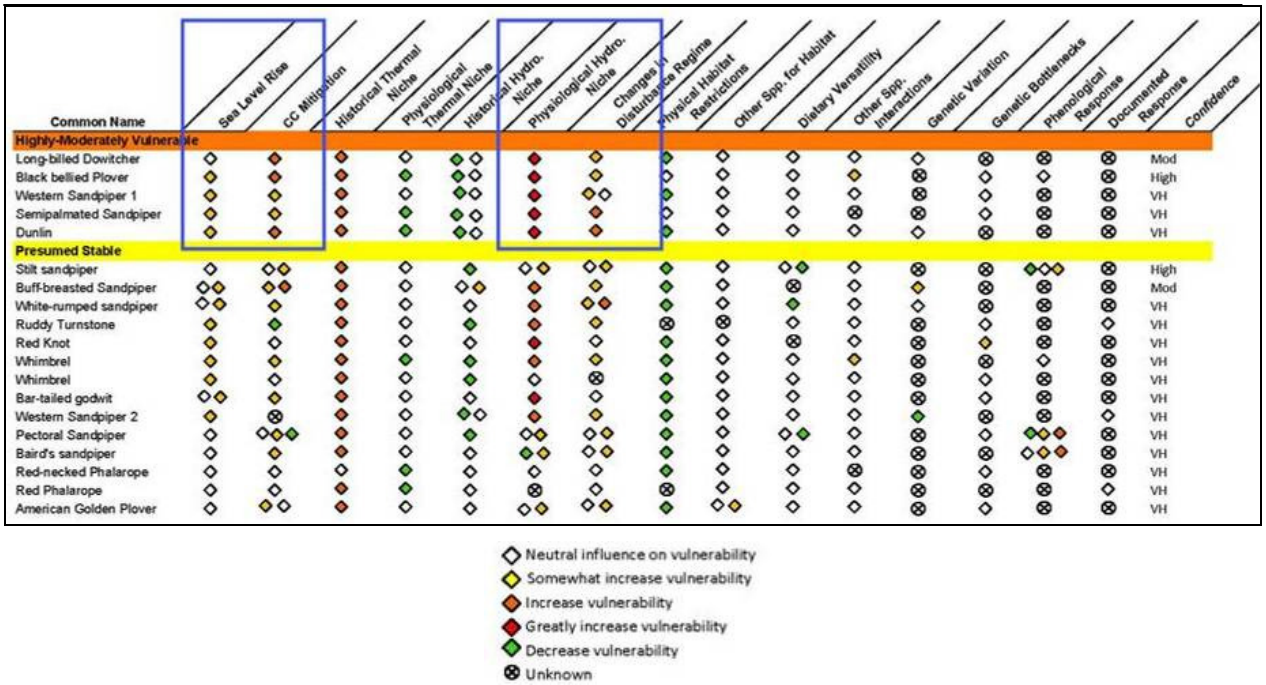

Figure AB.2. Sensitivity factor scores provided by species' expert for the 17 shorebird species and their resulting climate change vulnerability. Blue boxes show factors that contributed most to vulnerability results.

Passage Migration Vulnerability Assessment: Methods and Results

Methods: For passage migration, we only addressed the sensitivity component of vulnerability, with questions targeted on migratory behavior, routes, and numbers and conditions of key staging stopover sites (as defined by Warnock 2010, Figure AB.4). The passage migration questions were included in the sensitivity survey (e.g., see Appendix F for the breeding range example) sent to species experts for the winter range assessment. Two species (Western Sandpiper and Whimbrel) were scored by multiple experts (2). The NatureServe tool was not applied because of the extensive geographic range used by many shorebirds as they migrate between breeding and wintering grounds and the tremendous variation in the projected changes to climate along these corridors (Figure AB.3). Written descriptions from various sources (e.g., NatureServe) and expert input helped to generally identify key stopover sites within migratory corridors. Ideally, a spatially explicit exposure component would be integrated and focused on key staging and stopover grounds in the assessment.

We developed a straightforward scoring system for the sensitivity factors (Table AB.3) with positive values indicating a contribution toward increasing vulnerability. We simply summed the scores assigned to a given species. We intentionally capped the maximum value of 10 allowed by this scoring system to be generally consistent with the threshold value of 10 used by the NatureServe tool to assign the "Extremely vulnerable" category to a species (see Methods in main body of report). With limited basis for assessing climate change vulnerability for migratory species at present, we chose this simple approach to enable the generation of a numerical vulnerability score, as well as initiate discussion at the expert workshop in December 2011 about how climate change might affect species during migration.

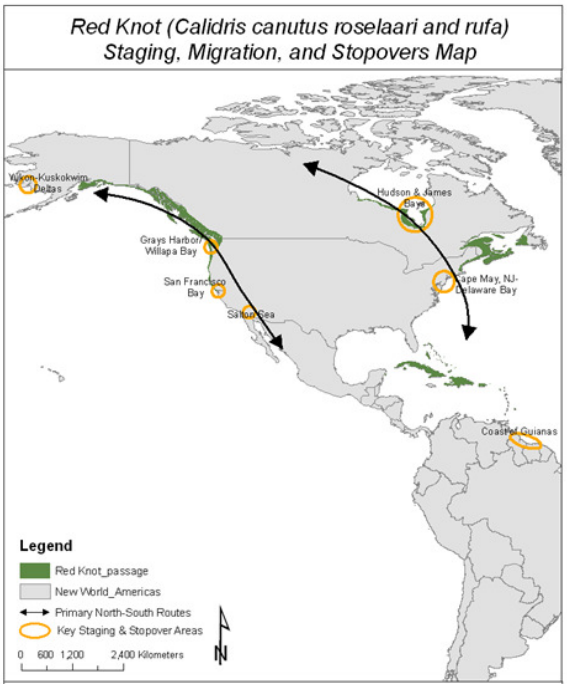

Figure AB.3. An example of the passage migration range used in this component of the assessment.

Table AB.2. The sensitivity factors potentially contributing to climate change vulnerability that we considered for the passage migration component.

Sensitivity Factors for Migration
Sociality: (a) Migrate in small or large groups (b) Aggregate >500 at stopover sites (c) Intermix with other species
Dependence on wind as migration aid
Geography on northbound and southbound migration routes (coastal/inland/open ocean)
Number of Staging Areas
Migration site bottlenecks (>50% population stop in given area)
Stopover timing linked to food source availability
Location (a) and number (b) of key wintering areas

Results: The results of this assessment may best be considered a starting point to develop an alternative method, but they do highlight potential sources of vulnerability during migration. The results, depicted in table AB.3, indicate increasing level of vulnerability as integer value increases (up to maximum score of 10). Several species (total scores >3) might warrant further scrutiny, such as, the Western Sandpiper, White-rumped Sandpiper, Bar-tailed Godwit, and Whimbrel (Table AB.3). Potential sources of vulnerability for these species include: migration routes restricted to coastlines, a limited number of sites for staging prior to migration (<5), low plasticity in departure timing of migration (i.e., timing linked to other resources), and migrations that occur in large groups (i.e., increased potential for stochastic, extreme climate events impacting a significant part of the population.

		Decrease Vuln	*Increase Vuln*	*Unknown*
	Score	*-1*	*1*	*0*
Migration Questions	Sociality (a)	Sm. Group	Lg. Group	
	Sociality (b)**	Sm. Group	Lg. Group	
	Sociality (c)**	Less interaction	More interaction	
	Wind Patterns*	Low dependent	Highly dependent	
	Migrat Geog-N*	Interior	Coastal/Open ocean	
	Migrat Geog-S*	Interior	Coastal/Open ocean	
	Staging	>5, few individuals	<5, large numbers	
	Bottlenecks-N	No	Yes	
	Bottlenecks-S	No	Yes	
	Timing Plasticity	High	Low	
	Winter Grounds (a)	Interior	Coastal/Open ocean	
	Winter Grounds (b)	Many areas	Few areas	

*Mixed route/Mod=0
**"Sometimes"=0.5

Figure AB.4. Scoring options for the sensitivity factors considered in the passage migration vulnerability assessment. A score of 0.5 was given when experts responded with "sometimes". See Table A2.2 for further factor explanations.

Table A2.3. Total of scores assigned to migration-related sensitivity factors for the 17 shorebird species. "Partial response" indicates that the sensitivity survey was incomplete.

Common Name	*Summed Total*
Stilt Sandpiper	-2
Western Sandpiper 1	6.5
Long-billed Dowitcher	2
White-rumped Sandpiper	3.5
Black-bellied Plover	1
Buff-breasted Sandpiper	-1
Ruddy Turnstone	5 (partial response)
Red Knot	2
Red-necked Phalarope	0
Whimbrel 1	1
Bar-tailed Godwit	6
Whimbrel 2	3
Western Sandpiper 2	3
Semipalmated Sandpiper	3 (partial response)
Red Phalarope	5
Dunlin	1
American Golden-plover	-1 (partial response)
Pectoral Sandpiper	-4.5
Baird's Sandpiper	0

Discussion

Undoubtedly different parts of the annual range of a migratory species will contribute differentially to their vulnerability to climate change. Even if the species' degree of vulnerability is similar throughout the annual life cycle, it is likely that the factors influencing vulnerability in different geographies will vary. While tentative, Figure A2.5 illustrates how climate change vulnerability might be apportioned among the components of the shorebirds' life cycle. For many species, our results very speculatively suggest that the greatest contributions toward climate change vulnerability may occur in wintering ranges and along migratory routes. While the vast areas occupied by some species during migration and winter pose challenges for potential adaptation interventions, they may actually offer the best opportunities for conservation actions. In general, the magnitude of change projected for these portions of the species' ranges are much lower than projections of climate change and related impacts anticipated for Arctic Alaska. If little else, our preliminary effort to integrate climate change vulnerability across the annual life cycle of the migratory shorebirds reinforces the acknowledged need to consider the potential effects of climate change and options for adaptation (management and conservation) in geographies beyond the arctic breeding grounds.

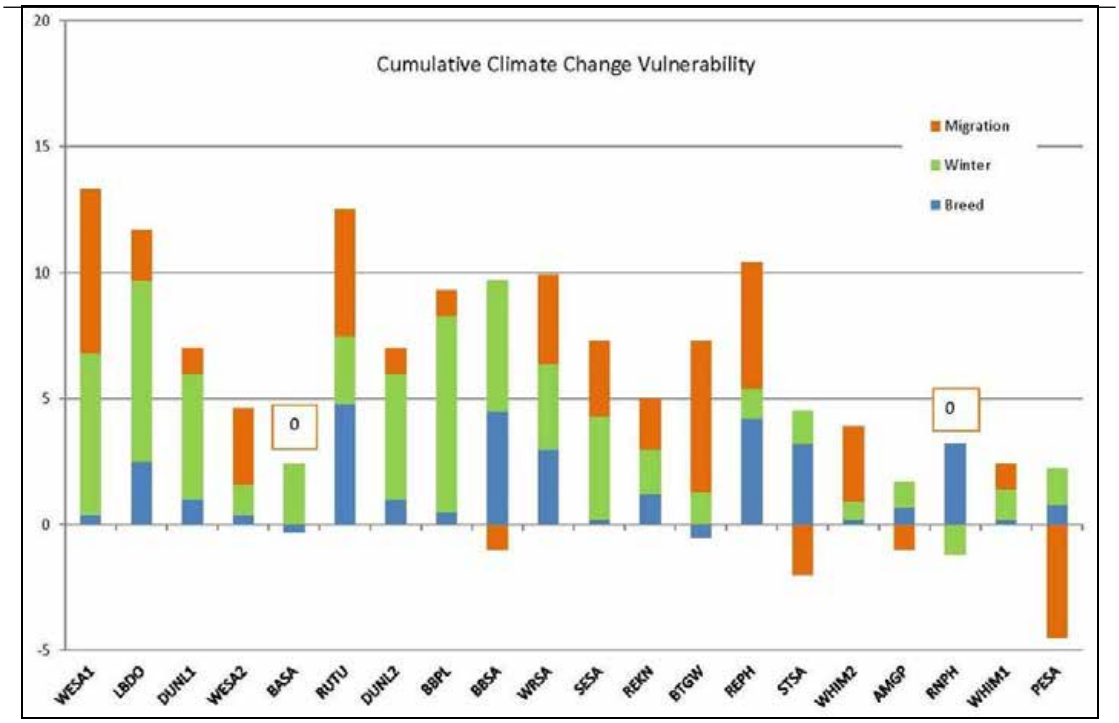

Figure A2. 5. Cumulative climate change vulnerability for the 17 shorebird species throughout their annual life cycle.

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Warnock, N. 2010. Stopping vs. staging: the difference between a hop and a jump. Journal of Avian Biology 41: 621-626.

Appendix D

Sensitivity Survey Experts

Expert	Affiliation
Breeding Grounds	
Brad Andres	U.S. Fish and Wildlife
Stacia Backensto	National Park Service
Rebecca Bentzen	University of Alaska - Fairbanks
Travis Booms	Alaska Department of Fish and Game
Stephen Brown	Manomet Center for Conservation Sciences
Phil Bruner	Brigham Young University
Katie Christie	University of Alaska - Fairbanks
Chris Dau	U.S. Fish and Wildlife Service
Susan Earnst	U.S. Geological Survey
Robert Gill	U.S. Geological Survey
Sue Guers	Alaska Bird Observatory
Chris Harwood	U.S. Fish and Wildlife Service
Jerry Hupp	U.S. Geological Survey
David Irons	U.S. Fish and Wildlife Service
Jim Johnson	U.S. Fish and Wildlife Service
Steve Kendall	U.S. Fish and Wildlife Service
Eunbi Kwon	Kansas State University
Richard Lanctot	U.S. Fish and Wildlife Service
Joe Liebezeit	Wildlife Conservation Society
Philip Martin	Arctic Landscape Conservation Cooperative
Kate Martin	U.S. Fish and Wildlife Service
Laura McKinnon	Trent University
Steffen Oppel	Royal Society for the Protection of Birds
Abby Powell	University of Alaska - Fairbanks
John Reed	U.S. Geological Survey
Bob Richie	ABR, Inc – Environmental research & services
Dan Rizzolo	U.S. Geological Survey
David Safine	U.S. Fish and Wildlife Service
Brett Sandercock	Kansas State University
Joel Schmutz	U.S. Geological Survey
Matt Sexson	U.S. Geological Survey
Susan Sharbaugh	Research Professional
John Shook	ABR, Inc – Environmental research & services
Paul Smith	Smith and Associates Ecological Research, Ltd.
Iain Stenhouse	Biodiversity Research Institute

Appendix D (continued)

Audrey Taylor	University of Alaska - Anchorage
Diane Tracy	Research Professional
David Ward	U.S. Geological Survey
Nils Warnock	Audubon Alaska
Emily Weiser	University of Otago
Teri Wild	University of Alaska - Fairbanks
Kent Wohl	U.S. Fish and Wildlife Service (retired)
Steve Zack	Wildlife Conservation Society
Passage Migration and Wintering Grounds	
Phil Battley	Massey University
Joseph Buchanan	Washington Department of Fish and Wildlife
Rob Clemens	The University of Queensland
Jesse Conklin	Massey University
Richard Fuller	The University of Queensland
Guillermo Fernandez Aceves	University of Mazatlan
David Mizrahi	New Jersey Audubon
Pablo Rocca	Aves Uruguay

* Seven of the breeding season experts also completed passage migration/wintering grounds sensitivity surveys.

Reassessment Experts

Expert	**Affiliation**
Breeding Grounds	
Greg Balogh	Arctic Landscape Conservation Cooperative
Joe Liebezeit	Wildlife Conservation Society
Philip Martin	Arctic Landscape Conservation Cooperative
Paul Smith	Smith and Associates Ecological Research, Ltd.
David Ward	U.S. Geological Survey
Steve Zack	Wildlife Conservation Society

Appendix E

Workshop Attendees and Agenda
December 9-10, 2011

Expert Attendees	Affiliation
Breeding Grounds	
Greg Balogh	Arctic Landscape Conservation Cooperative
Travis Booms	Alaska Department of Fish and Game
Stephen Brown	Manomet Center for Conservation Sciences
Phil Bruner*	Brigham Young University
Roy Churchwell*	University of Alaska - Fairbanks
Molly Cross	Wildlife Conservation Society
George Divoky	Friends of Cooper Island
Guillermo Fernandez Aceves	University of Mazatlan
Tom Fondell*	U.S. Geological Survey
Chris Harwood	U.S. Fish and Wildlife Service
Jerry Hupp	U.S. Geological Survey
Richard Lanctot	U.S. Fish and Wildlife Service
Joe Liebezeit	Wildlife Conservation Society
Wendy Loya	The Wilderness Society
Philip Martin	Arctic Landscape Conservation Cooperative
Brian McCaffery	U.S. Fish and Wildlife Service
David Payer	U.S. Fish and Wildlife Service
John Pearce*	U.S. Geological Survey
Abby Powell	University of Alaska - Fairbanks
Martin Robards	Wildlife Conservation Society
Pablo Rocca	Aves Uruguay
Erika Rowland	Wildlife Conservation Society
Sarah Saalfeld*	Manomet Center for Conservation Sciences
Susan Savage	U.S. Forest Service
Joel Schmutz*	U.S. Geological Survey
Jon Slaght	Wildlife Conservation Society
Paul Smith	Smith and Associates Ecological Research, Ltd.
Diana Solovyeva	Zoological College of the Russian Academy of Science
David Ward	U.S. Geological Survey
Nils Warnock	Audubon Alaska
Ryan Wilson	The Wilderness Society
Steve Zack	Wildlife Conservation Society

* Day 1 only

Appendix E (continued)

Climate change vulnerability assessment for breeding birds in Arctic Alaska

A collaborative workshop sponsored by the Wildlife Conservation Society

USGS Alaska Science Center – Glenn Olds Building
4210 University Drive
Anchorage, Alaska 99503
December 9-10, 2011

AGENDA

Workshop objectives:

- Describe the methods and present results of our assessment ranking the climate change vulnerability of bird species that breed in Arctic Alaska.
- Get feedback from workshop participants on the preliminary findings and suggest any refinements in the assessment that may improve its efficacy.
- Identify how this information can feed into subsequent planning, conservation, and management (e.g. adaptation planning, research and management focus, etc.).

Day 1

8:45 am	Welcome and introductions – *Joe Liebezeit*
9:00 am	Overview of workshop: Background, scope & objectives – *Steve Zack / Joe Liebezeit*
9:15 am	Current state of knowledge on Climate Change impacts to Arctic Alaskan birds – *Philip Martin*
9:45 am	What is a vulnerability assessment and why do one? – *Molly Cross*
10:15 am	Break (beverages/snacks provided)
10:35 am	Methods used for the Arctic Alaska breeding bird vulnerability assessment – *Erika Rowland*
11:30 am	Questions regarding the methods
12:00pm	Lunch break (deli lunch provided)
12:15 pm	Lunchtime talk #1: Population structure and genetic identity of Western Sandpipers during the nonbreeding season in Northwestern Mexico – *Guillermo Fernández Aceves*

Appendix E (continued)

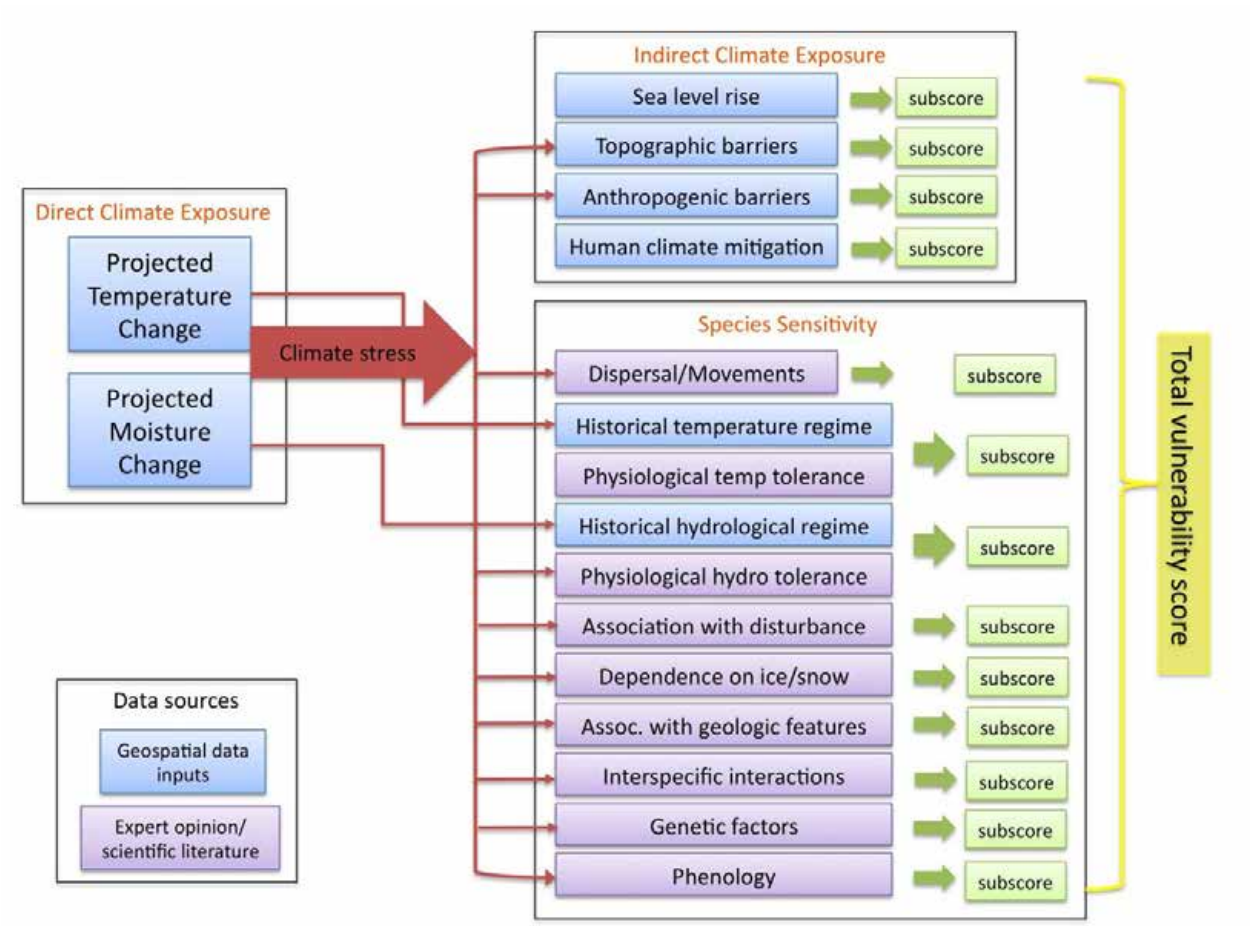
12:45 pm	Lunchtime talk #2: Changes in bird communities in Chaun Delta, Chukotka Russia, from 1970 to the present with reference to climate change and anthropogenic factors – *Diana Soloveyva*
1:30 pm	Presentation of the vulnerability assessment results – *Erika Rowland*
2:15 pm	Break (beverages/snacks provided)
2:35 pm	Discussion of vulnerability assessment results
5:00 pm	Adjourn
6:30 pm	Dinner provided by WCS at the Snow Goose Restaurant
Day 2	
9:00 am	Recap of Day 1 and overview of Day 2 – *Joe Liebezeit*
9:15 am	Applying vulnerability information – *Molly Cross*
10:00 am	Discussion: How might we use the vulnerability analyses presented here
10:30 am	Break (beverages/snacks provided)
10:50 am	Continue discussion on applying vulnerability assessment information
12:00 pm	Lunch (deli lunch provided)
12:15 pm	Lunchtime talk: Towards bird vulnerability assessment and adaptation to climate change in Laguna de Rocha, Uruguay – *Pablo Rocca*
1:00 pm	Arctic LCC goals and direction and "habitat / species group" effort – *Philip Martin*
1:30 pm	Next steps and/or recommendations
3:45pm	Concluding comments – *Joe Liebezeit*
4:00 pm	Adjourn

Appendix F

NatureServe Climate Change Vulnerability Index

Species Sensitivity Worksheets
Revision
(In response to comments made at workshop in Anchorage, AK on 12/9-10/2011)

2/26/2012



Based on: Young et al. (2010). Guidelines for Using the NatureServe Climate Change Vulnerability Index, Release 2.01. NatureServe, Arlington VA.

PLEASE KEEP THESE POINTS IN MIND AS WE COMPLETE THE REASSESSMENT OF ARCTIC BREEDING BIRD SPECIES:
1. Multiple responses to each factor may be made to capture uncertainty.
2. In the original assessment, we also requested "confidence ratings" for factor responses to understand whether uncertainty in responses was due to uncertainty in the exposure/climate change components of each factor question or lack of knowledge about the given species ecology/biology. Because we have tried to reduce the exposure-sensitivity confounding in the revised questions, we will only assign a 1-2-3 confidence rating associated with the groups understanding of species biology/ecology.
3. If there is no information known that addresses the factor questions, "insufficient data for assessment" is an option. However, I did not include it with each factor.

(B2) Distribution Relative to Barriers

This factor assesses the degree to which natural and anthropogenic barriers limit a species' ability to shift its range in response to climate change. This factor assesses the distribution of the species on the landscape and focuses on conditions that limit dispersal at the range boundaries. This factor is not meant to address habitat fragmentation or how the availability of suitable habitat might shift within the species' range. These issues will be addressed in other factors.

NOTE: Barriers are not considered to contribute to the vulnerability of most bird species. But range shifts for bird species whose distributions are limited to the coast of the Arctic Coastal Plain (ACP) in Alaska will likely be impaired, assuming that because there is no landmass to the north, the extensive northern ocean represents a barrier to birds that have restricted distributions along the northernmost circumpolar coastlines. Please follow the ACP guidance instructions embedded in the questions for your response to this factor.

---

1. Barriers **completely or almost completely** surround the current distribution such that the species' range in the assessment area is unlikely to be able to shift significantly OR the direction of climate change-caused shift in the species' favorable climate envelope is fairly well understood and barriers prevent a range shift in that direction. *Examples: None for migratory bird species breeding in Alaska.*

2. Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be **greatly** impaired. *Examples: None for migratory bird species breeding in Alaska.*

3. Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be **significantly** impaired. *Examples: Coastally breeding bird species, with the majority of the breeding population within the northern 1/3rd of the Arctic Coastal Plain (e.g., Steller's Eider, Spectacled Eider.)*

4. Small barriers exist for this species but are not likely to significantly impair distributional shifts with climate change. *Examples: Species that have coastal to near-coastal breeding (northern 2/3rd of Arctic Coastal Plain) but whose distributions also extend into the high arctic Canadian Archipelago and/or Yukon-Kuskokwim Delta (e.g., Snow Goose).*

5. Significant barriers do not exist for this species. Examples: Most birds with broad distributions outside arctic Alaska and Canada (e.g. Greater Scaup, Lapland Longspur)

(B3) Predicted Impact of Land Use Changes Resulting from Human Responses to Climate Change

Strategies designed to mitigate or adapt to climate change have the potential to physically affect large areas of land and the species that depend on these areas. **This factor is NOT intended to capture habitat loss resulting from on-going human activities, as these are already included in existing conservation status ranks.** Also, consider only the direct physical impacts of the land use change, including direct habitat destruction or habitat loss through resulting impacts on hydrology (e.g. impoundment of water from road construction) or other physical processes. Do NOT consider any indirect affects of human activity here (e.g. increased subsistence hunting, increasing subsidized predators) that may be associated with these activities. Lastly, include only new activities related directly to climate change mitigation or adaptation here.

Examples of ongoing or highly plausible activities **ONLY** in the Arctic LCC[1]:

- Shoreline eroding fortification
- Conversion of ice roads to all-weather roads (residents and related to energy)/additional culverts and water-crossings

[1] Other potential climate change related human mitigation activities (e.g. wind-farm developments, hydro dams, natural gas infrastructure) were deemed unlikely to be developed in the region in the next 50 years.

Note: As you answer these questions take into account the likely **scale** of the mitigation/adaptation related land use change as well as the **importance to the species of individual sites** where such developments are likely to be constructed.

---

1. The species is **likely or very likely to** be significantly impacted by mitigation/adaptation-related land use changes that are occurring or likely will occur in the assessment area in the next 50 years.

2. The species **may possibly be** significantly impacted by mitigation/adaptation-related land use changes that are occurring or likely will occur in the assessment area/species' range in the next 50 years.

3. The species is **unlikely to be significantly affected** by mitigation/adaptation-related land use changes that are occurring or likely will occur within the assessment area OR it is unlikely that any mitigation/adaptation-related land use changes will affect large areas of the assessment area/the species' range.

4. The species may possibly **benefit** from mitigation/adaptation-related land use changes that are occurring or likely will occur within the assessment area/the species' range.

5. The species is **likely to benefit** from mitigation/adaptation-related land use changes that are **likely or very likely to occur** within the assessment area/the species' range.

(C2aii) Physiological Thermal Niche

This factor assesses the degree to which a species is restricted to relatively cool or cold above-ground terrestrial or aquatic environments for at least part of their stay on the breeding grounds. Because the upper thermal tolerance is not documented for most species, this question is **intended to approach thermal niche indirectly through habitat association**, whereby it is actually the preferred habitat that is thermally limited. It is meant to refer to the cold sites **within** the assessment area--the highest elevations, northernmost areas, but not sites that are likely to simply shift in location without reduction or loss (e.g. shady ravines). The restriction to these relatively cool environments may be permanent or seasonal. Consider the extent of and constraints on the species' distribution in Alaska and adjacent Canada outside the Arctic LLC boundaries, if relevant, in your response to this factor.

Note: While thermal and hydrological niche are sometimes closely linked, if species is more strongly restricted by hydrology, select option #3 and respond with reference to hydrological constraints in the next question.

1. Species is **completely or almost completely restricted** (>90% of occurrences or range) to relatively cool or cold environments in the assessment area. (we don't know of any examples)

2. Species is **moderately restricted** (50-90% of occurrences or range) to relatively cool or cold environments in the assessment area. (We don't know of any examples)

3. Species distribution **is not restricted to cool or cold** environment in the assessment area**.** **(most species)**

4. Species **shows a preference** for environments towards the warmer environments in the assessment area (e.g. south-facing slopes). (e.g. Lapland Longspur nesting on south facing substrates)

(C2bii) Physiological Hydrologic Niche

Check multiple boxes to capture uncertainty and also do a bit of a sensitivity analysis. The multiple choices do not have to fall along a continuum—especially given the uncertainty in hydrological trajectories for the region (drying or wetting).

This factor pertains to a species' dependence on a narrowly defined precipitation/hydrologic regime, including strongly seasonal precipitation patterns and/or specific aquatic wetland habitats. Consider the level of dependence of the species on particular hydrologic conditions. Dependence may be permanent or seasonal.

Examples:

- Specific aquatic wetland habitats-wet and emergent tundra
- Birds dependent on foraging in small waterbodies and nesting in wet tundra habitat
- Birds nesting on "island" sites to avoid predators

1. Species is **completely or almost completely** dependent (>90% of occurrences or range) on a specific aquatic/wetland habitat or seasonal precipitation patterns.

2. Species is **moderately** dependent (50-90% of occurrences or range) on a specific aquatic/wetland habitat or localized moisture regime.

3. Species is **somewhat** dependent (10-50% of occurrences or range) on a specific aquatic/wetland habitat or seasonal precipitation.

4. Species has **little or no** dependence on a specific aquatic/wetland habitat or seasonal precipitation patterns.

5. Species has very broad moisture tolerances.

(C2c) Dependence on Specific Disturbance Regimes

This factor pertains to a species' response to specific disturbance regimes that are likely to be impacted by climate change, such as fires, floods, severe winds, pathogen outbreaks, or similar events. Consider disturbances that impact species indirectly, such as changes in flood frequency impacting sand/gravel bar nesting species. Also consider potential impacts on species that currently benefit from a lack of disturbance.

Consider ONLY the following disturbances, recent trends in changes to their frequency, severity and extent and their potential impacts:

- Increased coastal erosion and overwash linked to storm frequency/intensity (e.g., Common Eider nesting sites on barrier islands)
- Thermokarst processes/events— lake drainage, ice wedge degradation in drainage areas, upland slumps and effects on aquatic systems (e.g. influencing prey availability for piscivorous species like loons.)
- Upland tundra fire impact on quality of nesting sites
- Extreme rain/snow events (e.g. snow storms can cause region-wide abandonment or delay in nesting)
- Expansion into assessment area of pathogens currently in adjacent regions

1. Species' distribution, abundance, or habitat quality.is **very likely to be reduced** by a change in the frequency, severity, or extent of a disturbance regime over the next 50 years.

2. Species' distribution, abundance, or habitat quality **may possibly be reduced** by a change in the frequency, severity, or extent of a disturbance regime over the next 50 years.

3. Species' distribution, abundance, or habitat quality **is unlikely to be affected** by a change in the frequency, severity, or extent of a disturbance regime over the next 50 years.

4. Species' distribution, abundance, or habitat quality **may possibly be increased** by a change in the frequency, severity, or extent of a disturbance regime over the next 50 years.

5. Species' distribution, abundance, or habitat quality **is likely to be increased** by a change in the frequency, severity, or extent of a disturbance regime over the next 50 years.

(C3) Restriction to Uncommon Geological Features

This factor pertains to a species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs, active sand dunes) for one or more portions of its life cycle. Do not include features that have been addressed by previous factors, such as springs or ephemeral pools or biotic habitat components, such as a particular type of plant community, as these will be addressed elsewhere. Response should be based on the **commonness** of feature and **degree of species restriction**.

Example:

- Species dependent on cliffs for nesting (e.g. Gyrfalcon)
- Species that utilize protected waters as on the leeward side of barrier islands (e.g. post-breeding phalaropes)
- Species dependent on gravel river/stream bed habitat for nesting (e.g. Semipalmated Plover)

---

1. Species is **very highly dependent** on (>85% of occurrences) a particular highly uncommon geological feature or derivative.

2. Species is **moderately to highly dependent** on (65-85% of occurrences) a particular highly uncommon geological feature or derivative OR is restricted to a geological feature or derivative that is not one of the dominant types within the species' range.

3. Species is **dependent** on (>85% of occurrences) a common geological feature or derivative that is among the dominant types within the species' range.

4. Species is **somewhat flexible** but not highly generalized in dependence upon geological features or derivatives. This category should include species found on a subset of dominant substrates occurring within the species' range (e.g., many birds and mammals).

5. Species is **highly generalized** relative to dependence upon geological features or derivatives.

(C4a) Dependence on Other Species to Generate Habitat

For this factor, habitat refers to any physical habitat necessary for completion of the life cycle, including those used on a seasonal basis (but not including restricted diets-next factor). Consider how specialized the species is in its association with another species to generate habitat. If a species is dependent on a single species to generate habitat, but the vulnerability of that species is unknown, check the first two boxes below — (We could think of no examples for Arctic Alaska).

---

1. Required habitat is generated primarily by a **single species** and that species may be **highly vulnerable** to climate change within the assessment area.

2. Required habitat is generated primarily by a **single species** and that species may be **vulnerable** to climate change within the assessment area.

---

3. Required habitat is generated by one or more, but not more than **a few species**.
Examples: burrowing owls depend on excavations made by relatively few species of mammals, marbled murrelets depend on a few species of large trees to provide nesting platforms

4. Required habitat is generated by **more than a few species** or does not involve species-specific processes.

(C4b) Dietary Versatility

This factor pertains to the diversity of food types consumed by animal species.

1. Diet is completely or almost completely dependent (>90%) on **one species** during any part of the year. *Example: Clark's nutcracker depends heavily on the seeds of whitebark pine; pomarine jaeger depends on brown lemming population eruptions for successful reproduction*

2. Diet is completely or almost complete dependent (>90%) on a **few species** from a single guild of species during any part of the year. *Example: the larvae of various fritillary butterflies rely heavily on a few species of violets, during winter ptarmigan depend heavily on few species of willows for forage*

3. Diet is **flexible**, including several species but either solely plant or animal-based.
Example: post-breeding shorebird species may rely on a few species of benthic invertebrates

4. Omnivorous diet, includes several species of both plants and animals.

(C4e) Other Interspecific Interactions

This factor refers to interactions unrelated to habitat, diet, or propagule dispersal, such as mutualism, parasitism, or commensalism, or predator-prey relationships.
Examples:

- Some waterfowl species are known to nest within the nesting territory of birds of prey affording protection from nest predators
- Documented changes in predator-prey relationships - e.g., ability of waterfowl to fend off Arctic fox vs. red fox predation

1. Species requires an interaction with a **single** other species for persistence OR changes in a specific predator-prey relationship has the potential to strongly effect the persistence of the species.

2. Species requires an interaction with one member of a **small group** of taxonomically related species for persistence OR changes in a specific predator-prey relationship has the potential to somewhat effect the persistence of the species. *Select this category in cases for which specificity is suspected but not known for certain.*

3. Does not require an interspecific interaction OR many potential candidates can be used.

(C5a) Measured Genetic Variation (not included in revision)

(C6) Phenological Response

This factor assesses changes in a species' phenological response (e.g., timing of migration, breeding, etc.) relative to observed (historical) changes in temperature or precipitation dynamics Potential sources of data include large databases such as that of the U.S. National Phenology Network other multi-species studies.

Note: If there are no data available to make comparisons between the observed responses of the species under question with other species in similar habitats or taxonomic groups, **select all of the last 3 options**.

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1. Phenological variables measured for the species show no detectable change in response to documented changes in seasonal temperature or precipitation patterns or other climate-related phenological variables (green-up, snowmelt/cover, ice-out, freeze up, etc.) within the assessment area. (Increase vulnerability)

2. Phenological variables measured for the species show detectable change in response to documented changes in seasonal temperature or precipitation patterns or other climate-related phenological variables (green-up, snowmelt/cover, ice-out, freeze up, etc.) within the assessment area, but the phenological change is significantly less than that of other species in similar habitats or taxonomic groups. (Somewhat increase vulnerability)

3. Phenological variables measured for the species indicate detectable change in response to documented changes in seasonal temperature or precipitation patterns or other climate-related phenological variables (green-up, snowmelt/cover, ice-out, freeze up, etc.) within the assessment area, but the phenological change is similar to that of other species in similar habitats or taxonomic groups (Neutral)

4. Phenological variables measured for the species indicate detectable change in response to documented changes in seasonal temperature or precipitation patterns or other climate-related phenological variables (green-up, snowmelt/cover, ice-out, freeze up, etc.) within the assessment area but the phenological change is significantly greater than that of other species in similar habitats or taxonomic groups (Somewhat decrease vulnerability)

(D1) Documented Changes in Distribution or Abundance in Response to Recent Climate Change

This factor pertains to the degree to which distribution or abundance has changed in response to recent climate change, for example range contractions or population declines due to phenology mismatches and critical resources. Consider a time frame of 10 years or three generations, whichever is longer. — Only consider population level declines in abundance or distribution contractions for responses #1, #2, and #3. Northward shifts in range limits without overall reductions/contractions at the southern edge should are captured in #5 and #6 (e.g., mallard).

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1. Distribution or abundance has undergone a **major reduction** (>70% over 10 years or three generations) believed to be associated with climate change.

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2. Distribution or abundance has undergone a **moderate reduction** (30-70% over 10 years or three generations) believed to be associated with climate change.

3. Distribution or abundance has undergone a **small but measurable reduction** (10-30% over 10 years or three generations) believed to be associated with climate change.

4. Distribution or abundance is not known to be increasing or decreasing with climate change. Includes species undergoing range shifts without significant change in distributional area or species undergoing changes in phenology but without a change in net range or population size.

5. Distribution or abundance has undergone a **small but measurable increase** (10-30% over 10 years or three generations) believed to be associated with climate change. Distribution changes must be true increases in area, not range shifts.

6. Distribution or abundance has undergone a **moderate or major increase** (>30% over 10 years or three generations) believed to be associated with climate change. Distribution changes must be true increases in area, not range shifts.

Note: Eighteen of the 54 experts responded to this question. The response can alter the overall vulnerability results just based on the B&C sections if they are contrary to those results. For example, if a species is calculated to be MV based on the B&C factor responses, D responses indicating that model or observed changes to distribution show reductions, the MV could get bumped to a HV.