Alaska Ecosystems of Conservation Concern: Biophysical Settings and Plant Associations

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Abstract

Biological conservation is most effective when limited resources can be directed towards the species, habitats, and environmental processes of greatest need. Rare ecosystems support unique assemblages of specialized and/or diverse flora and fauna within a small geographic area or restricted range often represent vulnerable elements of biodiversity. The description, mapping, and assessment of rare ecosystems is a necessary and initial conservation action, yet this has not been completed for Alaska. Here we provide the first formal recognition of Alaska's rare ecosystems. Thirty-five ecosystems, representing different levels of ecological organization (plant associations and biophysical settings) and geographic scale are presented. In addition, a gap analysis was conducted to evaluate the systems' current level of land management protection relative to their conservation need. Eleven of the mapped ecosystems are considered adequately protected, two are moderately protected, and 22 are less protected. Conservation ranks are incongruously aligned with land management protection levels such that the rarest systems are often not well protected, and the less-imperiled systems are often well protected. On the ecoregion scale, systems with arctic distributions are less protected than are those with boreal and maritime distributions. This rare ecosystem assessment complements species- and landscape-scale conservation studies previously completed for Alaska. Collectively, these assessments provide a comprehensive and thus precautionary approach to bioconservation in Alaska. More specifically the recommendations from these assessments provide a science-based strategy for biological conservation in a vulnerable region of the world.

Introduction

From arctic tundra to temperate rainforests, numerous ecosystems span the broad and varied landscapes of Alaska. Ecosystems such as boreal forests and sedge wetlands cover extensive geographic areas of the state and are composed of common species assemblages. In contrast, ecosystems such as karst fens and lodgepole pine woodlands cover small geographic areas and support unique assemblages of species. Collectively rare ecosystems (Figure 1) offer an opportunity to understand conservation opportunities across the state. Rare ecosystems often contribute disproportionately to regional biodiversity relative to their size, presenting a tremendous opportunity for conservation (Gaston 1994). However, these same systems may be poorly described and mapped, which has implications for their management, protection, and long-term persistence (Williams et al. 2007). Such geographically restricted ecosystems are likely to face more severe consequences and have a higher probability of extirpation from threats relative to widespread ecosystems (Cole and Landres 1996; Wilson et al. 2016).

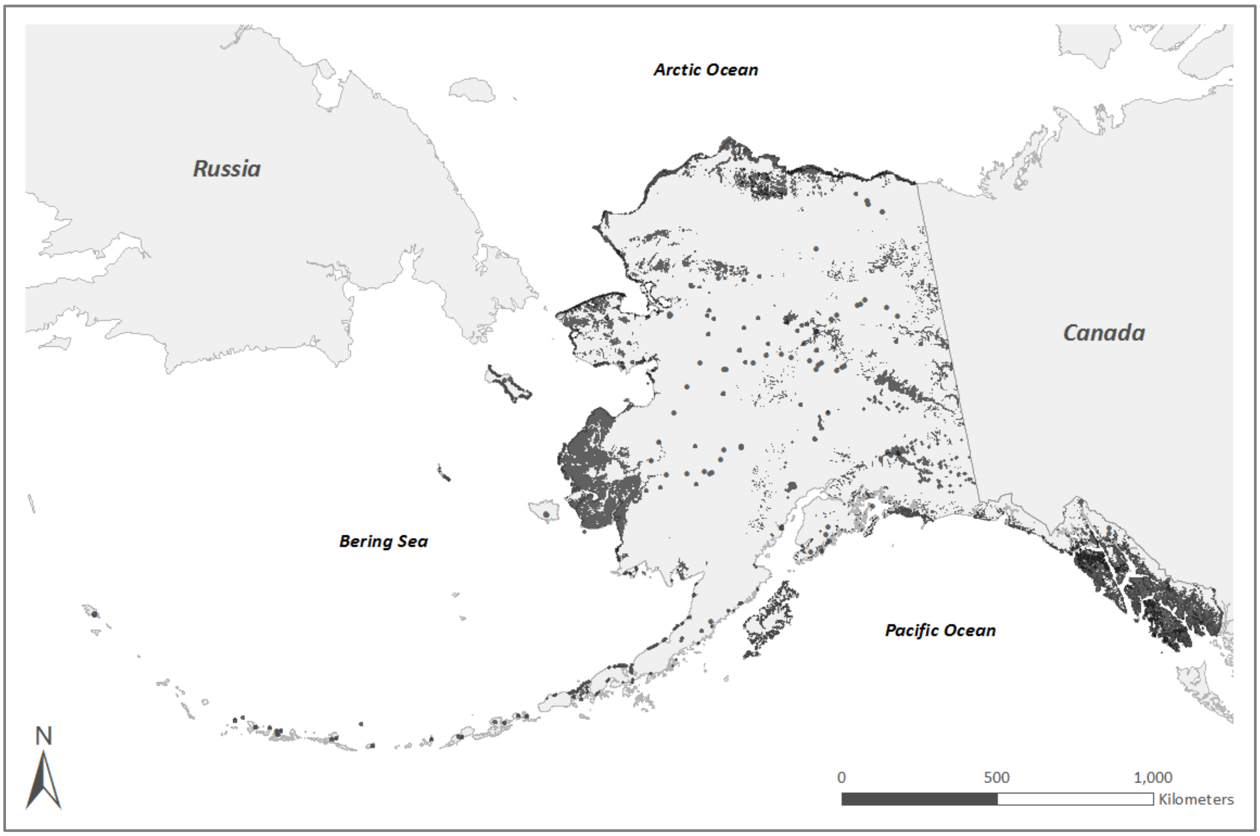

Figure 1. Rare ecosystems are found throughout the entire state of Alaska with some ecosystems overlapping. Areas of higher rare ecosystem concentration appear darker.

In Alaska, remoteness preserves many ecosystems in pristine condition. Over 95% of the state is considered to have the highest level of ecological intactness (Reynolds et al. 2018), and only approximately 1,300 km^2 of urban development in the state (Trammell and Aisu 2015). Yet some naturally uncommon systems are in decline due to their intrinsic vulnerabilities or external threats.

Determining which elements of regional biodiversity are most vulnerable to threats is critical to their conservation (NatureServe 2015). Globally, the primary threat to conservation is habitat conversion (Meffe and Carroll 1997, Wilcove and Master 2008). While Alaska has been less affected by habitat conversion compared to other states (Duffy et al. 1999, Trammell and Aisu 2015, Reynolds et al. 2018) current and proposed large-scale natural resource extraction activities are affecting more area and habitat types across the state, increasing threats to both rare species (Carlson and Cortés-Burns 2013) and ecosystems. In the northern latitudes, climate change, rather than direct anthropogenic action, is arguably the primary driver of ecological change (ACIA 2005, Chapin et al. 2014). Climate change has the potential to threaten the persistence of individual species, as well as the ecology of communities and ecosystems of which they are part (Bjorkman et al. 2018). In just the last 30 years, there has been a +2 °C increase in mean annual temperature in the arctic biome (ACIA 2005) and temperature is predicted to continue to increase more rapidly than at lower latitudes (IPCC 2007; Chapin et al. 2014). Species, communities, and ecosystems already appear to be responding to these changes in climate. For example, there are numerous examples of increases in shrub and tree expansion in arctic and alpine tundra habitats around the state that in turn are driving alterations in ecosystem processes (Klein et al. 2005; Dial et al. 2007; Tape et al. 2006; Roland et al. 2013). In addition, climate change is influencing the frequency and severity of disturbances, such as insect outbreaks and wildfires (Soja et al. 2006; Chapin et al. 2008), and is likely affecting the rate of establishment of non-native species (Carlson and Shephard 2007; Sanderson et al. 2012). All of these phenomena pose a substantial risk to the current composition and function of rare ecosystems.

Furthermore, lands managed for biological conservation may not encompass sufficient components of regional biodiversity. Early conservation efforts in Alaska were often directed towards alpine environments and unique landscape features (Racine & Anderson 1979, Racine & Young 1978, Scott et al. 2001, Young & Racine 1976, 1977), and as a result, currently-protected lands may neither coincide with areas of high terrestrial biodiversity (Smith et al. 2006), nor harbor individual species of conservation concern (Duffy et al. 1999).

Rare ecosystems present a tremendous opportunity for conservation, because relative to their size, they often contribute disproportionately to regional biodiversity. Yet, owing to their infrequent occurrence and/or restricted distribution, these same systems are often poorly described and mapped, which has implications for their management, protection, and long-term persistence (Williams et al. 2007). In Alaska, rare ecosystems may be categorized by substrate (e.g. karst), geomorphic processes (e.g. mud volcanism), microclimates (e.g. south-facing slopes), or floristics (e.g. communities dominated by the rare poppy, *Papaver gorodkovii*). Generally, rare ecosystems that derive their existence from uncommon substrates or geomorphological processes (Figure 2) develop as larger-scale, persistent biological communities that reflect the interaction of physical setting and abiotic factors. Conversely, systems derived from unique microclimates or supporting uncommon floristic assemblages tend to be smaller scale, homogenous with respect to species composition, and potentially more ephemeral.

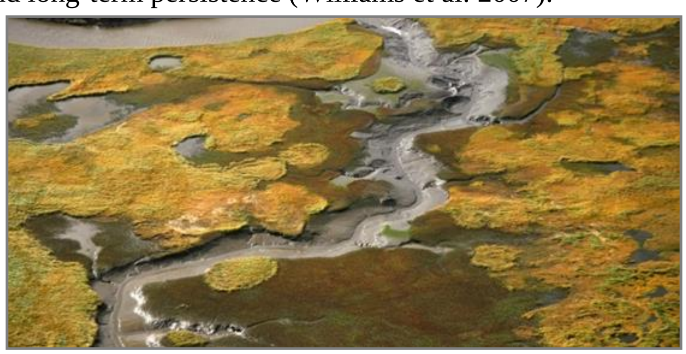

Figure 2. A mosaic of tidal marsh and mudflats across the Yukon-Kuskokwim Delta, Southwest Alaska

Methods

Ecosystem Assessment

The identification and description of potentially rare ecosystems in Alaska was an iterative process drawing from the ecological research and expertise of many individuals. To the extent possible, publicly available data and standardized mapping and ranking methodologies were used to generate the distributions and assess the conservation status of the systems considered in this assessment.

Identification of Candidate Ecosystems

The biophysical settings and plant associations of conservation concern included herein were advanced from a larger pool of candidate systems either described in published literature or recommended by professional ecologists. Significant literature sources include The Alaska Vegetation Classification (Viereck et al. 1992), The Nature Conservancy's (TNC) Alaska ecoregional conservation plans (Albert and Schoen 2006, TNC 2004, 2007), the National Wildlife Federation's special ecological sites (Cline 2005), the Alaska Wildlife Action Plan (ADF&G 2015), the National Park Service (NPS) National Natural Landmarks Program (NPS 2009), Bureau of Land Management (BLM) Areas of Critical Environment Concern (BLM 2015), and U.S. Forest Service (USFS) land and resource management plans (USFS 2002, 2008, 2016) and Research Natural Areas reports (Juday 1988, 1989, 2001). The list of candidate systems has been refined over numerous years through formal and informal discussion with ecologists with extensive experience in Alaska. Input has been solicited from the experts at the USFS, NPS, BLM, U.S. Fish & Wildlife Service (USFWS), ADF&G, TNC, and Audubon Alaska. Candidate systems that were not included here have been listed in the results section for future consideration.

Identification and Classification of Candidate Ecosystems

In this synthesis, we use two levels of classification to describe these ecosystems: the biophysical setting (BpS) and the plant association (PA). Biophysical settings represent the vegetation that dominates the landscape in the absence of human action for a specific physical environment and natural disturbance regime (Landfire 2013) and are similar in concept to ecological site descriptions (NRCS 2014) and potential natural vegetation (Kuchler 1973, Mueller-Dombois & Ellenberg 1974, Tüxen 1956). Common biophysical settings have been described for Alaska by the Landfire vegetation mapping initiative (Landfire 2013) and have been refined for arctic ecoregions by the BLM Assessment, Inventory and Monitoring project (Boucher et al. 2015). Plant associations are the finest level of vegetation classification, represent a community of definite floristic composition and uniform habitat (Flahault and Schroter 1910, Jennings et al. 2006), and have been used to classify vegetation across Alaska (Viereck et al. 1992, Raynolds et al. 2005) and nationally (Anderson et al. 1998). As plant associations lack a successional component, the concepts differ with respect to heterogeneity, yet are complementary in that plant associations may be used to describe stages or states within successional sequences or transition models, respectively, which, in turn are represented by the biophysical setting.

Ecosystems recommended for consideration were evaluated with respect to their representation on the landscape. Ecosystems intimately connected to substrate or geomorphic process were treated at the biophysical setting level; whereas systems defined by microclimate or floristics were treated at the plant association level. Where possible, plant associations of conservation concern were nested within a biophysical setting; plant associations were considered members of the same biophysical setting if they shared existing vegetation, successional relationships and environmental factors. Biophysical settings supporting plant associations of conservation concern were by extension, identified as systems of conservation concern. Plant associations with no ecologically-meaningful connection to a greater biophysical setting of conservation concern were treated independently. In this document, we provide both new and updated descriptions for rare ecosystems developed from field sampling and comprehensive review of relevant literature including plant association classifications, ecosystem and succession descriptions, and landcover and ecosite maps.

Spatial designations were assigned in accordance with the parameters set forth by Poiani and others (2000) where 1. local geographic scale refers to a discrete, geomorphologically-defined, and spatially-fixed ecosystem occupying meters to thousands of hectares, 2. intermediate geographic scale refers to relatively-discrete ecosystems defined by physical factors and environmental regimes and occupying hundreds to tens of thousands of hectares, and 3. coarse geographic scale refers to nondiscrete, ecosystems defined by widespread climatic and elevational gradients and occupying hundreds of thousands to millions of hectares.

Regional Designation

For broad-ranging biophysical settings with considerable variation in plant community composition, separate regional descriptions were developed. Biophysical settings and plant associations that are not modified by a regional designation have comparatively narrow distributions that are restricted to a single geographic region. The *Andreaea blyttii* (Blytt's andreaea Moss) plant association and the Geothermal Spring and Mud Volcano biophysical settings are the only systems included here that occur across the state but have not received regional treatment as microclimate and plant community composition are consistent among sites. Where appropriate, regional designations were assigned in accordance with the boundaries defined in Land Resource Regions of Alaska (Moore et al. 2004), which are intended to represent areas of broad regional climate and climatic conditions, patterns, and processes and as such have good correlation with the natural floristic and hydrologic divisions of Alaska (Figure 3). Generalized ranges and defining characteristics of these regions follow:

Arctic Alaska: This region has an arctic climate and includes the northern slopes of the Brooks Range, the western Brooks Range and the northern and western Seward Peninsula. The predominant vegetation is arctic and alpine tundra dominated by low and dwarf scrub and herbaceous communities. The region is within the zone of continuous permafrost.

Beringian Alaska: This region includes the western part of the state near the Bering Sea from the Alaska Peninsula and Bristol Bay lowlands to the southern Seward Peninsula as well as the northern Bering Sea islands. The climate ranges from maritime near the coast, to sub-arctic continental away from the coast and at higher elevations. The predominant vegetation is arctic and alpine tundra dominated by low and dwarf scrub and herbaceous communities. The region is within the zone of discontinuous permafrost.

Boreal Alaska: This region has a continental boreal climate and includes the vast interior of Alaska, from the south slopes of the Brooks Range to the north slopes of the Alaska Range as well as the Cook Inlet Ecoregion. Expansive lowland boreal forests are dominated by combinations of *Picea glauca* (white spruce), *P. mariana* (black spruce), *Betula neoalaskana* (Alaska paper birch), and *Populus tremuloides* (quaking aspen). The region is within the zone of discontinuous permafrost.

Pacific Alaska: This region includes the arc of coastal lowlands and mountains along the Gulf of Alaska from the Alexander Archipelago in the southeast to Kodiak Island and the southern portion of the Alaska Peninsula in the west. The climate varies from maritime at lower elevations along the coast to transitional maritime-continental at higher elevations. Coastal forests are dominated by *Picea sitchensis* (Sitka spruce) and *Tsuga heterophylla* (western hemlock) along the Gulf of Alaska and with *Thuja plicata* (western red cedar) and *Callitropsis nootkatensis* (yellow cedar) present further south. Isolated pockets of permafrost occur in the northern part of the region.

Aleutian Islands: This region has a maritime climate and includes the southwest portion of the Alaska Peninsula, the Aleutian Islands, and the Pribilof Islands. This is a treeless region that is not underlain by permafrost. Dwarf scrub vegetation occurs at higher elevations and wind-exposed areas and herbaceous meadows occur on low elevations and more protected areas.

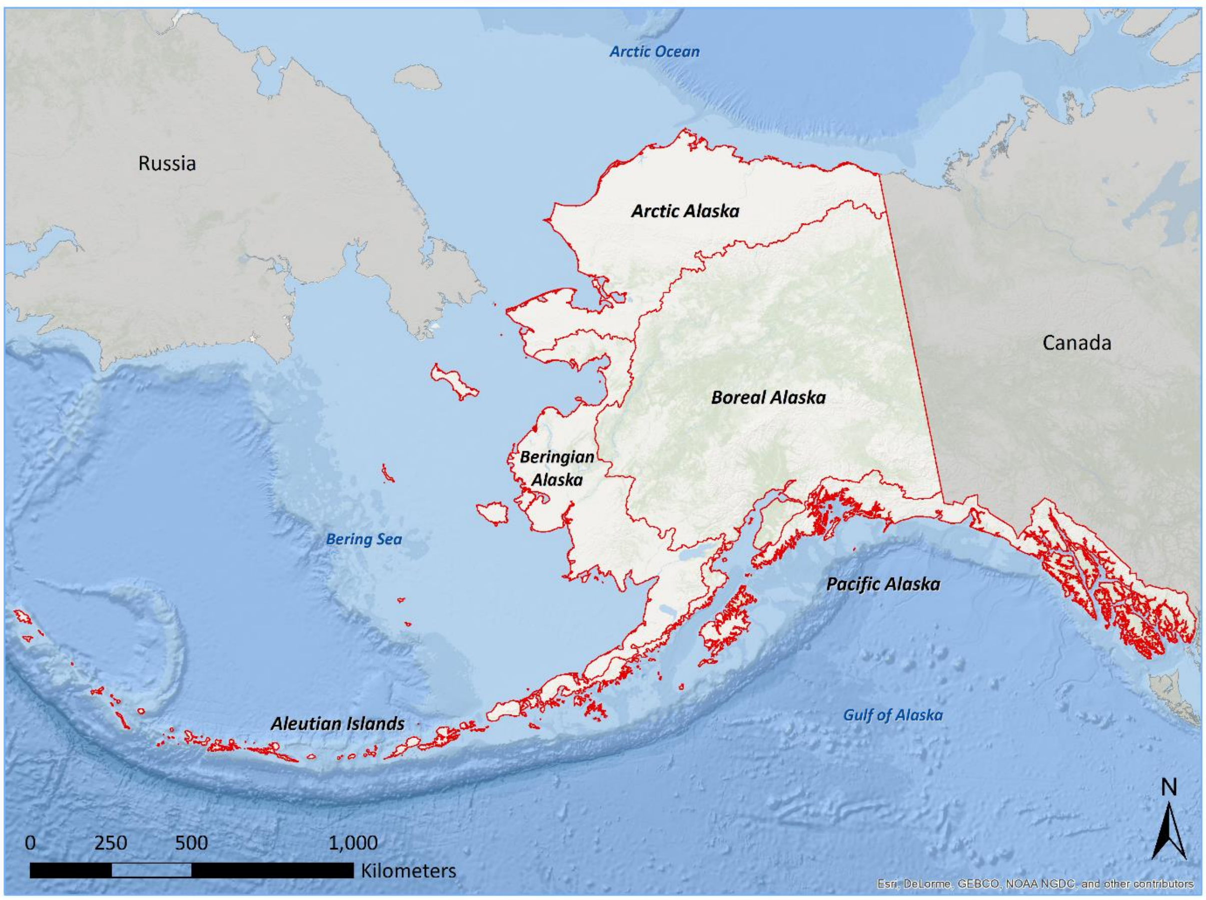

Figure 3. Land Resource Regions of Alaska developed by the Natural Resources Conservation Service (Moore et al. 2004) ***and*** modified to reflect physical geography.

Distribution Mapping

Distribution maps for each biophysical setting or plant association were developed from the best available and most appropriate geospatial data. However, because rare ecosystems are often under documented and the sources used to map their occurrences are variable in quality, the accuracy of our mapping is not consistent among systems. We evaluated each systems area of occupancy independently, map data were not combined for comparison, which allowed us to complete the ranking, establish percent land ownership and provide data on level of protection for each system. The Alaska Vegetation Map, developed by ACCS, provided the basis for most biophysical setting distribution maps (Boggs et al. 2016a, b). This product was developed from a mosaic of over 30 individual landcover datasets and provides a uniform legend so that landcover classes that are similar in concept yet different in nomenclature may be reconciled. Whereas, the Consortium of Pacific Northwest Herbaria provided the basis for the distribution of most plant associations (CPNWH 2016). Where these primary sources were not informative to the distribution of a given biophysical setting or plant association, maps were developed from alternate geospatial datasets such as those describing elevation (USGS 2009; National Elevation Dataset), surface geology (Wilson et al. 2015; Geologic Map of Alaska), wetland type (USDI 2015; National Wetlands Inventory), glacial extent (GLIMS 2015), or coastline morphology (NOAA 2015; ShoreZone). Distribution of the Steppe Bluff Biophysical Setting was modeled in a separate project (Boucher et al. 2013) Using the MaxEnt application (Phillips & Dudík 2008). We chose a modeled extent of steppe bluff distribution rather than a conventionally mapped distribution because we perceived the documented locations to grossly underestimate the actual number and extent of steppe bluffs and occurrence of the steppe bluff system has been shown to be highly correlated to the climate and landscape features used as model inputs (Boucher et al. 2013). The Steppe Bluff biophysical setting distribution was the only ecosystem modeled from existing locations documented in literature or represented by collections of *Artemisia frigida* (and *Calamagrostis purpurascens*), which are reliable indicators of the habitat. Herbaria records were only accepted into the model if location notes explicitly described the site as steppe habitat and/or inspection of the underlying remotely-sensed imagery indicated steppe habitat.

Unless indicated otherwise, all distribution mapping and conservation gap analyses were conducted in a GIS environment using ArcGIS 10.4 software.

Conservation Status Ranking

NatureServe's rank calculator (version 3.186) was used to assign preliminary conservation status to biophysical settings and plant associations (Faber-Langendoen et al. 2009; Master et al. 2012). This methodology, developed as a globally applicable, standard ranking system sums weighted values for factors related to rarity, trends, and threats to calculate conservation status. The rarity of a system is derived from its direct area of occupancy (i.e. distribution), estimated percent of current area occupied considered to have good ecological integrity and geographical range. Unless more spatially-specific information was available (i.e. published accounts of range), range was calculated as a convex-hull polygon encompassing all occurrences of the system using the minimum bounding geometry tool available in ArcGIS. The trend of a system relates to expected change in area of occupancy across the short- (50 years) and long- (200 years) terms and was estimated based on our ecological understanding as well as potential threats to a given system. Threats to a system consider the severity, scope, impact, and timing of stressors, as well as the response and resilience of the system to those stressors. Threats were assessed by best professional judgement with adherence to the guidance provided within the ranking calculator (Master et al. 2012). The range of possible status ranks generated by the rank calculator are: 1 - critically imperiled, 2 - imperiled, 3 - vulnerable, 4 - apparently secure, 5 - secure, and are preceded by a letter reflecting the appropriate geographic scale of the assessment: G - global, N - national, or S - subnational (i.e. state) (Table 1). Ranks were adjusted from the preliminary, calculated rank if justified by professional judgment or expert opinion. Plant associations and biophysical settings were considered of conservation concern when assessed to be less than secure at the state level (i.e. ≤ S4), following the principle of precaution (O'Riordan and Cameron, 1994) and allowing for a broader concept of ecosystem rarity for a large state with high levels of ecosystem intactness (Reynolds et al. 2018), but facing threats that impact large geographies (i.e. climate change).

Table 1. Conservation status rank designations.

Conservation Ranking System					
Geographic Scale		Value		Modifier	
G	global	1	critically imperiled	NR	not ranked
S	state	2	imperiled	U	unrankable
		3	vulnerable	T	infraspecific ranking
		4	apparently secure	B	breeding
		5	secure	N	non-breeding
				Q	questionable

Associated Species and Communities of Conservation Concern

To more fully describe the elements of biodiversity of Alaska's rare ecosystems, associated animal and plant species of conservation concern were listed for each biophysical setting and plant association. Plant associations of conservation concern were also listed for biophysical settings. Only those species or associations considered to be less than apparently secure (S4) within the state (regardless of global rank) were included. Species were identified in several ways including field sampling, the spatial intersection of ecosystem and rare plant or animal distributions, as well as published accounts of occurrence and habitat descriptions.

Where access permitted, site visits were conducted to increase our understanding of the system and to document the presence or absence of species of conservation concern. However, owing to the remote location of most rare ecosystems, direct sampling of all types was often not possible. As an alternative to site visits, the potential linkages between rare species and rare ecosystems were inferred from the spatial intersection of known rare animal and plant occurrences with the distribution map for each system of conservation concern. Animal occurrences were gleaned from the Alaska GAP Analysis Occurrence Geodatabase (Gotthardt et al. 2013). Rare plant occurrences were taken from the rare plant database housed at ACCS (ACCS 2016). Distributions developed from point data (e.g., Arctic Pingo, Geothermal Spring, and Steppe Bluff Biophysical Settings) were buffered by 1 km to account for low accuracy of geographic coordinates, an issue that is exacerbated in older records collected before the use of GPS. A model incorporating the iterator function and clip tool was then built in ArcGIS (version 10.3.1) to generate rare plant and animal point shapefiles for each rare ecosystem.

Summary tables of species associated with each rare ecosystem were reviewed by ACCS botanists and zoologists. Spatial correlations between a rare ecosystem and a given species is subject to the limitations of their input data, specifically the accuracy of species locations and the ecosystem distribution maps. Thus, cooccurrence of species and systems do not necessarily indicate that the species relies upon services provided by the rare ecosystem that cannot be provided by other nearby habitats. For example, several bird species of conservation concern were omitted from the species list because owing to their natural movement, occurrences were difficult to associate with a specific habitat, and thus, their inclusion could artificially inflate the significance of the rare ecosystem in which they were documented (DeCicco pers. comm. February 2016). To address these limitations, we removed species that were clearly not likely to utilize the ecosystem and added species that based on literature review and professional judgment, were likely to be supported by the ecosystem in question.

Plant associations of conservation concern were listed for biophysical settings where published accounts existed. These associations were selected using professional judgement by ACCS ecologists from a list of over 1,300 types that have been formally described for Alaska (ACCS 2016).

Gap Analysis

The Gap Analysis Program (GAP), administered by the U.S. Geological Survey (USGS), is a nationwide program which aims to assess the extent to which species and vegetative communities are represented within protected areas (Scott et al. 1993). To support this goal, USGS developed the Protected Areas Database (PAD-US) which serves as the official inventory of terrestrial and marine protected open space dedicated to the preservation of biological diversity across (USGS 2016). To determine conservation gaps for the rare ecosystems presented here, occupancy distribution maps were overlain with the PAD-US layer for Alaska (USGS 2012) in a GIS environment. The PAD-US layer is attributed by a GAP status code, which can be used as a proxy for management intent to conserve biodiversity (Table 2).

Table 2. National Gap Analysis Program protection status codes and definitions, as derived from the Protected Areas Database of the United States (PAD-US) version 1.3 geodatabase.

<table>
<tr><th>Status Code</th><th>Management Definition</th><th>Disturbance</th></tr>
<tr><td rowspan="2">1</td><td>Managed for biodiversity</td><td>Disturbance events proceed or are mimicked</td></tr>
<tr><td colspan="2">An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.</td></tr>
<tr><td rowspan="2">2</td><td>Managed for biodiversity</td><td>Disturbance events suppressed</td></tr>
<tr><td colspan="2">An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.</td></tr>
<tr><td rowspan="2">3</td><td>Managed for multiple uses</td><td>Subject to extractive (e.g., mining or logging) or OHV use</td></tr>
<tr><td colspan="2">An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging, OHV recreation) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area.</td></tr>
<tr><td rowspan="2">4</td><td>No known mandate for protection</td><td>Unknown</td></tr>
<tr><td colspan="2">There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout or management intent is unknown.</td></tr>
</table>

The methodology used to attribute GAP status code to a given protected area is outlined in the PAD-US Standards Manual (USGS 2013) and defaults to the minimum level of conservation afforded. Conservation status of each land management category is shown in Table 3.

Table 3. Conservation status of land management categories

Land Management Category	GAP Status Code
National Designations	
National Park	2
National Forest-National Grassland	3
National Trail	4
National Wildlife Refuge	2
National Natural Landmark	2
National Landscape Conservation System - Non Wilderness	3
National Landscape Conservation System - Wilderness	2
Native American Land	4
Other Designations	
Protective Management Area - Feature	3
Protective Management Area - Land, Lake or River	3
Habitat or Species Management Area	2
Recreation Management Area	3
Resource Management Area	3
Wild and Scenic River	2
Research and Educational Land	3
Marine Protected Area	3
Wilderness Area	1
Area of Critical Environmental Concern	3
Research Natural Area	2
Historic / Cultural Area	3
Mitigation Land / Bank	3
Military Land	4
Watershed Protection Area	3
Access Area	4
Special Designation Area	3
Other Designation	4
Not Designated	4
State Designations	
State Park	3
State Forest	3
State Trust Lands	3
State Other	4
Local Government Designations	
Local Conservation Area	2
Local Recreation Area	4
Local Forest	3
Local Other	4
Private Designations	
Private Conservation Land	2
Agricultural Protection Land	4
Conservation Program Land	3
Forest Stewardship Land	3

To evaluate the gaps in protected areas, we intersected each system's distribution with the PAD-US version 1.4 layer developed for Alaska (USGS 2016). Prior to this intersection, we 'flattened' the protected areas layer to remove areas of overlapping conservation status. Specifically, the PAD-US layer was converted from its native vector format to a raster dataset with the GAP status code informing the pixel value. In areas of no overlap the value of the GAP code at the center of the cell was adopted as the pixel value, however in areas of overlap, the highest level of conservation (i.e. lowest GAP code value) was given precedence.

To intersect the PAD-US layer with the 12 systems that were represented by point occurrence data only, it was first necessary to buffer the points. We were able to buffer two of the systems (Arctic Pingos Biophysical Setting and Mud Volcano Biophysical Setting) using literature-supported values, however for the remaining ten systems we were forced to adopt estimated areas of occupancy. A 0.01 km^2 area of occupancy (corresponding to a buffer value of 56.4 m) was used for the *Andreaea bylttii* Snowbed Plant Association based on personal observation (Flagstad and Boucher 2015). An estimated area of 0.3 km^2 (corresponding to a buffer value of 309 m) was used for the *Luzula confusa - Poa arctica*, *Luzula confusa - Sphaerophorus globosus* and *Papaver gorodkovii* Volcanic Scree Plant Associations and was based on a professional judgement of average area ranging from 0.1 to 0.5 km^2. The remaining six systems: namely the *Artemisia arctica - Trisetum spicatum* Nunatak, *Picea sitchensis / Oplopanax horridus / Circaea alpine*, and *Picea sitchensis/Calamagrostis nutkaensis* Plant Associations and the Geothermal Spring, *Larix laricina* Wetland, and *Picea glauca* Floodplain Old-growth Forest Biophysical Settings were thought to occupy a larger per-occurrence area and thus assigned a default 0.1 km^2 area of occupancy (corresponding to a buffer value of 564 m).

The final output for each ecosystem represented the portion of the PAD-US raster that was spatially coincident with the distribution of the system. For each PAD-US extraction we calculated the percent area of each GAP status category and calculated a status-weighted protection index for each ecosystem, in accordance with the following formula:

$$Index = \frac{(1 * \%Area_{Status1}) + (2 * \%Area_{Status2}) + (3 * \%Area_{Status3}) + (4 * \%Area_{Status4})}{100}$$

This index provides a continuous-variable metric of protection for each ecosystem. Index values have the same range as, and are thus easily compared to, the categorical GAP status codes. For example, an ecosystem-wide score of 1.0 indicates that the entire rare ecosystem is managed for biodiversity (e.g., the entirety of the system is within Wilderness Area boundaries), while a score of 4.0 indicates that no known management mandate for protection has been issued for any part of that ecosystem's extent (e.g., the system occurs only on private lands).

Since determining what constitutes sufficient protection of fine-scale ecosystems occupying a small proportion of the landscape is difficult, we used both protection index and percent of area managed for biodiversity (Status Codes 1 and 2) to summarize conservation status. Systems with a protection index less than 2.5 or at least 50% of their area managed for biodiversity were considered sufficiently protected. This percent area threshold is adopted from literature recommendations (Noss et al. 2012) and represents an approximate average percent of terrestrial land required to meet conservation goals as derived from numerous evidence-based assessments (e.g. scientific research, reviews, and expert opinion).

To assess the levels of spatial organization represented by plant associations and biophysical settings, we placed each system in a local-, intermediate-, or coarse-geographic scale category in accordance with the parameters set forth by Poiani and others (2000) where local scale refers to a discrete, geomorphologically-defined, and spatially-fixed ecosystem occupying meters to thousands of hectares; intermediate scale refers to relatively-discrete ecosystems defined by physical factors and environmental regimes and occupying hundreds to tens of thousands of hectares, and; coarse scale refers to non-discrete, ecosystems defined by widespread climatic and elevational gradients and occupying hundreds of thousands to millions of hectares. We considered both area of distribution as well as the ecological characteristics of systems when assigning categories of spatial organization.

We tested for a linear relationship between protection index value and conservation rank of the rare ecosystems using correlation analysis as well as differences in mean conservation rank and mean protection index value among the five geographic groups (Arctic, Beringian, Boreal, Pacific, and Statewide) using analysis of variance (ANOVA) (with Holm-Sidak post hoc tests) and with Kruskal-Wallis ANOVA on ranks for conservation rank data that did not meet normality of variance assumptions.

Results

Descriptions summarizing the climate, environmental characteristics, vegetation, disturbance, conservation status, and associated species and communities of conservation concern were developed for 24 biophysical settings and 10 plant associations (Table 4). Conservation status ranks were assigned at the statewide level for each ecosystem and distribution maps were developed for all but one ecosystem. The majority of ecosystems (15 of 35) are located in Southern Alaska, which includes Southeast Alaska and the Aleutian Islands. Northern and Interior Alaska are represented by five rare ecosystems each, four systems are found in Western Alaska, and only three systems have been recognized to span the entire state. When summarized by category of rarity, 14 systems are primarily influenced by geomorphic processes, nine systems are characterized by unusual floristics, seven systems develop on uncommon substrates, and the remaining four systems occupy distinct microclimates.

Table 4. Conservation status ranks for biophysical settings and plant associations of conservation concern presented by ecoregion and category of rarity.

Ecosystem Name	Alaska Region	State Rank	Category of Rarity
Andreaea blyttii Snowbed PA	Statewide	S4	Microclimate
Anthelia juratzkana–Gymnomitrion corallioides Biological Crust PA	Pacific	S4	Floristics
Arctic Barrier Island and Spit BpS	Arctic	S4	Geomorphic Process
Arctic Inland Dune BpS	Arctic	S4	Substrate, Geomorphic Process
Arctic Pingo BpS	Arctic	S4	Geomorphic Process, Microclimate
Arctic Tidal Marsh BpS	Arctic	S3	Geomorphic Process
Artemisia alaskana – Dianthus repens PA	Boreal	S2	Geomorphic Process
Artemisia arctica-Trisetum spicatum Nunatak PA	Pacific	S4	Floristics
Beringian Alpine Limestone *Dryas* BpS	Arctic, Beringian	S4	Substrate, Floristics
Beringian Barrier Island and Spit BpS	Beringian	S4	Geomorphic Process
Beringian Dwarf Shrub-Lichen Peatland Plateau BpS	Beringian	S4	Microclimate

Ecosystem Name	Alaska Region	State Rank	Category of Rarity
Beringian Tidal Marsh BpS	Beringian	S4	Geomorphic Process
Boreal Forested Glacial Ablation Plain BpS	Boreal	S4	Geomorphic Process
Boreal Inland Dune BpS	Boreal	S4	Substrate, Geomorphic Process
Callitropsis nootkatensis Wetland BpS	Pacific	S4	Microclimate
Geothermal Spring BpS	Statewide	S4	Geomorphic Process, Microclimate
Karst Alpine Herbaceous Meadow and Heath BpS	Pacific	S4	Substrate
Karst Fen BpS	Pacific	S2	Substrate
Karst *Tsuga heterophylla-Picea sitchensis* PA	Pacific	S3	Substrate
Larix laricina Wetland BpS	Boreal	S3	Floristics
Luzula confusa-Poa arctica PA	Arctic	S4	Floristics
Luzula confusa-Sphaerophorus globosus PA	Arctic	S4	Floristics
Mud Volcano BpS	Statewide	S4	Geomorphic Process, Microclimate
Pacific Barrier Island and Spit BpS	Pacific	S4	Geomorphic Process
Pacific Forested Glacial Ablation Plain BpS	Pacific	S4	Geomorphic Process
Pacific Tidal Marsh BpS	Pacific	S4	Geomorphic Process
Pacific Uplifted Tidal Marsh BpS	Pacific	S3	Geomorphic Process
Papaver gorodkovii Volcanic Scree PA	Beringian	S3	Substrate, Floristics
Picea glauca Floodplain Old-growth Forest BpS	Boreal	S4	Geomorphic Process
Picea sitchensis Floodplain Old-growth Forest BpS	Pacific	S3	Substrate
Picea sitchensis/Calamagrostis nutkaensis PA	Pacific	S4	Floristics
Picea sitchensis/Oplopanax horridus/Circaea alpina PA	Pacific	S4	Floristics
Pinus contorta var. *latifolia/Cladina* species PA	Pacific	S2	Floristics
Pohlia wahlenbergii–Philonotis fontana Seep PA	Pacific	S3S4	Floristics
Steppe Bluffs BpS	Boreal	S3	Microclimate, Floristics

Distribution Mapping

Distribution maps were developed for 34 of the 35 ecosystems considered here, no rare ecosystems treated here are endemic to the Aleutian region. Due to the paucity of geospatial information, we were not able to generate a defensible distribution map for the *Pohlia wahlenbergii–Philonotis fontana* Plant Association.

Cumulatively, ecosystems of conservation concern represent 3% of the total area of Alaska, with *Callitropsis nootkatensis* (Yellow Cedar) Wetland Biophysical Setting (1.0%), Beringian Dwarf Shrub-Lichen Peatland Plateau Biophysical Setting (0.8%), Beringian Alpine Limestone *Dryas* Biophysical Setting (0.6%), Beringian Tidal Marsh Biophysical Setting (0.3%), and Pacific Forested Glacial Ablation Plain Biophysical Setting (0.2%) representing the five largest systems. The Arctic Poppy (*Papaver gorodkovii)* Volcanic Scree, Blytt's andreaea Moss (*Andreaea blyttii*) Snowbed, Alaska Wormwood - Boreal Carnation (*Artemisia alaskana* - *Dianthus repens*) Gravel Bar, and Lodgepole Pine/Reindeer Lichen

(*Pinus contorta* var. *latifolia / Cladina*) species Plant Associations and the Karst Fen Biophysical Setting, represent the four smallest systems with individual areas of 0.5 km^2 or less (Table 5).

Plant associations largely represent the smallest areas of occupancy, with the *Papaver gorodkovii* Volcanic Scree Plant Association, *Artemisia arctica-Trisetum spicatum* Nunatak Plant Association, Karst Fen Biophysical Setting, *Anthelia juratzkana–Gymnomitrion* corallioides Biological Crust Plant Association, and *Pinus contorta* var. *latifolia/Cladina* species Plant Association representing the five smallest systems (listed in order of decreasing area) (Table 5).

Table 5. Alaska's rare ecosystems presented in increasing value of protection index.				Percent Area					
Ecosystem Name	Scale	Conservation Rank	Area (km^2)	Status 1	Status 2	Status 3	Status 4	Protection Index	Percent Area Managed for Biodiversity (Status 1 and 2)
Anthelia juratzkana – Gymnomitrion corallioides Biological Crust PA	local	S4	1.1	100.0	0.0	0.0	0.0	1.00	100.0
Boreal Inland Dune BpS	local	S4	106.6	99.8	0.0	0.0	0.2	1.00	99.8
Artemisia alaskana – Dianthus repens Gravel Bar PA	local	S2	0.1	89.1	0.0	0.0	10.9	1.33	89.1
Pacific Forested Glacial Ablation Plain BpS	intermediate	S4	67.0	77.8	0.9	17.0	4.3	1.48	78.7
Artemisia arctica – Trisetum spicatum Nunatak PA	local	S4	1.5	75.0	0.0	25.0	0.0	1.50	75.0
Boreal Forested Glacial Ablation Plain BpS	intermediate	S4	7.4	75.3	1.6	4.2	18.9	1.67	76.9
Beringian Dwarf Shrub – Lichen Peatland Plateau BpS	coarse	S4	10,407.6	67.4	0.0	0.4	32.2	1.97	67.4
Pinus contorta var. *latifolia / Cladina* species PA (Lodgepole pine/Reindeer lichen)	local	S2	<0.1	0.0	100.0	0.0	0.0	2.00	100.0
Pacific Barrier Island and Spit BpS	intermediate	S4	178.2	24.0	52.1	10.7	13.2	2.13	76.1
Papaver gorodkovii (Arctic Poppy) Volcanic Scree PA	local	S3	1.5	60	0.0	0.0	40.0	2.20	60.0
Beringian Tidal Marsh BpS	intermediate	S4	3,898	56.4	0.0	1.2	42.4	2.30	56.4
Andreaea blyttii (Blytt's andreaea) Snowbed PA	local	S4	0.2	52.8	0.0	9.2	38.0	2.32	52.8
Picea sitchensis Floodplain Old-growth Forest BpS	intermediate	S3	466	26	18.4	41.5	14.1	2.44	44.4
Geothermal Spring BpS	local	S4	102.9	42.2	4.9	13.2	39.7	2.50	47.1
Steppe Bluffs BpS	local	S4	30.9	37.9	11.8	12.7	37.6	2.50	49.7
Callitropsis nootkatensis (Yellow cedar) Wetland BpS	intermediate	S4	12,676	25.3	7.3	58.3	9.1	2.51	33.6
Pacific Uplifted Tidal Marsh BpS	intermediate	S3	554.4	2.5	57.5	23.9	16.1	2.54	60
Beringian Alpine Limestone *Dryas* BpS	coarse	S4	7,572	40.7	0.0	13.8	45.5	2.64	40.7
Picea sitchensis / Oplopanax horridus / Circaea alpina PA	local	S2	2.0	12.6	47.4	0	40	2.67	60
Luzula confusa – Sphaerophorus globosus PA	local	S4	5.7	36.7	0.0	21.1	42.2	2.69	36.7
Karst Alpine Herbaceous Meadow and Heath BpS	intermediate	S4	63.2	10.4	8.2	79.6	1.8	2.73	18.6

Picea sitchensis / Calamagrostis nutkaensis PA	local	S4	10.0	27.5	0.0	39.1	33.4	2.78	27.5
Karst *Tsuga heterophylla – Picea sitchensis* PA	local	S3	479.4	17.6	5.3	57.6	19.5	2.79	22.9
Karst Fen BpS	local	S2	0.2	0.0	0.0	100.0	0.0	3.00	0.0
Pacific Tidal Marsh BpS	intermediate	S4	3,007	10.2	23.4	11.32	55.1	3.11	33.6
Picea glauca Floodplain Old-growth Forest BpS	intermediate	S4	351.0	25.5	0.0	12.12	62.4	3.11	25.5
Arctic Inland Dune BpS	local	S4	92.9	0.0	0.0	77.1	22.7	3.23	0.0
Arctic Pingo BpS	local	S4	121	2.7	0.0	61.0	36.3	3.31	2.7
Beringian Barrier Island and Spit BpS	intermediate	S4	118.6	12.2	7.4	2.9	77.5	3.46	19.6
Arctic Tidal Marsh BpS	intermediate	S3	1,156	5.9	0.33	23.35	70.4	3.58	6.2
Larix laricina Wetland BpS	local	S3	35.2	8.5	0.8	10.7	80	3.62	9.3
Luzula confusa – Poa arctica PA	local	S4	7.8	0.0	0.0	23.1	76.9	3.77	0.0
Arctic Barrier Island and Spit BpS	intermediate	S4	190.4	3.9	0.0	8.7	87.4	3.80	3.9
Mud Volcano BpS	local	S4	4.7	0.0	0.0	14.7	85.3	3.85	0.0
*Pohlia wahlenbergii – Philonotis fontan*a Seep PA (not mapped)	local	-	-	-	-	-	-	-	-

Conservation Status Ranking

Conservation status ranks were generated at the state level for each biophysical setting and plant association. NatureServe methodology (Faber-Langendoen et al. 2009); each rank was further evaluated through professional review; seven systems were adjusted based on professional judgment.

Revision of the Wahlenberg's Pohlia Moss-Philonotis Moss Seep Plant Association rank represents the greatest change in rank. The calculated rank of S1 was downgraded to an adjusted range rank of S3S4 on the basis that this system is significantly under-surveyed. While less than 20 occurrences have been documented, the component moss species occur throughout the state and are likely to co-occur in other locations along the Aleutian Islands and greater southern Alaska region. Ranks for the Lodgepole Pine/Reindeer Lichen, Alaska Wormwood - Boreal Carnation Gravel Bar, Sitka Spruce/Devil's Club/Enchanter's Nightshade (*Picea sitchensis/Oplopanax horridus/Circaea alpina*) Plant Associations, and the Karst Fen Biophysical Setting were adjusted from the calculated value of S1 to the next lower level of conservation rank (S2) on the assumption that these systems are under-surveyed. Alternatively, the conservation status rank for the Beringian Alpine Limestone *Dryas* and the Pacific Tidal Marsh Biophysical Settings were adjusted from the calculated rank of secure (S5) to apparently secure (S4) on the basis that the areas of occupancy generated for these systems are likely overestimated.

In total, four systems are designated as imperiled (S2), six systems are vulnerable (S3), one system is vulnerable to apparently secure (S3S4), and the remaining 24 are apparently secure (S4). The most imperiled ecosystems in Alaska as currently assessed are the Lodgepole Pine/Reindeer Lichen Plant Association, the Alaska Wormwood - Boreal Carnation Gravel Bar Plant Association, Sitka Spruce/Devil's Club/Enchanter's Nightshade Plant Association, and the Karst Fen Biophysical Setting.

Alaska's rarest ecosystems differ in physiognomy (e.g., forested and not forested, wetland and upland), but are largely united by uncommon surficial geologies that are very sporadic and isolated on the landscape. The systems of lesser conservation concern are also associated with uncommon substrates, but either occupy a greater area or geographic range. A single occurrence of the Lodgepole Pine/Reindeer Lichen Plant Association has been documented in southeastern Alaska where stands of this subspecies of tree, which is uncommon in Alaska, develop in deep lichen mats overlying well-drained granitic bedrock outcrops. The Alaska Wormwood - Boreal Carnation Gravel Bar Plant Association has been described from two gravel river bars in subarctic, continental Alaska and is considered rare for both its unusual combination of diagnostic species as well as its restriction to well-drained substrates derived from ultramafic parent materials. Sitka Spruce/Devil's Club/Enchanter's Nightshade Plant Association has only been documented on wind-deposited silt on hillslopes adjacent to the Stikine River delta in southeastern Alaska. Karst fens are considered one of the rarest wetland types in North America and, in Alaska, are represented by only three occurrences located in coastal rainforests overlying calcareous bedrock.

Within each category of conservation rank, both plant associations and biophysical settings are represented. Likewise, we did not detect a difference in conservation rank among the regions of Alaska (Kruskal-Wallis $X^2 = 3.97$, $p = 0.41$; (Table 5). One S3 and five S4 systems occur in Arctic Alaska, one S3 and four S4 systems occur in Beringian Alaska, one S2, one S3, and four S4 systems occurring in Boreal Alaska, and three S2, three S3, one S3S4, and eight S4 systems occurring in Pacific Alaska. Only three apparently secure (S4) systems: Blytt's andreaea Moss Snowbed Plant Association, Geothermal Spring, and Mud Volcano Biophysical Settings, have statewide distributions of widely scattered and small areas of occurrence.

Conservation Gap Analysis

Overall protection of rare ecosystems in Alaska is relatively high with 35% of systems (12 of 34 mapped systems) have adequate protection (Table 5). Three systems are marginally protected with either 50% of their extent managed for biodiversity or a protection index less than 2.5, but not both. The remaining 19 systems are considered under protected.

The comparison of gap analysis protection index value to conservation rank (S1-S5) (Table 5) shows no detectable relationship between the magnitudes of protection values and conservation ranks (Pearson's r = 0.005, p = 0.98, n = 34). Two of the four imperiled (S2) systems, namely the Alaska Wormwood - Boreal Carnation Gravel Bar, and Lodgepole Pine/Reindeer Lichen Plant Associations have a protection index less than 2.5, indicating a high level of protection; the Sitka Spruce/Devil's Club/Enchanter's Nightshade Plant Association has a moderate protection index of 2.67. However, no portion of the state's most imperiled system, the Karst Fen Biophysical Setting is managed for biodiversity. Only one of the state's six vulnerable (S3) systems are associated with lands that are managed for biodiversity protection, yet nine of 24 apparently secure (S4) systems are afforded adequate protection based on land management designations. Less-protected ecosystems often occur in coastal (e.g. barrier islands, spits, tide marshes) or other accessible, low-elevation areas (e.g. uplifted tidal marshes, and old-growth forests). Conversely, well-protected ecosystems are often found in high-elevation (e.g. alpine and nunatak associations) or otherwise extreme (e.g. xeric, wetland, periglacial, permafrost) environments.

When evaluated by protection index, relatively consistent levels of protection were found among systems with shared environmental factors, processes, or regimes. For example, the protection indices for the Boreal Forested Glacial Ablation Plain and the Pacific Forested Glacial Ablation Plain biophysical settings are similar (1.67 and 1.48, respectively). Also, the related systems of Boreal (where *Picea glauca* is diagnostic) and Pacific (where *Picea sitchensis* is diagnostic) Old-growth Forest Biophysical Settings had similar protection indices of 3.11 and 2.44, respectively. Coastal systems represented by tidal marshes and seaward complexes of barrier islands and spits also show considerable overlap in their range of protection indices. The Arctic, Beringian, and Pacific Tidal Marsh Biophysical Settings have protection indexes averaging 2.99 with range in values from 2.30 to 3.58; whereas the Arctic, Beringian, and Pacific Barrier Islands and Spit biophysical settings have protection indexes averaging 3.13 with range in values from 2.13 to 3.80. Arctic and Boreal Inland Dunes had the greatest spread in protection indexes among environmentally similar systems at 3.23 and 1.00, respectively.

Ecosystem level of protection is related to region (F (4, 33) = 3.89, p = 0.012). Systems with arctic distributions are not as well-protected as Boreal and Pacific systems (post-hoc Arctic-Boreal Holm-Sidak t = 3.44, p = 0.018 and Arctic-Pacific Holm-Sidak t = 3.14, p = 0.034). When summarized by region, systems in Arctic, Beringian, Pacific, and Boreal Alaska have average protection indices of 3.4, 2.5, 2.3, and 2.2, respectively.

There is a relatively good distribution of spatial scales among category of protection index (). When systems are grouped by protection index value (<2, 2-3, and >3), all spatial scales (local, intermediate, and coarse) are represented in systems managed for biodiversity (Protection Index <3). In general, coarse scale ecosystems are not as well represented among those of conservation concern (11%, represented by 4 of 33 mapped systems), but where documented are adequately protected. Conversely, local-scale systems are disproportionally under-protected. For systems with a protection index >3, local-scale systems comprise 88% or 7 of 8 under-protected systems.

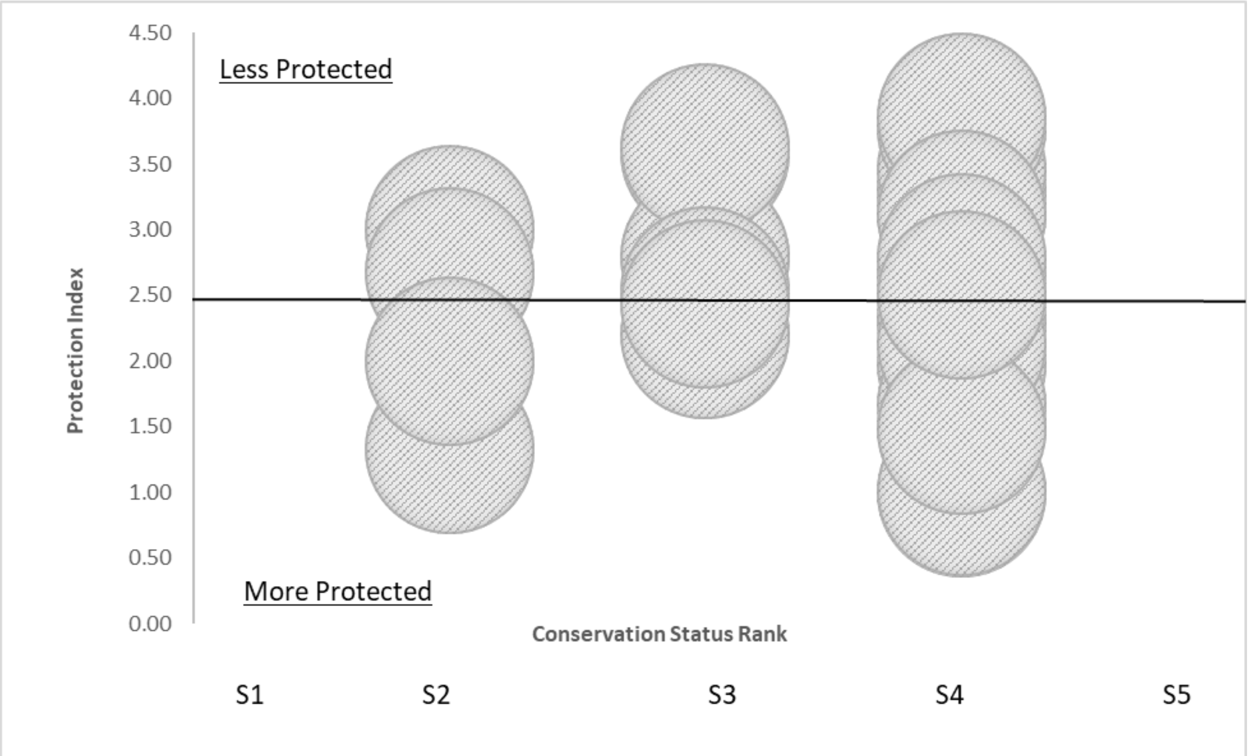

Figure 4. Distribution of ecosystems (circles) of conservation concern in Alaska by protection index value and category of conservation status (S1-S5). S1 = "critically imperiled", S2 = "imperiled", S3 = "vulnerable", S4 = "apparently secure", S5 = "secure". The horizontal line indicates a conceptual threshold in biodiversity protection between those deemed "more protected" and those deemed "less protected".

With respect to land ownership, ecosystems whose distributions occurred mostly on NPS lands had the highest level of protection (i.e. *Anthelia juratzkana-Gymnomitrion corallioides* Plant Association, Boreal Inland Dunes Biophysical Setting, and *Artemisia arctica-Trisetum spicatum* Nunatak Plant Association), whereas ecosystems with most of their distribution on private, tribal, and state land had the lowest levels of protection (i.e. Mud Volcano Biophysical Setting, *Luzula confusa-Poa arctica* Plant Association, *Larix laricina* Wetland Biophysical Setting)(Table 6).

Ecosystems with the lowest level of protection (78 to 100% of their distributions in Status 3 and 4 and a protection index of 3.0 to 3.8) all typically occur at lower elevations (e.g. Karst Fen Biophysical Setting, Arctic Inland Dunes Biophysical Setting, Arctic Pingo Biophysical Setting, *Picea glauca* Floodplain Old-growth Forest Biophysical Setting, Arctic Tidal Marsh Biophysical Setting, *Larix laricina* Wetland Biophysical Setting, *Luzula confusa-Poa arctica* Plant Association, and Mud Volcano Biophysical Setting).

Relatively consistent protection status was found among systems with common physical factors or regimes that spanned several regions (e.g. barrier islands, tide marshes, old-growth forests, glacial ablation plains). Arctic, Beringian, and Pacific Barrier Islands and Spits had protection indexes averaging 2.7 and ranging from 2.1-3.0 while Arctic, Beringian, and Pacific Tidal Marshes had protection indexes averaging 2.5 and ranged from 2.2-3.2. Boreal and Pacific Forested Glacial Ablation Plains protection indexes were 1.8 and 1.9 respectively. Boreal (where *Picea glauca* is diagnostic) and Pacific (where *Picea sitchensis* is diagnostic) Old-growth Forests had the greatest spread in protection indexes at 3.2 and 2.1, respectively.

Land Ownership by System

When evaluated on a per system basis, NPS manages the highest percent area across the greatest number of ecosystems (top landowner in 8 of 35 mapped systems), followed by USFS (top landowner in 7 of 33 mapped systems), and USFWS (top landowner in 6 of 35 mapped systems).

Table 6. Total and percent area of ecosystems of conservation concern presented by land ownership.

Ecosystem Name	Land Owner	Total Area (km2)	Percent Area Managed
Andreaea blyttii Snowbed PA	US Fish and Wildlife	5	36%
	Native American Land	2	18%
	State Department of Natural Resources	2	13%
	National Park Service	2	12%
	Unknown	1	11%
	US Forest Service	1	10%
Anthelia juratzkana–Gymnomitrion corallioides Biological Crust PA	National Park Service	1	100%
Arctic Barrier Island and Spit BpS	Native American Land	56	35%
	Bureau of Land Management	29	18%
	National Park Service	24	15%
	US Fish and Wildlife	23	14%
	Private	16	10%
	State Department of Natural Resources	13	8%
	Department of Defense	0.3	0.2%
Arctic Inland Dune BpS	Bureau of Land Management	44	92%
	Native American Land	3	7%
	Private	0.4	1%
Arctic Pingo BpS	Bureau of Land Management	44	92%
	Native American Land	3	7%
	Private	0.4	1%
Arctic Tidal Marsh BpS	Bureau of Land Management	339	47%
	State Department of Natural Resources	177	25%
	Native American Land	106	15%
	US Fish and Wildlife	85	12%
	Private	11	2%
	Department of Defense	1	0.1%
	Joint Ownership	0.3	0.04%
	National Park Service	0.05	0.01%
	Unknown	0.004	0.001%

Ecosystem Name	Land Owner	Total Area (km2)	Percent Area Managed
Artemisia alaskana-Dianthus repens PA	US Fish and Wildlife	0.074	100%
Artemisia arctica-Trisetum spicatum Nunatak PA	National Park Service	2	74%
	US Forest Service	1	26%
Beringian Alpine Limestone *Dryas* BpS	National Park Service	2,456	46%
	State Department of Natural Resources	1,509	28%
	Bureau of Land Management	787	15%
	Native American Land	495	9%
	US Fish and Wildlife	130	2%
	Private	1	0.02%
	Unknown	0.0001	0.000003%
Beringian Barrier Island and Spit BpS	Native American Land	34	47%
	US Fish and Wildlife	19	26%
	State Department of Natural Resources	18	24%
	Private	2	2%
	Bureau of Land Management	1	1%
	Unknown	0.04	0.1%
Beringian Dwarf Shrub-Lichen Peatland Plateau BpS	US Fish and Wildlife	7,810	75%
	Native American Land	2,316	22%
	Private	263	3%
	Bureau of Land Management	17	0.2%
	State Department of Natural Resources	0.04	0.0004%
Beringian Tidal Marsh BpS	US Fish and Wildlife	2,463	58%
	Native American Land	1,467	35%
	Private	125	3%
	Bureau of Land Management	119	3%
	National Park Service	42	1%
	State Department of Natural Resources	30	1%
	Department of Defense	0.002	0.00004%
	Unknown	0.0002	0.000004%
Boreal Forested Glacial Ablation Plain BpS	National Park Service	5	71%
	State Department of Natural Resources	1	14%
	Private	1	9%
	Bureau of Land Management	0.3	4%
	Native American Land	0.2	3%
	US Forest Service	0.001	0.02%
	US Fish and Wildlife	0.001	0.01%
Boreal Inland Dune BpS	National Park Service	57	53%
	US Fish and Wildlife	44	41%
	Unknown	6	6%

Ecosystem Name	Land Owner	Total Area (km2)	Percent Area Managed
	Private	0.2	0.2%
Callitropsis nootkatensis Wetland BpS	US Forest Service	7,225	94%
	Native American Land	242	3%
	State Department of Natural Resources	146	2%
	National Park Service	43	1%
	Private	6	0.1%
	US Fish and Wildlife	1	0.01%
	Unknown	1	0.01%
	Joint Ownership	0.1	0.002%
	Bureau of Land Management	0.1	0.001%
Geothermal Spring BpS	US Fish and Wildlife	22	37%
	US Forest Service	9	14%
	Native American Land	9	14%
	National Park Service	7	12%
	State Department of Natural Resources	6	10%
	Bureau of Land Management	5	9%
	Private	2	3%
	Unknown	0.02	0.03%
Karst Alpine Herbaceous Meadow and Heath BpS	US Forest Service	61	97%
	State Department of Natural Resources	1	2%
	National Park Service	0.5	1%
	Native American Land	0.2	0.3%
Karst Fen BpS	US Forest Service	2	100%
Karst *Tsuga heterophylla-Picea sitchensis* PA	US Forest Service	403	88%
	Native American Land	34	7%
	State Department of Natural Resources	19	4%
	Unknown	1	0.2%
	Private	1	0.1%
	Bureau of Land Management	0.003	0.001%
Larix laricina Wetland BpS	State Department of Natural Resources	5	40%
	Department of Defense	2	18%
	Native American Land	2	17%
	National Park Service	2	13%
	Bureau of Land Management	1	9%
	Private	0.3	2%
Luzula confusa-Poa arctica PA	Native American Land	4	43%
	Bureau of Land Management	3	32%
	State Department of Natural Resources	3	25%
Luzula confusa-Sphaerophorus globosus PA	US Fish and Wildlife	4	46%
	Native American Land	3	31%

Ecosystem Name	Land Owner	Total Area (km2)	Percent Area Managed
	Bureau of Land Management	2	23%
Mud Volcano BpS	Private	2	50%
	State Department of Natural Resources	1	33%
	Bureau of Land Management	1	17%
Pacific Barrier Island and Spit BpS	State Department of Natural Resources	100	60%
	US Fish and Wildlife	36	22%
	US Forest Service	17	10%
	Native American Land	11	6%
	National Park Service	2	1%
	Bureau of Land Management	0.3	0.2%
	Unknown	0.3	0.2%
	Private	0.1	0.1%
Pacific Forested Glacial Ablation Plain BpS	National Park Service	492	56%
	Bureau of Land Management	223	25%
	US Forest Service	85	10%
	State Department of Natural Resources	52	6%
	Native American Land	30	3%
	Private	2	0.3%
Pacific Tidal Marsh BpS	State Department of Natural Resources	150	40%
	US Forest Service	109	29%
	Native American Land	40	11%
	National Park Service	33	9%
	US Fish and Wildlife	31	8%
	Private	8	2%
	Unknown	1	0.4%
	Bureau of Land Management	0.3	0.1%
	Joint Ownership	0.1	0.02%
Pacific Uplifted Tidal Marsh BpS	State Department of Natural Resources	308	57%
	US Forest Service	136	25%
	Native American Land	90	17%
	Private	5	1%
	National Park Service	1	0.2%
	Joint Ownership	1	0.1%
	Unknown	0.4	0.1%
Papaver gorodkovii Volcanic Scree PA	US Fish and Wildlife	2	62%
	Native American Land	1	38%
Picea glauca Floodplain Old-growth Forest BpS	Native American Land	10	37%
	State Department of Natural Resources	7	26%
	US Fish and Wildlife	6	22%
	Department of Defense	2	7%

Ecosystem Name	Land Owner	Total Area (km2)	Percent Area Managed
	Bureau of Land Management	2	6%
	Private	0.5	2%
	Joint Ownership	0.4	1%
Picea sitchensis Floodplain Old-growth Forest BpS	US Forest Service	111	55%
	National Park Service	52	26%
	State Department of Natural Resources	27	13%
	Native American Land	9	5%
	Bureau of Land Management	3	1%
	Private	0.4	0.2%
	US Fish and Wildlife	0.1	0.03%
Picea sitchensis/Calamagrostis nutkaensis PA	US Forest Service	107	35%
	Native American Land	67	22%
	National Park Service	49	16%
	State Department of Natural Resources	36	12%
	US Fish and Wildlife	34	11%
	Private	10	3%
	Unknown	6	2%
	Bureau of Land Management	0.02	0.01%
Picea sitchensis/Oplopanax horridus/Circaea alpina PA	US Forest Service	4	62%
	State Department of Natural Resources	1	18%
	Private	1	9%
	Bureau of Land Management	0.5	8%
	National Park Service	0.2	3%
	Native American Land	0.01	0.2%
Pinus contorta var. *latifolia/Cladina* Species PA	National Park Service	0.004	100%
Pohlia wahlenbergii–Philonotis fontana Seep PA	not mapped	NA	NA
Steppe Bluffs BpS	National Park Service	6	41%
	Bureau of Land Management	2	12%
	Department of Defense	2	11%
	US Fish and Wildlife	2	10%
	Private	2	10%
	Native American Land	1	9%
	State Department of Natural Resources	1	5%
	Unknown	0.4	3%

Associated Species and Communities of Conservation Concern

A total of 508 spatial associations of species of conservation concern with ecosystems of conservation concern were identified, representing 185 plant, 181 bird, 51 mammal, six amphibian, and two amphipod associations. Because a single species may be spatially associated with multiple rare ecosystems (e.g. the Western toad is associated with multiple wet forest types), it is important to note that these totals do not represent the cooccurrence of 508 unique species. Two systems; *Andreaea blyttii* Snowbed Plant Association and the Boreal Forested Glacial Ablation Plain Biophysical Setting are not associated with any plant, animal, or plant associations of conservation concern.

Coastal habitats tend to support the greatest diversity of bird species of conservation concern, while mammal species of conservation concern reach peak levels in forested habitats. The total number of associated species does not appear to be correlated to ecosystem area, ecosystem type (e.g. biophysical setting or plant association), category of rarity (e.g. geomorphic process, floristics, microclimate, substrate), or conservation status rank.

Candidate Ecosystems of Conservation Concern

In the process of soliciting recommendations from professional ecologists regarding rare ecosystems in Alaska, numerous candidate systems were suggested. Several were not fully evaluated as the paucity of published literature precluded their mapping and description, or majority opinion did not consider the system sufficiently unique or threatened (Table 7). These systems have been retained as candidate ecosystems of conservation concern and may be included in future evaluations if further study can accurately assess their relative rarity, the trend of their occurrence, the threats posed to them and/or their intrinsic vulnerability.

Table 7. Candidate ecosystems of conservation concern

Candidate Ecosystems of Conservation Concern	**Preliminary Regional Designation**
Arsenic springs	Statewide
Boreal sky islands	Boreal
Calcareous Fens	Boreal
Carex kelloggii-Sphagnum spp. plant association in sedge-moss bogs on St. Paul Island	Arctic, Beringian
Caves	Statewide
Coastal cliffs	Statewide
Coastal rocky beaches	Statewide
Crustose lichen associations on basalt substrates	Arctic, Beringian
Domed bogs	Pacific
East Asian plant communities in the western Aleutian Islands	Pacific
Eelgrass communities	Statewide
Festuca altaica–Calamagrostis spp. Plant Association	Boreal
Frost boil tundra	Arctic, Beringian
Fruticose lichen associations on Hall Island.	Arctic, Beringian
Glacial refugia on outer coast adjacent to Lituya Bay	Pacific
Hill Prairie: also known as Midgrass-Shrub plant community	Boreal

Candidate Ecosystems of Conservation Concern	Preliminary Regional Designation
Luzula arcuata–Cladina species Plant Association	Pacific
Nunatak plant communities	Statewide
Nutrient-rich herbaceous meadows associated with coastal bird colonies	Statewide
Outcrops of Uranium-rich rock	Statewide
Picea sitchensis uplifted beach ridges	Pacific
Plant associations dominated by *Racomitrium lanuginosum*	Statewide
Plant associations dominated by *Umbilicaria* species	Statewide
Plant associations dominated or co-dominated by *Carex limosa*	Statewide
Plant associations dominated or co-dominated by *Kobresia* species	Arctic, Beringian
Populus balsamifera plant associations beyond latitudinal treeline	Arctic, Beringian
Pyroclastic flow biophysical setting	Arctic, Beringian
River-associated dunes	Pacific
Rock glaciers	Statewide
Salix setchelliana Gravel Bar plant association	Boreal, Pacific
Serpentine biophysical setting	Statewide
Sloped Fens in Prince William Sound	Pacific
Tall *Pinus contorta* var. *latifolia* in the vicinity of Gustavus	Pacific
Tidal mud flats	Statewide
Trona (hydrous sodium carbonate and bicarbonate occurring in partly-evaporated lake basins)	Boreal
Unglaciated gypsum outcrops	Statewide
Plant associations on mafic or ultramafic substrates	Statewide

Discussion

While most rare ecosystems in Alaska are not of immediate conservation concern, only a third of the systems identified here are managed for biodiversity. The remaining two thirds of systems occur in areas without explicit biodiversity protection and thus may be threatened by development or other factors.

The absence of critically imperiled (S1) and the low number of imperiled (S2) and vulnerable (S3) ecosystems identified for Alaska is due in part to low levels of human disturbance, which return modest scores in the threats section of the conservation ranking calculator. Interestingly, the development pattern in Alaska, where the anthropogenic footprint occurs in smaller patches embedded in a breadth of intact ecosystems, is largely reversed from the contiguous United States. However, all ecoregions in the state have some level of human development (Reynolds et al. 2018), and anthropogenic disturbance in natural areas associated with large- and small-scale industry and other forms of development continue. Unchecked, such disturbance will eventually cause adverse effect to under-protected ecosystems of conservation concern.

It is important to note that a designation of 'Managed for Biodiversity' in the PAD-US database does not necessarily preclude development. For example, the 1002 Area of the Arctic National Wildlife Refuge, which is ostensibly managed for biodiversity has recently been opened for oil and gas exploration. Similarly, the State of Alaska has requested exemptions (e.g., Alaska Roadless Rule in the Tongass National Forest) from federal conservation policies to promote economic development. Alternatively, federal laws, such as the National Environmental Policy Act, Clean Water Act, Endangered Species Act, and others could afford greater protection to ecosystems under their purview, such as wetlands and riparian floodplains, regardless of land management intent. Because the granting of exemptions and enforcement of regulation often occurs on a case-by-case basis we were not able to consistently account for the effect of individual rulings in this assessment.

Associated Species and Communities of Conservation Concern

The apparent lack of correlation between the total number of associated species to ecosystem area, type, category of rarity, and conservation status rank likely relates to an incomplete assessment of species use and should not necessarily be perceived as a lack of correlation. Further research and analysis targeting the use of these habitats by wildlife is recommended. Specifically, additional literature review and site visits are recommended to better understand species composition and use of the *Andreaea blyttii* Snowbed Plant Association and the Boreal Forested Glacial Ablation Plain Biophysical Setting, for which no plant or animal species or plant associations of conservation concern are currently associated. Also recommended is the qualification of animal species occurrences as 'suspected' where the record cannot be confirmed by published account.

Associations between bird diversity and coastal habitats likely relates to the variety of vegetation offered by these ecosystems that are transitional between aquatic and terrestrial types. Specific to barrier islands, high bird species diversity likely relates to the protection from predators afforded to migrating, nesting and breeding bird populations. Associations between mammal diversity and forested habitats may relate to the structural complexity and scale of these habitats, which is commensurate with the larger mammals that these systems support.

Closing the Gap Between Conservation Status and Current Level of Protection

Ecosystems of conservation concern vary in physiognomy, spatial extent, and land management status. Thus, the gap between conservation status and current level of protection is easier to close for some systems than for others. For example, the conservation status of systems presumed to be under documented, such as the Lodgepole Pine / Reindeer Lichen and the Alaska Wormwood - Boreal Carnation Gravel Bar Plant Associations, as well as the Karst Fen Biophysical Setting, may be artificially high and thus the gap between status and protection may belie the insecurity of such systems. For discrete systems, such as the Inland Dune, Steppe Bluff, Mud Volcano, and Geothermal Spring Biophysical Settings, a revision of land management intent towards conservation would address the discrepancy between conservation rank and protection status. Climate change resilience for the Boreal Inland Dune or Steppe Bluff systems, for example, can be strengthened by minimizing proximal factors that affect ecosystem vulnerability such as invasive species establishment and off-road vehicle use. Resilience for other discrete ecosystems of conservation concern can be addressed by protection of adjacent landscapes and likely migration corridors. However, providing adequate protection to more widely distributed systems presents a greater challenge. For example, systems derived from calcareous substrates, such as the Karst Alpine Herbaceous Meadow and Heath Biophysical Setting and the Karst Western Hemlock – Sitka Spruce (*Tsuga heterophylla - Picea sitchensis*) Plant Association have broad geographic range, the protection of which would require increased commitment among multiple landowners within the supporting watersheds. Similarly, systems that develop along major environmental gradients such as barrier islands, spits, and tidal marshes are more difficult to protect as their ecological integrity is often controlled by processes that transcend local control. Conservation strategies developed for tidal wetlands for example, can focus on maintaining biological integrity through cross jurisdictional recognition of the carbon sequestration function of these wetlands. These strategies could include wetland conservation, protection, or restoration, and incorporation of coastal wetlands into the carbon market.

Even more problematic are systems whose existence is reliant on the stasis of a particular climatic regime. The greater rate of climate change at high latitudes (ACIA 2005) in combination with the lesser protection of systems with arctic distributions relative to those with boreal and maritime distributions, places the arctic and alpine systems described here at heightened risk. High-elevation, montane systems such as the Beringian Alpine Limestone *Dryas* Biophysical Setting cannot be maintained by up gradient migration indefinitely and similarly, the northward movement of arctic systems such as the Northern Woodrush – Arctic Bluegrass (*Luzula confusa* - *Poa arctica*) and the Northern Woodrush - Globe Ball Lichen (*Luzula confusa* - *Sphaerophorus globosus*) Plant Associations will be ultimately curtailed by the Arctic Ocean. Without a northward migration route, individual rare plant species that are currently restricted to the Arctic Coastal Plain in Alaska are projected to face substantial declines in available suitable habitat by 2060 (Carlson and Cortés-Burns 2013).

The adequate protection of permafrost-dependent systems such as Arctic Pingos and Dwarf Shrub – Lichen Permafrost Plateaus is perhaps most challenging. In just the last 30 years, there has been a 2 °C increase in mean annual temperature in the arctic biome (ACIA 2005) and temperature is predicted to continue to increase more rapidly than at lower latitudes (IPCC 2007; Chapin et al. 2014). There are numerous examples of shrub and tree expansion in arctic and alpine tundra habitats around the state that in turn drive alterations in ecosystem processes (Klein et al. 2005; Dial et al. 2007; Tape et al. 2006; Roland et al. 2013). Furthermore, climate change influences the frequency and severity of disturbances, such as insect outbreaks and wildfires (Soja et al. 2006; Chapin et al. 2008) and is likely affecting the establishment rate of non-native species (Carlson and Shephard 2007; Sanderson et al. 2012). These phenomena have direct effect on species and communities and by extension, pose substantial risk to the current composition and function of rare ecosystems. Management action for such ecosystems threatened by climate change may include minimizing compounding local anthropogenic impacts and ensuring protection of adjacent landscapes and likely migration corridors

As the rate, extent, and severity of global climate change increases, both a commensurate expansion in our concept of adequate conservation (Noss et al. 2012) and facilitation of cross-jurisdictional planning for natural resource management (Trammell et al. 2017) are necessary. Local, national, and international conservation that aims to preserve multiscale ecological patterns and processes provides a precautionary approach to sustain the full complement of biota and their supporting natural systems (Poiani et al. 2000). In this assessment of rare ecosystems, we have considered multiple levels of biological and geographical organization ranging from coarse-scale biophysical settings to local-scale plant associations. This multiscale approach identifies systems large enough to protect the ecological processes that support their embedded communities and species while simultaneously capturing species-based or spatially restricted systems that can be harbingers of greater ecosystem change. Particularly in combination with the species- and landscape-scale conservation assessments that have been previously completed for Alaska, the description, mapping, and conservation gap analysis presented here furthers effective ecological conservation in Alaska. By closing the gap between the conservation need and protection status of Alaska's rare ecosystems we build awareness and capacity to accommodate the growing impacts of changing climate and development in a vulnerable region of the world.

The descriptions, distribution mapping, and conservation ranking provided herein is a formal recognition of the types, locations, and conservation need of rare ecosystems in Alaska. The documentation of current condition subsequently allows monitoring of future change in extent and condition. Additionally, the prioritization of these rare ecosystems with respect to conservation need informs decision making and enhances stewardship of the natural systems upon which we ultimately rely.

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Northern and Western Alaska Biophysical Settings and Plant Associations

Arctic Barrier Island and Spit Biophysical Setting

Arctic Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Barrier islands and spits are elongate, broadly-arcuate features that may be separated from each other by inlets and from the mainland by lagoons, estuaries or bays. Unlike barrier islands, spits maintain connection to the mainland and are thought to represent continuations of coastal dunes into the ocean (Figure 5; Ritter 1986). Global distribution of barrier islands is strongly related to sea level history. Rising sea level in the late Holocene (5,000 YBP – Present) is associated with the greatest island abundance, especially in the Arctic coastal plains (Stutz & Pilkey 2011). Due to similarities in landform, geomorphic process, and parent material, barrier islands and spits are treated here as a single biophysical setting. Two types of barrier islands are present in the Arctic Ocean; remnant barrier islands are relict coastline supporting tundra vegetation underlain by permafrost, whereas constructed barrier islands are comparatively recent depositions of sediment with little development of vegetation and permafrost (Hopkins and Hartz 1978, Morack and Rogers 1981, Short 1979). Due to their greater susceptibility and response to coastal erosion, this discussion focuses on the constructed barrier islands.

Barrier islands provide shelter to shorebird populations, denning habitat for polar bears, and physical protection of the mainland shoreline. Use of beaches by walrus in northwestern Alaska in recent summer months (Rosen 2014), increases the likelihood that barrier islands and spits could provide occasional coastal haulout habitat for walrus as the extent of sea ice changes. Both barrier islands and spits represent dynamic ecosystems, which in the context of a rapidly changing climate are migrating and losing mass at unprecedented rates (Holland et al. 2006, ACIA 2005, Chapman and Walsh 2007, IPCC 2007, Martin et al. 2009, Gibbs et al. 2008).

Distribution

Constructed barrier islands and spits are common along both the Beaufort and Chukchi Seacoasts. Of particular note are the barrier islands enclosing the Chukchi Sea's Kasegaluk Lagoon, which at 185 km, represents one of the longest systems in North America. Remnant barrier islands are restricted to the Beaufort Sea and include, from west to east, the Plover and Jones Islands, from Midway to Flaxman Island and in the vicinity of Barter Island (Jorgenson and Brown 2005, Short 1979).

The distribution map for barrier islands and spits in Northern Alaska was primarily developed from the estuarine and marine intertidal subsystems of the National Wetland Inventory (USFWS 2015). Because both of these classes are considered to be undermapped, and National Wetlands Inventory (NWI) coverage is not available for some portions of the coastline, additional barrier islands and spits were hand-digitized from remotely-sensed imagery. Where the NWI classes corresponded to mainland beaches, the attributed polygon was removed from the distribution (Figure 6).

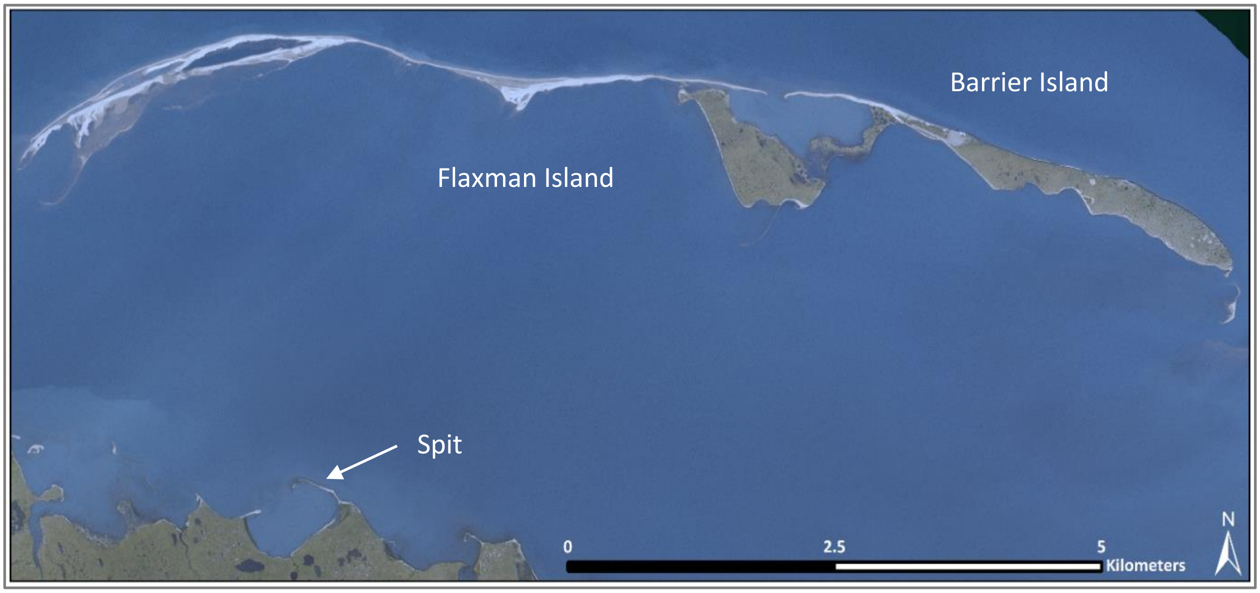

Figure 5. Aerial view of a barrier island (Flaxman Island) and inset of a spit along the Arctic Ocean.

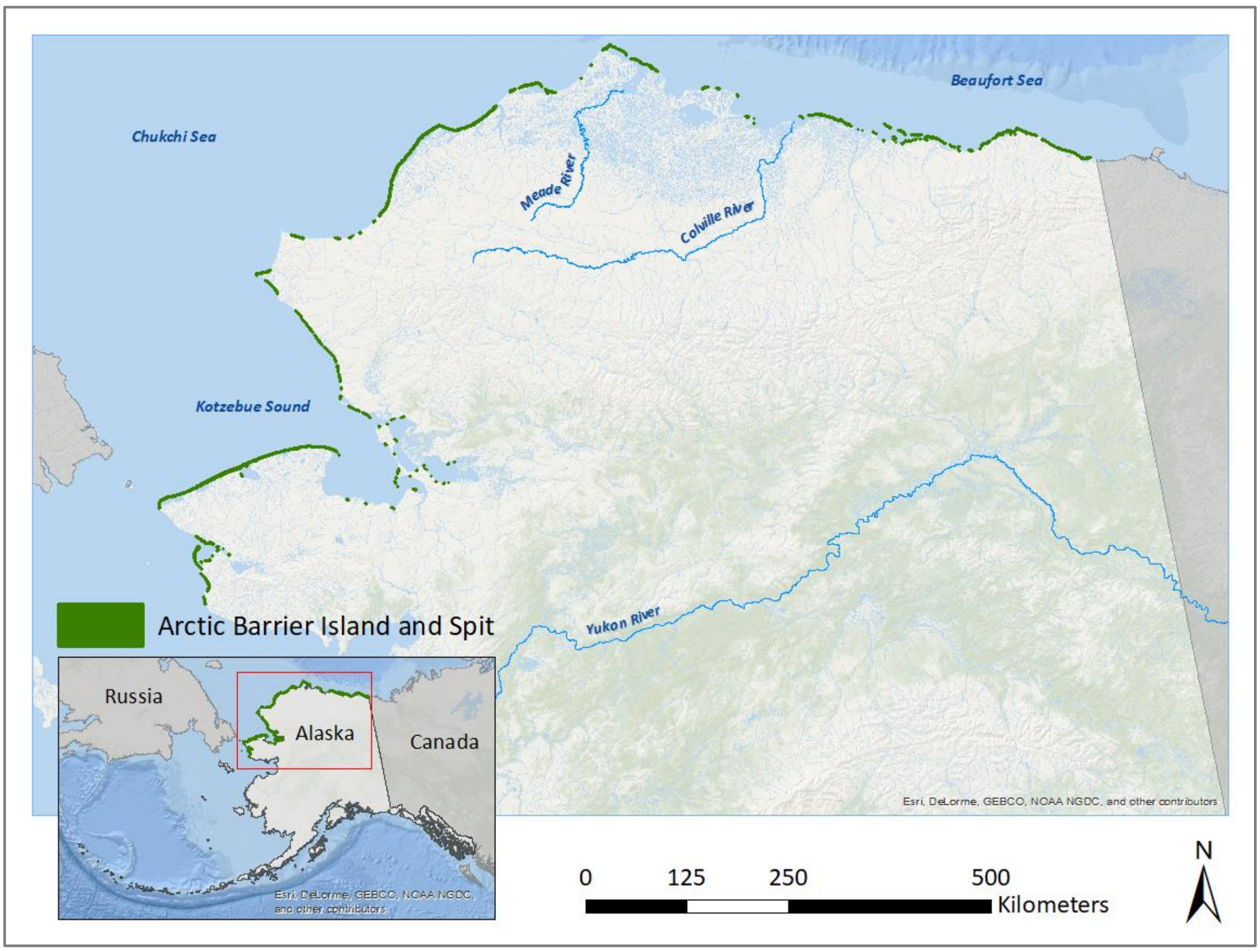

Figure 6. Distribution of the Arctic Barrier Island and Spit Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate
In the northern Alaska region, the arctic climate is dry and cold, characterized by very short summers and long winters (Natural Resources Conservation Service, 2004). The mean annual precipitation ranges from about 10 to 26 cm. Annual precipitation mostly falls as snow during the winter. The average annual temperature ranges from -13 to -6 ºC, and freezing temperatures can occur in any month. Summers are frequently foggy because of close proximity to the Arctic Ocean.

Environmental Characteristics
Constructed barrier islands and spits are temporary in location and shape with their geomorphology controlled by the amount and type of sediment, the magnitude of natural processes (wave-tide regime) and the stability of sea level (Dolan 1980). Along Alaska's Arctic Coast, these islands are low (less than 2 m high), narrow (50-200 m wide) and long (up to 9 km) accumulations of sand and gravel sourced from coastal buffs and/or the shallow continental shelf (Short 1979). Storm frequency in the high latitudes is thought to result in shorter and narrower islands relative to those on swell-dominated low-latitude coasts (Stutz & Pilkey). Sediment is delivered by waves driven by prevailing winds and subsequently transported by longshore drift (Hopkins and Hartz 1978, Morack and Rogers 1981, Ritter 1986). Along the northeast-facing sections of the Beaufort and Chukchi Sea coasts, prevailing winds from the northeast direct westward transport of sediment (Short 1979). However, along both coastlines storm events are principally responsible for the sculpting and migration of barrier island complexes (Dolan 1980), particularly along the Chukchi Sea coast where summer storms from the south west transport and estimated 5,000-25,000 m^3 of sediment per year (Short 1979). Near Kotzebue, some of these islands and spits fully enclose lagoons with only small tidal outlets (Figure 7). Others, such as Sheshalik Spit near Kotzebue, extend far into the ocean with wide tidal inlets (Figure 8).

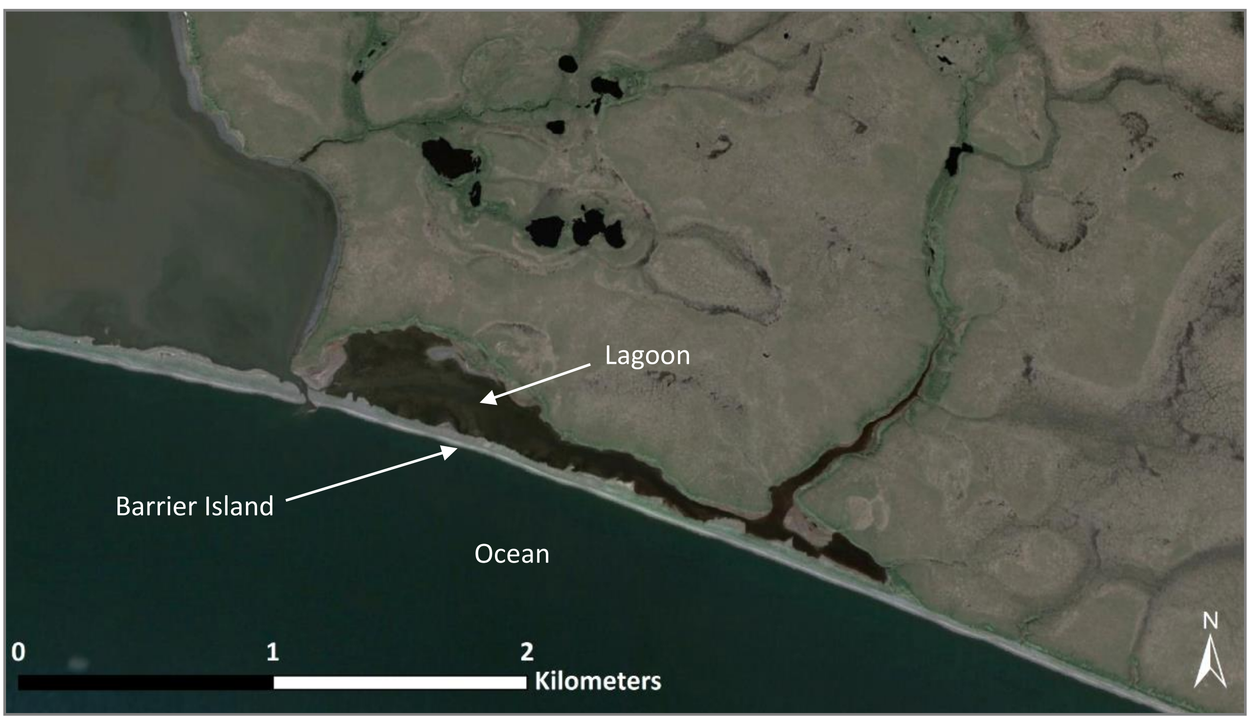

Figure 7. Aerial view of a barrier island northwest of Kotzebue (source: Google Earth, accessed September 2, 2015).

Figure 8. Sheshalik Spit northwest of Kotzebue, Alaska (source: Google Earth, accessed June 28, 2016).

In the Arctic, these depositional and erosional processes operate in the brief, ice-free period extending from approximately mid-July to mid-September. Strong northwesterly winds common in the late summer can produce storm surges up to 3.4 m above normal sea level (Reimnitz and Maurer 1979, Taylor 1981) that frequently breach the low-relief barrier islands and spits. During such overwash events, material is transported from the island or spits' high-energy; erosive environment on the windward side to the low-energy, depositional environment on the leeward side and in this way form gravel beaches backed by sandy dunes that grade to fine sand beaches and washover fans.

The lagoons and estuaries that form between barrier islands and the mainland grade to tidal flats and marshes landward. The multiple, recurved spits attendant to most constructed barrier islands and sections of the mainland coast may be deposited and shaped by single storm events that extend the westward terminus of an island past a previously-formed spit (Hopkins and Hartz 1978, Short 1979). These repeated cycles of erosion and deposition result in the migration of barrier islands and spits westward and landward with little net loss of mass (Hopkins and Hartz 1978). Also, during the open water period, rafted ice may scour vegetated surfaces and dredge sediment shoreward across barrier islands and spits creating furrows tens of meters long and ridges up to a meter high (Figure 9; Hopkins and Hartz 1978, Martin et al. 2009).

Vegetation

While barrier islands and spits are largely devoid of vegetation, sparse cover may develop in protected dune areas that are older than 30 years (Hopkins and Hartz 1978, Short 1979). Pioneer species tolerant of salt and sand accumulation are the first to establish. The beachgrass, *Leymus mollis* is most common on topographic highs (Figure 10), with the succulent, halophytic forb, *Honckenya peploides* occurring on lower, often tidally-influenced substrates. Due to the challenges of germination posed by wind and desiccation in a dune environment, most species reproduce vegetatively and quickly develop to clonal stands (Carter 1988, Howard et al. 1977). Sand may become stabilized by plant associations dominated by

Leymus mollis and *Lathyrus japonicus* var. *maritimus* with *Honckenya peploides, Mertensia maritima* and *Festuca baffinensis* occurring as minor associates. Moss cover is low (Boggs et al. 2015).

Figure 9. Ice-push and sediment deposition on a spit near Wainwright on the Chukchi Sea.

Figure 10. *Leymus mollis* stabilizing a dune near Wainwright, Alaska.

Conservation Status

Rarity: Barrier islands and spits are common along the coast of the Arctic Ocean, although their total area is small (190 km^2).

Threat: The combined effects of rising global sea level, diminishing sea ice, increasing summer ocean temperature, increasing storm power and frequency, and subsidence of coastal permafrost have had a dramatic effect on arctic coastlines (Jones et al. 2008, Ping et al. 2011, Forbes 2011). In particular, a longer open water period and increased occurrence of larger waves is at least partially responsible for the accelerating rate of barrier island and spit migration. Where features are prograding their persistence is largely dependent on the degree to which sedimentation keeps pace with sea level rise. Projected increases in temperature and precipitation in arctic Alaska suggest a trend toward increased rates of sedimentation, which for these depositional features may compensate for sea level rise (Martin et al. 2009). Impacts not related to climate change are primarily associated with human development. Due to their landscape position, barrier islands are highly susceptible to damage from oil spills and human use. Degree of damage from an oil spill to nearshore waters is expected to vary with factors such as degree of tidal influx, tide level, location, season and extent and duration of the spill. Off road vehicle use also occurs on some of the islands.

Trend: In general, barrier islands represent dynamic habitats capable of repositioning, growing and shrinking in response to changing conditions. In the Arctic, barrier island systems experience high rates of localized erosion, slight decrease in net area and tendency to rotate and migrate to the southwest with prevailing winds and nearshore currents (Gibbs et al. 2008, Erikson et al. 2012, Ravens and Lee 2007). Total surface area of barrier islands in the central Beaufort Sea (Colville River to Point Thomson) has decreased approximately 4% from the 1940s to the 2000s with the rate of change greatest since 1980 (Gibbs et al. 2008). A similar increase in migration rate is seen for Narwhal Island, a barrier island east of Prudhoe Bay, which in the period from 1955 to 1990 migrated 5 m/y; a rate that increased to 24 m/y for the period from 1990 to 2007 (Martin et al. 2009, Ravens et al. 2007). Sediment accumulates to lesser and more localized extents as capes attached to mainland coasts, spits attached to most barrier islands, and as ebb and flood tidal deltas that are formed on the seaward and landward sides of barrier island inlets by the exit and entrance of tidewater.

Species of Conservation Concern

Barrier islands offer shelter to large shorebird populations during the late summer resting period or molt, and, in a few exceptional areas, provide important nesting habitat (Hopkins and Hartz 1978). Coastal areas, including barrier islands and spits provide maternal denning habitat for polar bears (*Ursus maritimus*; Amstrup and Gardner 1994). The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 8, Table 9). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 8. Mammal and bird species of conservation concern in the Arctic Barrier Islands and Spit Biophysical Setting

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Pacific walrus	*Odobenus rosmarus*	G4	S3	Suspected to use barrier islands and spits near Cape Lisburne. Known haulouts at Point Lay.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Polar bear	*Ursus maritimus*	G3G4	S2	Known to use coastal areas for feeding and denning.
Spotted seal	*Phoca largha*	G4G5	S3S4	Known to use coastal haulouts along the Chukchi and Beaufort seas during the summer season.
Aleutian Tern	*Sterna aleutica*	G4	S3B	Known to nest on sandy spits along coastal northwest Alaska.
Bar-tailed Godwit	*Limosa lapponica*	G5	S3B	Nests in sedge meadows and coastal tundra. Staging in nearshore estuarine areas and beaches.
Black Guillemot	*Cepphus grylle*	G5	S2	Nest along beaches and in coastal cliff crevices in Northern Alaska.
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Black scoters could use inshore marine habitat during non-breeding seasons.
Bristle-thighed Curlew	*Numenius tahitiensis*	G2	S2B	Known to nest in the mountains of the Seward Peninsula and near Kotzebue Sound. Could use nearshore barrier island habitat near Kotzebue Sound during fall/spring.
Emperor Goose	*Chen canagica*	G3G4	S3S4	Nest on marshy edges of ponds, lakes, and potholes on the northern Seward Peninsula. Brood rearing areas include sloughs and rivers (with *Carex rariflora*) and tidal marshes.
King Eider	*Somateria spectabilis*	G5	S3BS3N	Known to nest in arctic coastal tundra.
Kittlitz's Murrelet	*Brachyramphus brevirostris*	G2	S2BS2N	Wintering areas largely unknown for most birds. Populations in the Bering and Chukchi Seas probably move south away from pack ice (Day et al. 1999). Nests on coastal cliffs, rock ledges.
Red Knot	*Calidris canutus*	G5	S2S3B	Nests on ground of barren tundra and well vegetated moist tundra in Northwest Alaska including the Seward Peninsula and less commonly near Point Barrow. Likely uses barrier island and spits for migration and staging.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Sanderling	*Calidris alba*	G5	S2B	Breeds in small area of high arctic tundra on north slope near Barrow. Likely uses barrier island and spits for migration and staging.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Suspected to winter in open areas near shorelines. Breeds in tundra from near treeline to the edge of polar seas.
Spectacled Eider	*Somateria fischeri*	G2	S2B, S2N	Molting occurs in near-shore waters containing an abundance of mollusks.
Steller's Eider	*Polysticta stelleri*	G3	S2B,S3N	During molting, utilize tidal flats and deeper bays. Winter habitat includes eelgrass, intertidal sand flats, and mudflats possibly foraging on invertebrates.
Stilt Sandpiper	*Calidris himantopus*	G5	S3B	Breeding range from Canadian border to Barrow, Alaska along coastal plain at least several km inland. Suspected to use nearshore marine habitat for migration.
White-rumped Sandpiper	*Calidris fuscicollis*	G5	S3B	Grassy or mossy tundra, often not far from water; wet tundra, with nest sites on tops of hummocks. Barrier islands and spits are likely used as feeding, staging, and migration habitat.
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Suspected to use nearshore protected seawater habitat for migration and molting. Nests on tundra near lakes and coastal areas.

Table 9. Plant species of conservation concern suspected or known to occur within the Arctic Barrier Islands and Spit Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Draba micropetala	GNR	S1S2	Grows on beach ridges, beach fronts, stream banks, and frost scars.
Draba pauciflora	G4	S2	Beach ridges, polygon tundra, polygon troughs, alpine slopes
Draba subcapitata	G4	S1S2	Found in sand and gravel soils of coastal bluffs, river bars, pingos, and hummocks.
Gentianopsis detonsa ssp. *detonsa* *(Gentianopsis richardsonii)*	G3G5T3T5	S1	Estuary shores, beaches, coastal marshes.

Scientific Name	Global Rank	State Rank	Habitat Description
Koeleria asiatica	G4	S3	Occurs in sandy, well drained soils of the Beaufort Coastal Plain.
Poa sublanata	GNR	S1?	Occurs in tundra, in meadows, in coastal sand and among pebbles.
Puccinellia andersonii	G3G5	S1S2	A coastal arctic species that grows near tideline and on otherwise barren reworked marine sediments of eroded floodplains.
Puccinellia banksiensis	G1G2	S1	Known from three locations in the Northwest Territories and two locations in Nunavut, Canada; and one location at Prudhoe Bay, Alaska.
Puccinellia vahliana	G4	S3	Found in seepage meadows brackish creeks as well as other habitats.
Ranunculus camissonis	G3G4	S2S3	Snowmelt drainages, swales, alluvial fans, beach ridges, gently sloping seepage terraces, glacial circles, lower mountain slopes.
Ranunculus sabinei	G4	S1	Tundra slopes, hummocks, estuary banks; all occurrences near coast.
Saxifraga rivularis ssp. *arctolitoralis*	G5T2T3	S2	Arctic seashores, soil banks, disturbed tundra, polygon tundra, hummocks.
Symphyotrichum pygmaeum	G2G4	S2	Occurs in sparsely vegetated, open Dryas tundra on the Beaufort Coastal Plain.
Puccinellia angustata	G4Q	S1	This species usually grows in clay or silt environments. Growing on cut banks and above coastline, disturbed, unstable banks facing ocean. Dryas-polygon terrace above coastline.

Plant Associations of Conservation Concern

Barrier islands and spits support a variety of plant associations but they are not listed here as they are common (G4-G5) in other biophysical settings.

Classification Concept Source

The classification concept for this biophysical setting is based on Hopkins and Hartz (1978).

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Arctic Inland Dune Biophysical Setting

Arctic Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Active inland dunes occur in areas where wind-deposited silts and sands form expansive deposits. Active inland dunes in arctic Alaska occur on sand sheets, along lake and river bluffs, river floodplains, slopes above drained lakes, deltas and ancient moraines (Figure 11). Several imperiled plant species, an abundance of Beringian endemics, and disjunct species are known from inland dune systems. Sandsheet and river or lake-associated dunes are treated collectively here, however further study may support the separation of these systems. This biophysical setting differs from the Boreal Inland Dune biophysical setting as it is underlain by continuous permafrost and occurs beyond or above treeline. Inland dune systems do not include coastal dune settings such as back beaches, barrier islands, and spits.

Figure 11. Dunes on bluffs above the Meade River, Alaska.

Distribution

Most active dunes in Arctic Alaska are associated with a large deposit of quaternary aeolian sands located between the Meade and Colville Rivers, however they also occur off of this sandsheet as small patches on lake and river bluffs, river floodplains, drained lakes, deltas and ancient moraines (Figure 12). The distribution map for inland dunes in Northern Alaska was developed for the BLM Assessment Inventory and Monitoring (AIM) program (Boucher et al. 2013).

Climate

In the northern Alaska region, the arctic climate is dry and cold, characterized by very short summers and long winters (Natural Resources Conservation Service, 2006). Most of the region is above the Arctic Circle and consequently receives continuous sunlight for several weeks in summer and continuous twilight for several weeks in winter. The mean annual precipitation ranges from about 10 to 26 cm at the lower elevations and 76 to 102 cm at the higher elevations. The average annual temperature ranges from -13 to -6 ºC, and freezing temperatures can occur in any month.

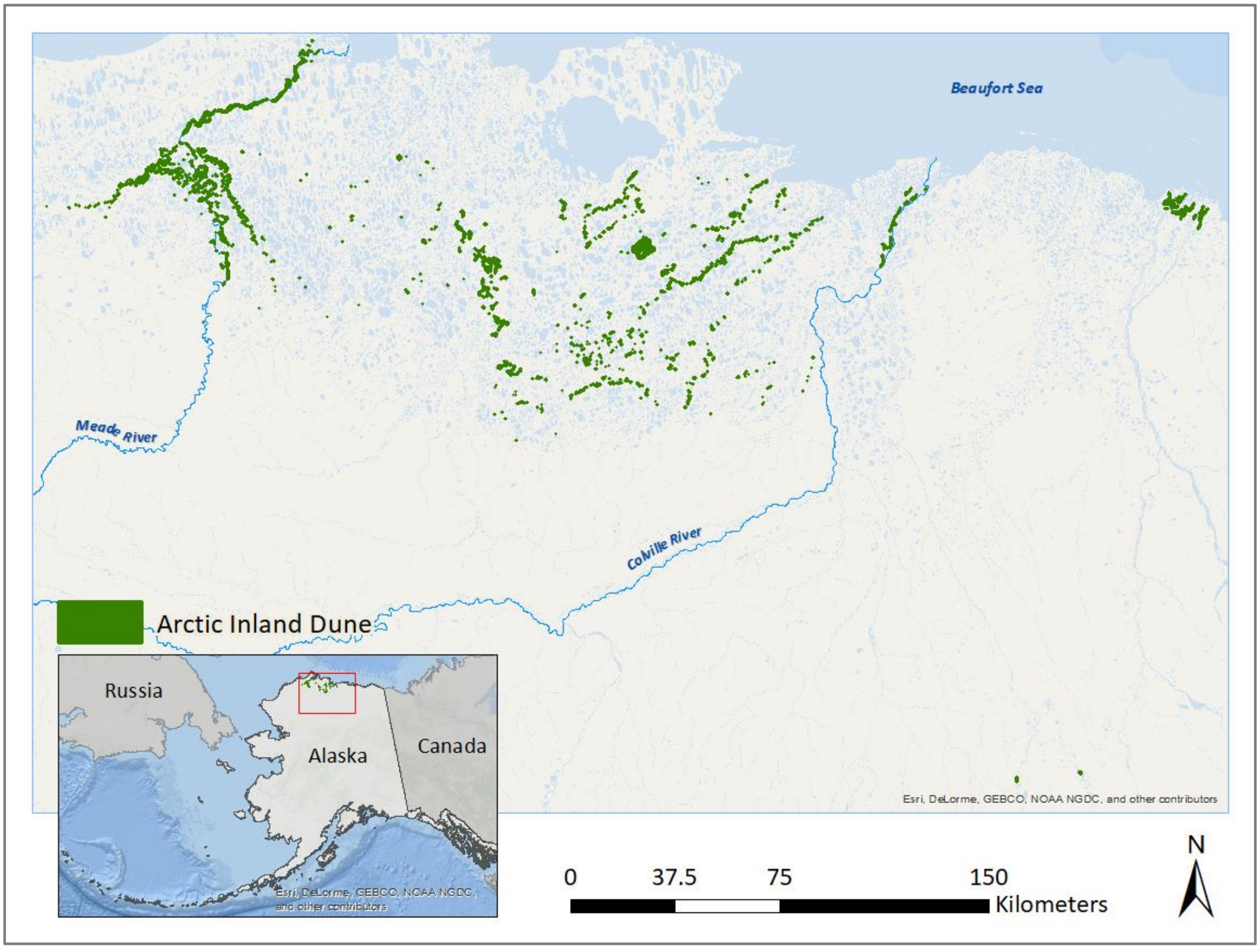

Figure 12. Distribution of northern Alaska's major inland sand dunes. Note that the areas of occupancy in this map are buffered for greater visibility.

Environmental Characteristics

Sandsheet-associated dunes in Alaska occur on or are derived from deposits that covered over 30,000 km^2 of northern Alaska during the last glacial period (Carter 1988, Hopkins 1982, Lea and Waythomas 1990). The largest sandsheet in northern Alaska lies between the Meade and Colville Rivers is sourced from these Pleistocene deposits. Much of this expansive sandsheet has been stabilized for thousands of years by permafrost and vegetation and is now a flat or gently sloped landscape punctuated by longitudinal and parabolic dunes and numerous lakes (Figure 13 and Figure 14) with the ancient dune formations controlling the distribution and form of the larger lakes (Everett 1979). Due in part to lower interstitial ice volumes, permafrost-related surface features such as ice wedge polygons, oriented lakes, peat ridges, and frost boils are less common and less pronounced on sand deposits (Jorgenson and Shur 2007).

Where vegetated, sand sheet deposits are characterized by tussock tundra, tussock-shrub tundra, birch and ericaceous low and dwarf shrubs, and wet sedge types. Erosion of vegetated lake margins and river banks may cause the rapid conversion of vegetated dunes to barren sand (Figure 11, Figure 13, and Figure 14). Similarly lake drainage produces a dry flat sandy surfaces where dunes form along the basin ridges and bluffs (Figure 15; Jorgenson and Shur 2007).

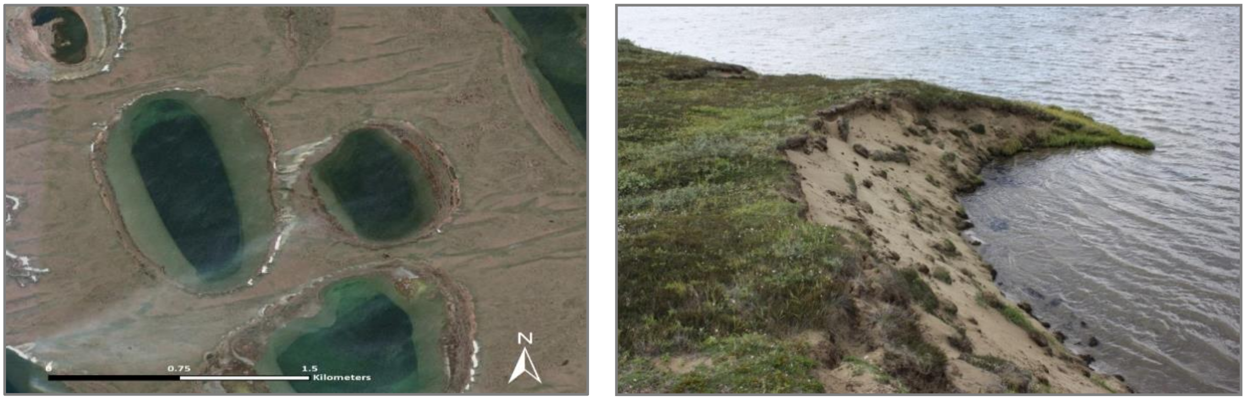

Figure 13. Lakes interspersed on a sand sheet near Inigok, Alaska where lighter areas are eroding sand (left, from Google Earth, imagery date June 2, 2010, eye altitude 3,700 m) and an eroding slope above a sand sheet lake near Inigok, Alaska (right).

River- and lake-associated dunes in Arctic Alaska develop along bluffs, floodplains, deltas, and ancient moraines. Sand deposited on a floodplain, river delta or peripheral to ancient moraines is reworked by wind and water to form an active dune (Figure 15). Alluvial activity during the last 10,000 years created sand deposits that are the source of the active serrate margin dunes along the Meade River downstream of the Pleistocene sand sheet (Everett 1979).

Figure 14. Deschampsia *sukatschewii* colonizing the sandy bottom of a drained lake south of Teshekpuk Lake, Alaska.

Soils: The soils of active sand dunes generally consists of unconsolidated sand with little evidence of soil genesis. As a result, these soils are of low fertility and productivity. The depth of the active layer is typically greater than 60 cm and often surpasses 120 cm, and the water table is rarely expressed at the surface outside of dune slacks. Sand sheet deposits are predominantly acidic (Walker et al. 2003).

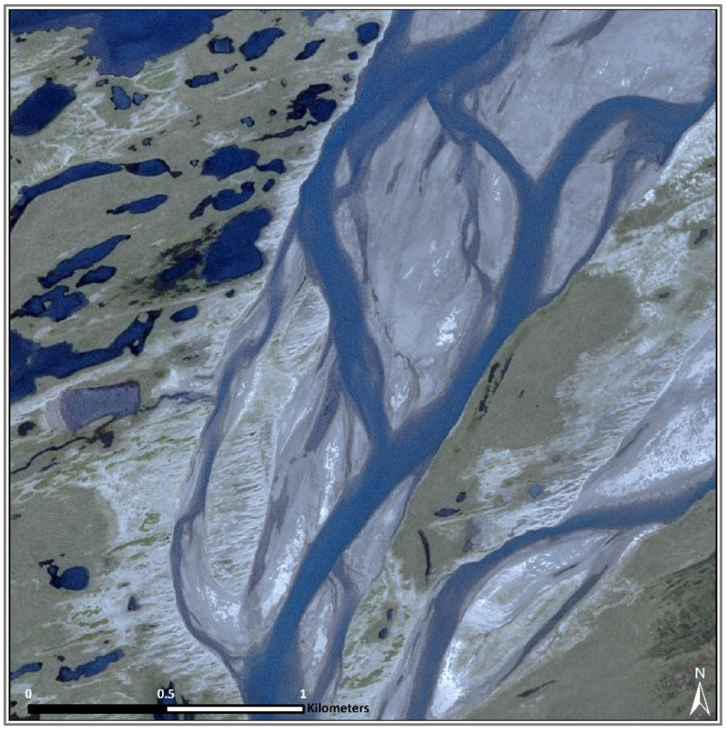

Figure 15. Dunes on the delta of the Sagavanirktok.

Vegetation and Succession

Studies of vegetation succession on sandy bluffs above the Meade River found that geomorphic processes and vegetation are related to the orientation of the dune with respect to the direction of the prevailing wind; bluffs facing away, parallel to, or towards prevailing winds show little, variable and extreme wind erosion and deposition effects, respectively (Peterson and Billings 1978).

Initially, small elliptical blowouts are oriented with their long axes aligned with the prevailing winds. Once formed, these blowouts create microtopography which causes an alteration in local drainage and in the accumulation of windblown snow. This extra snow cover plays an important role in slowing erosion and facilitating plant colonization (Peterson and Billings 1978). *Leymus mollis* is the most notable pioneer of open sand, where it rarely provides more than 10% coverage. The dead leaves of *Leymus* accumulate at the base of the stem, providing increased cover along the sand surface. Other colonizing species such as *Carex obtusata* and *Juncus arcticus*, have rhizomatal shoots, which catch windblown material. Windblown sand, plant fragments and seeds are thus retained at the bases providing microsites for the germination of additional plant species. As the dune stabilizes, plant diversity increases. Mid-seral species include the graminoids *Bromus pumpellianus, Dupontia fisheri*, *Festuca rubra, Kobresia sibirica, Leymus mollis,* and *Trisetum spicatum.* Willow shrubs, including *Salix ovalifolia, S. niphoclada, S. pulchra,* and *S. richardsonii* are also important components of mid-seral vegetation on active dunes. During this stage, dry-associated mosses such as *Polytrichum hyperboreum, Racomitrium lanuginosum, Distichium capillaceum,* and *Ditrichum flexicaule* and lichens such as *Stereocaulon* species, *Alectoria nigricans, Bryocaulon divergens* and *Thamnolia vermicularis* provide increasing coverage and stabilize sands.

Low depressions between dunes (slacks) may have higher moisture conditions and support species such as the forb *Equisetum arvense*, graminoids *Carex aquatilis, Carex maritima,* and *Juncus arcticus* ssp. *alaskanus*, *Dupontia fisheri* and shrubs including *Salix ovalifolia* (Peterson and Billings 1978).

Other barren dunes on the Arctic Coastal Plain are colonized by tall shrubs such as *Salix glauca*, *Salix alaxensis*, and/or *Salix niphoclada* (Figure 16; Boggs et al. 2015). The understory cover is typically sparse and may include *Festuca rubra*, *Leymus mollis*, *Poa glauca*, *Artemisia tilesii* ssp. *elatior*, *Astragalus alpinus*, *Chamerion latifolium*, and *Equisetum arvense*. Bryophyte cover is low although some sites support extensive biological crusts. On older sites, vascular cover may be high under the tall *Salix* overstory and include *Dryas octopetala*, *Rhododendron lapponicum, Arctous rubra*, and *Equisetum arvense*. Nonvascular cover may also be high and include *Aulacomnium acuminatum, Ditrichum flexicaule* and *Philonotis fontana*. Adjacent undisturbed tundra includes several vegetation classes: dwarf shrub, tussock tundra, tussock shrub tundra, birch ericaceous low shrubs, and wet sedge (Peterson and Billings 1978, Ducks Unlimited, Inc. 2013).

Figure 16. Photo of the *Salix niphoclada-Salix glauca* Sparse (Inland Dune) Plant Association (Boggs et al. 2015).

The stability of sand sheet tundra is facilitated by permafrost, which generally rises as vegetation cover increases (Peterson and Billings 1978). The details of the linkages between climate, vegetation, soils, and the active layer are not well understood but are integral to predicting their linked response to climate change (Benninghoff 1966, Klene et al. 2001, Shiklomanov and Nelson 2002, Vasiliev et al. 2003). In general, vegetation shades the soils and provides insulation that reduces summer heat flux. Moss and organic matter in the soil increase the water holding capacity affecting the hydrological properties. Thick moss carpets and organic soil horizons decrease active layer thickness, consequently decreasing the depth to which water is able to drain because of the presence of permafrost (Kane 1997). This process of waterlogging, or paludification, is thought to be the driving mechanism behind long-term vegetation succession and changes in the active layer thickness in the low arctic (Walker and Walker 1996, Mann et al. 2002).

Conservation Status

Rarity: Cold-climate dune fields in North America, Europe and Asia are estimated to cover an area of over 100,000 km^2 (Koster 1988). Although large systems of dunes and sand sheets developed during the late Pleistocene, most deposits have been stabilized by permafrost and tundra vegetation. Today, active inland dunes in Arctic Alaska are uncommon on the landscape and estimated to occupy a small cumulative area (less than 50 km^2).

Threats: Threats include anthropogenic disturbance, invasive plant species and permafrost degradation. Villages may be located on dune fields (e.g. Atqasuk) as they provide well-drained land that is less susceptible to thermokarst. Similarly, dune ridges provide a naturally elevated and dry corridor that is used preferentially by ATVs and snow machines. Dunes are ruderal habitats that are susceptible to nonnative plant infestation. Changes to the active layer induced by climate change are likely to be affected by concurrent changes to the vegetation and soils (Benninghoff 1966, Klene et al. 2001, Shiklomanov and Nelson 2002, Vasiliev et al. 2003).

Figure 17. The rare species *Mertensia drummondii* on an active sand dune adjacent to the Meade River (photo by J. Overholt).

Trend: Active dunes currently exist at a threshold wherein a minor change in climate could impact their future more strongly than human activity however, the magnitude and direction of this change is not well understood (Parker and Mann 2000). Ground disturbance from caribou seeking insect relief and ground squirrel burrowing could benefit the system by increasing its overall area.

Species of Conservation Concern

The plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 10, Table 11). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016). More research is needed to identify any birds or mammal species of conservation concern found within the Inland Dune Biophysical Setting.

Table 10. Plant species of conservation concern within the Arctic Inland Dunes Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Koeleria asiatica	G4	S3	Amphiberingian species of sand dunes, river banks and bluffs.
Mertensia drummondii	G2G3	S2	Endemic to arctic Alaska, where it grows on sparsely vegetated, active sand dunes and blowouts near rivers.
Poa hartzii ssp. *alaskana*	G3G4T1T2	S1S2	This bluegrass is endemic to arctic Alaska, where it is known from the Meade River and from Lake Peters in the eastern Brooks Range.
Poa sublanata	GNR	S1?	Known from active dunes on the Arctic Coastal Plain and Seward Peninsula
Puccinellia andersonii	G3G5	S1S2	Widespread, coastal arctic species that grows near tideline and on barren sediments.
Rumex aureostigmaticus	GNR	S1	Sparsely vegetated sand dunes, river banks and shores.
Symphyotrichum pygmaeum	G3G5	S1S2	Open, active, moist sand dunes, sandy or silty stream banks and terraces.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 11, Figure 17). Arctic inland dunes support a variety of other plant associations but we do not list them because they are common (G4-G5) in other biophysical settings.

Table 11. Plant associations of conservation concern within the Arctic Inland Dunes Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Salix niphoclada-Salix glauca Sparse (Inland Dune)	G3	S3	Boggs et al. 2015
Deschampsia cespitosa Sparse (Inland Dune)	G2	S2	Boggs et al. 2015

Classification Concept Source

The classification concept for this biophysical setting is based on Peterson and Billings (1978).

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Arctic Pingo Biophysical Setting

Arctic and Beringian Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Pingos are perennial, ice-cored domes of soil and vegetation, formed by the injection and freezing of water in near-surface permafrost (Figure 18). An estimated 11,000 pingos are present in the northern hemisphere (Grosse and Jones 2011) with more than 1,500 pingos occurring in Alaska and almost 1,300 of those occurring on the Arctic Coastal Plain (Jones et al. 2012, Jorgenson et al. 2008, Mackay 1998). Arctic pingos are also tightly concentrated in the northwestern Alaska in the Kotzebue Sound lowlands and west of the Baird Mountains north of Kotzebue.

Pingos have been classified into two categories based on their varying mechanisms of water pressurization. Hydrostatic pingos rely on continuous, ice-rich permafrost and are thus more common in arctic ecoregions, whereas hydraulic pingos develop in areas of discontinuous permafrost and are thus more common below the latitudinal treeline in boreal ecoregions. Hydrostatic pingos, hereafter referred to as arctic pingos, are recognized as a less common biophysical setting. Hydraulic pingos are numerous outside of the Arctic and are not considered as part of this biophysical setting.

Arctic pingos support unique plant associations, soils, and rare plants as well as a variety of bird and mammal populations (Koranda 1970, Walker et al. 1985). Arctic foxes (*Vulpes lagopus*), ground squirrels (*Spermophilus parryii*), American mink (*Neovison vison*) and Nearctic collared lemmings (*Dicrostonyx groenlandicus*) all den on pingos (Eberhardt 1977). Grizzly bears are attracted to pingos because of the high densities of ground squirrels, and caribou utilize pingos for mosquito relief. South of the Prudhoe Bay oil field, many pingos have south-facing *Salix* thickets that offer browse for moose. Snowy owls (*Bubo scandiacus*), long-tailed jaegers (*Stercorarius longicaudus*), rough-legged hawks (Buteo lagopus), peregrine falcons (*Falco peregrinus*), and golden eagles (*Aquila chrysaetos*) use pingos as hunting grounds

Figure 18. Photo of an arctic pingo south of Prudhoe Bay, Alaska (photo by T. Boucher).

and observation points. Lapland longspurs (*Calcarius lapponicus*), buff-breasted sandpipers (*Tryngites subruficollis*), and numerous passerine birds can regularly be found on pingos (Walker et al. 1985).

Distribution

Arctic pingos occur beyond latitudinal treeline in areas underlain by unconsolidated sandy or gravelly deposits which allow for the basal infiltration of water supplying pingo growth (Walker et al. 1985, Ferrians 1988). The distribution of arctic pingos (Figure 19) was developed from ranges mapped by Jorgenson and others (2008) and Jones and others (2012). An average basal diameter of 118 m was adopted from Walker and others (1985) who provide a range in pingo diameters of 70 - 400 m. While pingos are found on the Yukon-Kuskokwim Delta, their distribution has not been mapped and thus is not included in Figure 19 or accounted for in the conservation status assessment of this system.

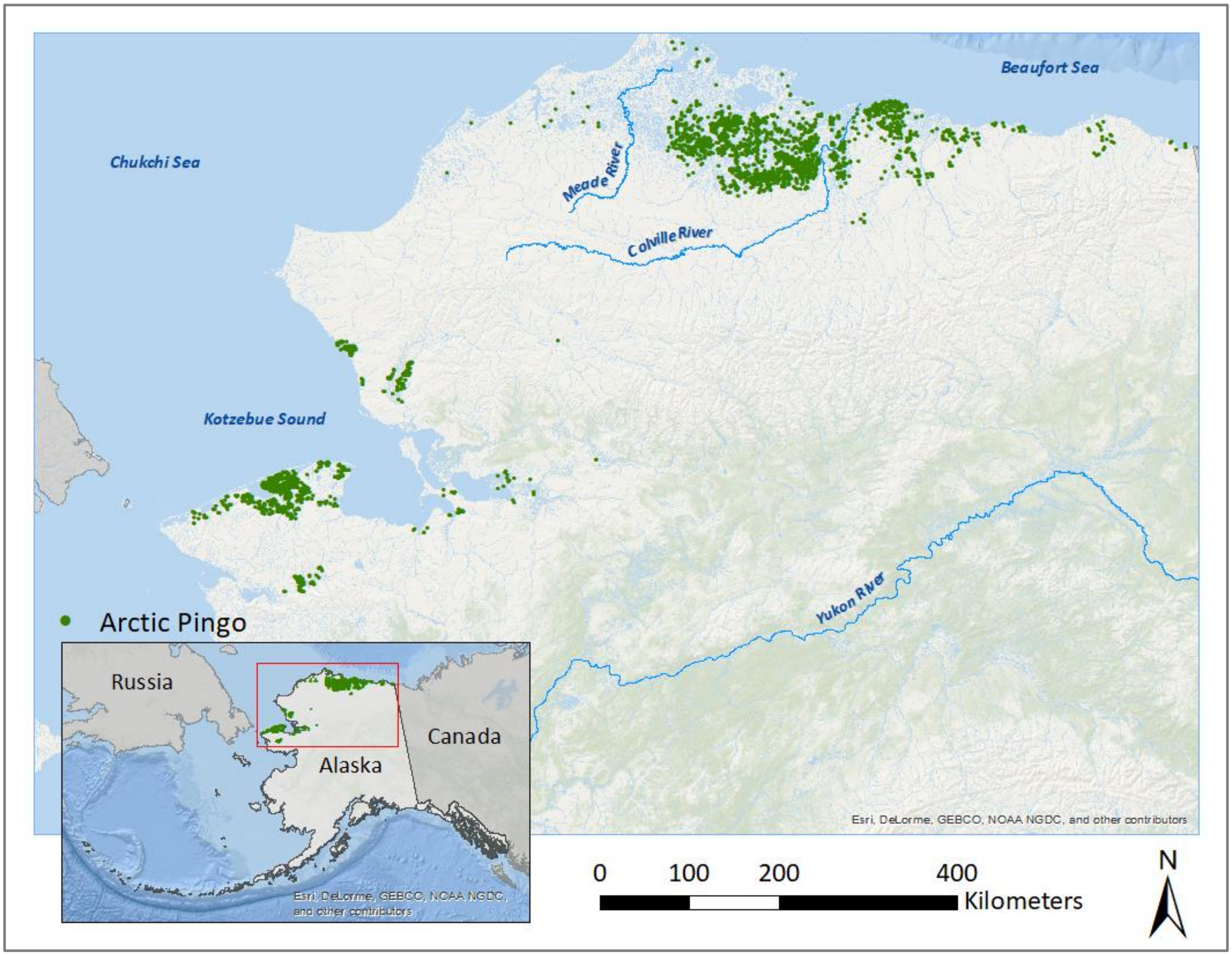

Figure 19. Distribution of the Arctic Pingo Biophysical Setting. Note that point occurrences in this map are buffered for greater visibility

Climate

In the northern Alaska region, the arctic climate is dry and cold, characterized by very short summers and long winters (Natural Resources Conservation Service, 2006). Most of the region is above the Arctic Circle and consequently receives continuous sunlight for several weeks in summer and continuous twilight for several weeks in winter. The mean annual precipitation ranges from about 10 to 26 cm at the lower elevations and 76 to 102 cm at the higher elevations. The average annual temperature ranges from -13 to -6 ^{o}C, and freezing temperatures can occur in any month.

In the western Alaska region, the climate ranges from maritime near the coast to subarctic continental away from the coast and at the higher elevations (Natural Resources Conservation Service, 2006). In the northern part of the region, the winter climate becomes more continental as the icepack forms in the Bering Sea. Summers are short and warm and cloudy along the coast, and winters are long and cold. The annual precipitation ranges from about 33 to 203 cm with the lowest precipitation in lowland areas and the Nulato Hills and the highest at the higher elevations of the Ahklun and Alaska Peninsula Mountains. The average annual temperature ranges from -4 to 2 ^{o}C). Frost may occur in any month, intense winds are common, and snow covers the ground for approximately 7 to 9 months each year.

Environmental Characteristics

Hydrostatic or closed-system pingos form by the injection and freezing of pressurized water in near-surface permafrost. The continuous injection of water and subsequent phase shift to ice causes a 9% increase in volume of the massive ice core and concurrent heave of the overlying sediments (Jones et al. 2012). Where ice core expansion outpaces the development of overlying vegetation and soil, tension cracks will reduce the insulating capacity of the overburden leading to eventual thermokarst collapse. Wetland vegetation may establish in the water-filled craters of collapsed pingos.

In the Arctic, pingos may also form in drained lake basins underlain by continuous permafrost. Lakes greater than 2 m deep do not freeze to the bottom in winter, which preserves an unfrozen, water-saturated zone (talik) in the otherwise frozen ground. Following some reduction in the insulating capacity of the water, typically a lake drainage event, permafrost aggrades into the talik from all sides. As freezing progresses, water is expelled from the pore spaces to sandy or gravelly materials into the remaining unfrozen area, where pressure builds. When the talik eventually freezes, the increase in volume uplifts the overlying sediments and a pingo is formed (Mackay 1979 and 1998, Everett 1980). Such pingos may be as tall as 50 m and have basal diameters greater than 1 kilometer but are more commonly between 5 and 20 m high with diameters between 70 and 400 m (Walker et al. 1985). Due to the importance of confining permafrost to the formation of hydrostatic pingos, their occurrence is uncommon in regions of discontinuous permafrost.

Soils: Sediment overlying the ice core of a pingo ranges in thickness from 1 to 14 m or more. Sandy or gravelly soils predominate on the surface of pingos, although silts of marine origin sometimes occur (Walker 1990). Soil pH measured on pingo summits ranges from 7.1 at Prudhoe Bay, to 5.5 at Kadleroshilik, and is partially influenced by the deposition of calcareous loess downwind from the Sagavanirktok River (Walker 1990, Parkinson 1978, Walker and Webber 1979). Over time, the accumulation of carbonates may elevate pH to 8.0. Lower pH is found in areas where organics accumulate or the soils are occasionally flushed surface flow such as snowmelt.

Vegetation

Pingos in northern Alaska are treeless and primarily dominated by the dwarf shrub *Dryas integrifolia* (Figure 20 and Figure 21). Vegetation on northern pingos is strikingly different from the expanses of wet sedge tundra that dominate the coastal plain. Habitat differentiation and vegetation patterns on pingos result from differences in slope, aspect, effects of wind, disturbance by animals, site stability, and deposition of snow (Koranda 1970, Walker et al. 1985, Walker 1990, Walker et al. 1991). The nutrient input from wildlife activity likely contributes to the diversity of plant species found on pingos.

Figure 20. Angel Pingo, Prudhoe Bay, Alaska (photo by D.A. Walker).

The following plant associations are described for pingos on the Arctic Coastal Plain (Walker 1990): the north and wind-exposed east to northeast slopes of pingos may support *Cerastium beeringianum-Minuartia rubella* or *Dryas integrifolia-Oxytropis nigrescens* associations. Warmer and drier summits and south slopes may support *Carex rupestris-Saxifraga oppositifolia* or *Cerastium beeringianum-Ranunculus pedatifidus* associations. Areas of late-lying snow may support *Cassiope tetragona-Dryas integrifolia*, or *Carex rupestris-Oxytropis nigrescens* associations and wetlands at the base of pingos may support *Phippsia algida-Saxifraga rivularis* associations.

Vegetation has also been described for pingos occurring on the Seward Peninsula (Sigafoos 1951, Pegau 1970, Wetterich et al. 2012). A diversity of plant communities have been described for pingos on the Seward Peninsula. On drier sites, pingos may support diverse dwarf and low shrub communities with *Andromeda polifolia, Betula nana, Spiraea stevenii, Ledum palustre* ssp. *decumbens* and *Dryas integrifolia* (Wetterich et al. 2012). On more mesic sites a typical shrub-graminoid tundra community dominated by dwarf shrub, *Eriophorum* and *Carex* species may establish (Pegau 1970) or herbaceous communities including *Arctagrostis latifolia* var. *arundinacea*, *Calamagrostis neglecta*, *Poa arctica, Aconitum delphinifolium, Polemonium acutiflorum, Rubus arcticus, Sedum rosea* ssp. *intergifolium, Trientalis europea*, and *Petasites frigidus* may establish at the summit with *Salix* species on the slopes. On wetter sites, a graminoid tundra dominated by *Carex aquatilis* over a thick layer of mosses in the *Sphagnum* and *Polytrichum* genera (Pegau 1970) or a thick sedge sod codominated by *Carex aquatilis* and *Eriophorum angustifolium* may develop (Sigafoos 1951).

Figure 21. Pingo near Prudhoe Bay supporting the *Dryas integrifolia-Astragalus umbellatus-Carex rupestris* Plant Association.

A succession of vegetation types has been described for pingos on the Yukon Kuskokwim Delta (Burns 1964). In their youngest, most unstable stages pingos support plant communities composed entirely of the ruderal grass *Calamagrostis canadensis*. As organic soils develop and the stability of the pingo increases *Spireaea stevenii* colonizes and may occupy from 20 to 80% of the total area; the forbs *Angelica lucida*, *Artemisia tilesii*, *Petasites frigidus*, and *Chamerion angustifolium* occur as minor associates. Mosses and lichens colonize in the next successional stage. The developing nonvascular mat insulates the soil and reduces the depth of annual thaw, which presumably causes the root system of *Spiraea stevenii* shrubs to die. When this mat reaches a threshold thickness, other plants, especially *Rubus chamaemorus*, become established along with other migrants from the surrounding tundra such as *Ledum palustre* ssp. *decumbens*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*. Secondary succession on pingos caused by localized changes in relief, drainage, exposure, and ground ice conditions commonly results in slumping and cracking, which disrupts the normal succession leading to tundra vegetation.

Conservation Status

Rarity: Arctic pingos are widespread across northern and western Alaska (Jorgenson et al. 2008, Burns 1964). On the Arctic Coastal Plain, 1,247 pingos taller than 2 m and larger than 30 m^2 in diameter occur (Jones et al. 2012). Although numerous, their small total area (87 km^2) makes them of conservation concern.

Threats: As pingos are among the very few dry, elevated sites on the arctic coastal plain, they attract activities of animals, providing wildlife habitat. Pingos are used by raptors as perch, caribou seeking insect relief and burrowing small mammals. Humans use pingos for survey points, bench marks, and radio towers. Disturbances from mechanized vehicles also occur. Pingos will likely be negatively impacted by climate change. They occur within regions of continuous and discontinuous permafrost and thus exist at a threshold wherein a minor change in climate could impact their stability.

Trend: Short- and long-term declines are predicted for pingos in a warming climate as permafrost thaw will lead to a change and possible collapse of their ice cores.

Species of Conservation Concern

Wildlife use pingos as hunting, nesting, burrowing, and resting grounds. The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 12, Table 13). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 12. Mammal and bird species of conservation concern in the Arctic Pingo Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Alaska Tiny shrew	*Sorex yukonicus*	GU	S3	The tiny shrew is a habitat generalist that will use pingo habitat when present.
Birds				
Arctic Peregrine Falcon	*Falco peregrinus tundriu*	G3	S3B, S3N	In Northern Alaska peregrine falcons are known to occur and as a habitat generalist likely use pingos for hunting.
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
King Eider	*Somateria spectabilis*	G5	S3B, S3N	Known to nest in arctic coastal tundra.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Suspected to winter in open areas near treeline.
Steller's Eider	*Polysticta stelleri*	G3	S2B	Nests on grassy edges of tundra lakes and ponds, or drained lake basins; occasionally on barren rocky tundra; on dry mossy site or in depression between grassy hummocks (Soothill and Whitehead 1978).
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Arctic tundra areas near open water are used as summer breeding grounds.

Table 13. Plant species of conservation concern within the Arctic Pingo Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Cardamine microphylla	G3G4T1T2	S2	Distributed in Siberia, Russian Far East, and 1,500 km disjunct in northwestern North America. It occurs on cobble, gravel, sand, silt, clay, and/or peat and is found mostly on slopes.
Erigeron muirii	G2G3	S2S3	Known from fewer than 20 locations in northern Alaska, where it occurs on alpine slopes, screes and outcrops; river terraces and bluffs; ridge crests, rocky tundra and meadows.
Erigeron ochroleucus	G5	S1S2	Distributed in Western North American cordillera and disjunct more than 2,800 km in American Beringia. It occurs on pingos and river banks in Arctic Tundra.
Oxytropis arctica var. *barnebyana*	G4T2Q	SU	Found on the Arctic Coastal Plain in wet meadow habitat of pingos with collapsed center.
Poa hartzii ssp. *alaskana*	G3G4T1T2	S1S2	Perennial grass found on sparsely vegetated rivers bars, floodplains, active sand dunes and pingos.
Puccinellia andersonii	G3G5	S1S2	Grows in sandy coastal areas and river deltas.
Puccinellia vahliana	G4	S3	Grows in dunes, seepage meadows, steep sloping fens, pond margins, stream banks, brackish creeks, gently sloping ridges, boulder slopes, high-center polygons, pingos, in shale in mountain passes.

Scientific Name	Global Rank	State Rank	Habitat Description
Stellaria umbellata	G5	S3/S4	Known from the Kadleroshilik Pingo, prefers wetter habitat of lower pingo slopes.
Symphyotrichum pygmaeum	G2G4	S2	Known from the western Canadian Arctic and the central and northeastern arctic coast of northern Alaska, where it grows on riverbanks and terraces, sand dunes, old river terraces, pingo slopes.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 14).

Table 14. Plant associations of conservation concern within the Arctic Pingo Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Artemisia frigida	G3	S3	Young and Racine 1976
Artemisia frigida - Bromus pumpellianus	G3	S3	Hanson 1951
Calamagrostis purpurascens	G3	S3	Howenstein et al. 1985
Calamagrostis purpurascens - Artemisia frigida	G3	S3	Hanson 1951
Festuca altaica – Calamagrostis spp.	G3	S3	Batten et al. 1979
Poa glauca - Artemisia frigida – Calamagrostis purpurascens	G3	S3	Hanson 1951

Classification Concept Source

The classification concept for this biophysical setting is based on Sigafoos (1951), Pegau (1970) and Koranda (1970).

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Arctic Tidal Marsh Biophysical Setting

Arctic Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

Tidal marshes develop where relatively flat land receives periodic input of tidal waters (Frohne 1953). As an interface between the ocean and land, tidal marshes combine aquatic and terrestrial habitats, anoxic and oxic conditions, as well as saline and fresh waters (Stone 1984). This dynamic environment supports life highly-adapted to saturation and saline conditions. The cumulative area of tidal marshes in Arctic Alaska is low and the plant species they support are often obligate. The microtidal regime (0.1 m) along the arctic coast reduces the elevational range across which tide marshes develop, however storm surges across the low-angle topography of the coastal plain can expand their inland extent (Figure 22). Although tidal marshes only occupy a small percentage of the total landscape, they are a critical staging area for waterfowl, several of which are species of conservation concern. Tidal marshes in northern Alaska are threatened by climate change; principally the acceleration of coastal erosion. Tidal marshes in northern Alaska are described separately from those found in western Alaska. While both regions share an arctic climate and are underlain by permafrost, arctic tidal marshes support several plant species that are uncommon in Beringian Alaska, including *Carex ursina*, *Dupontia fischeri*, *Puccinellia andersonii* and *Puccinellia arctica* (Bergman et al. 1977, Chapman 1960, Meyers 1985, Jefferies 1977, Taylor 1981) and are subject to more severe impacts related to coastal processes.

Figure 22. Tidal marsh vegetation, Arctic Coastal Plain, Alaska (photo by L. Flagstad).

Distribution

Along the Beaufort and Chukchi Sea Coasts of Arctic Alaska, tidal marshes form a narrow fringe (<100 m wide) in protected areas along tidal river channels, inlets and deltas and within tidal lagoons, estuaries and across inundated tundra (Figure 23). The distribution of tidal marshes in Northern Alaska was developed from estuarine and marine intertidal subsystems of the National Wetland Inventory (USFWS 2015).

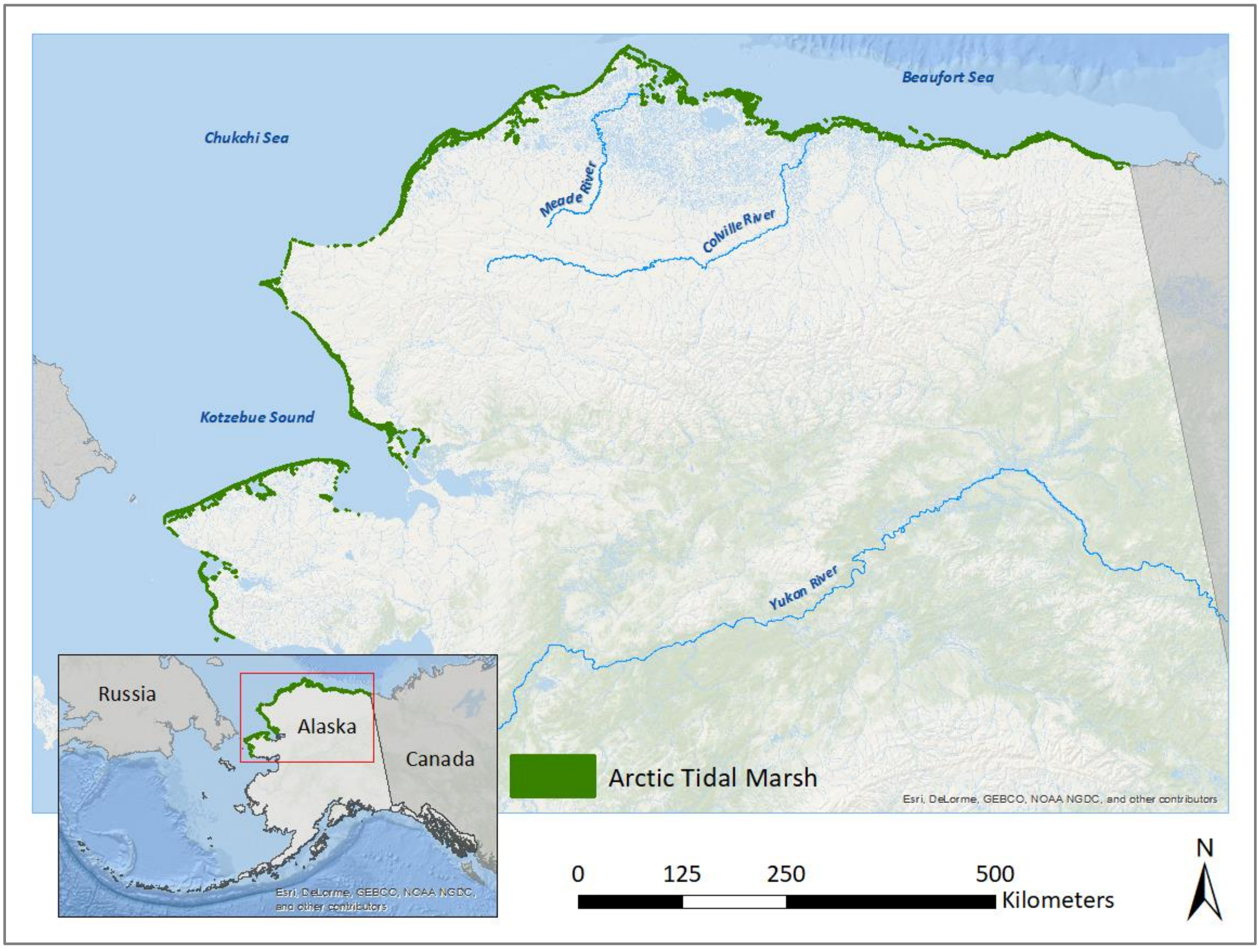

Figure 23. Distribution of the Arctic Tidal Marsh Biophysical Setting. Note that areas of occupancy in this map are buffered for greater visibility.

Climate

The coast of Alaska along the Arctic Ocean has dry polar conditions with short, cool summers and long, cold winters. Average summer temperatures range from 0 to 15 °C; average winter temperatures are between -30 and -21 °C. Freezing can occur in any month of the year but July and August are generally frost-free. Annual precipitation is 14 cm with 30-75 cm received as snow. Proximity to the Arctic Ocean and abundant sea ice contribute to increasing fog in August. Northeasterly winds are persistent and strong (Gallant et al. 1995, Nowacki et al. 2001).

Environmental Characteristics

The development of tidal marshes in northern Alaska is limited by coastal erosion, which truncates the seaward expansion of marsh systems. Due to the periodic reworking of shoreline sediments by storm events, tide marshes along exposed coastlines develop as small (less than 20 m^2) mosaics of vegetation with up to 80% cover of bare mud and sand. The average rate of erosion along the Arctic Coast is -1.4 m/y with a range of -18.6 to +10.9 m/y (positive rate indicates accretion; Gibbs and Richmond 2015). Analysis of historic aerial photography indicates the rate of erosion along the Beaufort Sea Coast has doubled over the last 50 years (Ping et al. 2011). High rates of coastal erosion relate to the combined factors of global sea level rise, permafrost degradation and the increase in ice free days. Sea level rise extends the impacts of storm surges and facilitates the degradation of permafrost. Storm surges 2 to 3 m above sea level flood

coastal and low-lying inland tundra (Taylor 1981). Permafrost degradation along the coast allows inundation of nearshore basins, polygonal ground and tussock tundra (Figure 24; Bergman et al. 1977, Jorgenson and Miller 2010). Exposure of tundra vegetation to saltwater weakens or kills the resident species and allows salt-tolerant species to colonize (Bergman et al. 1977, Jorgenson et al. 1994, Kincheloe and Stehn 1991). Similarly, an increase in ice-free days exposes the coastline to coastal erosion, ice rafting and storm surges for a greater period of time, thereby exacerbating the cumulative impacts of these processes.
Permafrost is present in most Arctic tidal marshes where it promotes inundation of surface waters by restricting drainage (Bergman et al. 1977, Jorgenson and Brown 2004, Jorgenson and Miller 2010, Meyers 1985). Arctic tidal marshes receive fresh water from streams and rivers, as well as overland and subsurface flow during spring and summer runoff (Meyers 1985, Kincheloe and Stehn 1991). Water salinity is inversely related to freshwater inputs and is subsequently lower in the spring when freshwater contributions from melting ice and snow are higher (Jefferies 1977). The fine sediment comprising tidal marshes is chiefly sourced from the large rivers and deltas that empty to the Beaufort Sea (Hopkins and Hartz 1978).

Figure 24. Tidal marsh species invading subsiding polygonal ground east of Barrow, Alaska.

Vegetation Patterns and Floristics

General patterns of vegetation are recognizable and predictable within the Arctic tidal marshes (Jefferies 1977, Jorgenson et al. 1994 and 1997, Jorgenson 2003, Meyers 1985, Taylor 1981). Unvegetated tidal flats are pioneered by the clonal, halophytic grass *Puccinellia phryganodes* with the halophytic, succulent forbs, *Stellaria humifusa* and *Cochlearia officinalis* colonizing the seaward edge (Jefferies 1977). In contrast, extensive marshes with continuous cover of emergent vegetation may develop in sheltered lagoons and estuaries. Here, the salt-tolerant grasses, *Arctophila fulva* and *Dupontia fisheri*, the forb *Hippuris tetraphylla* and the sedge *Carex ramenskii* are frequent*; C. subspathacea* also occurs but is restricted to areas of secondary erosion (Jefferies 1977).

The introduction of saltwater and sediment to terrestrial and freshwater systems can weaken or kill native species thereby facilitating the colonization of ruderal, salt-tolerant species and affecting the conversion of terrestrial or freshwater aquatic habitats to more saline types. Salt-killed tundra occurs where tundra has been inundated by tide water and tidal species have established; total live vegetation cover is often less than 30%. Tidal flooding may occur in any low-lying ecosystem adjacent to the coast. Consequently, salt-killed tundra soils typically preserve a surface organic layer relict from its previous landcover (e.g. tundra or lake). Salt-killed tundra is typically colonized by ruderal salt-tolerant graminoids *Puccinellia phryganodes, P. andersonii*, *Carex subspathacea*, and *C. glareosa*, the forb *Stelleria humifusa* and the dwarf willow, *Salix ovalifolia* (Figure 25) (Jorgenson et al. 1997, Flint et al. 2008).

Figure 25. The alkai grass, *Puccinellia phryganodes* on subsiding tundra near Deadhorse, Alaska.

Tidal marshes are also migrating inland along river channels and through the conversion of nearshore tundra by outward thawing or inward erosion by sea ice or water (Bergman et al. 1977, Jorgenson and Miller 2010). Due to these high rates of disturbance, we speculate that most Arctic tidal marshes are young. These young tidal marshes will continue to establish along the Arctic Ocean coastline, however, mature tidal marshes are rare.

Below we provide two profiles of vegetation and soil change; along a tidally-influenced river and a coastal lagoon (Boggs et al. 2015). On the tidal river, plant associations dominated by *Dupontia fisheri* often border the river, with participation of *Salix ovalifolia* increasing further inland (Figure 26). Both the *Dupontia fisheri* and the *Dupontia fisheri-Salix ovalifolia* plant associations are generally underlain by recently-deposited, sandy soils. On subsiding tundra *Carex subspathacea* and *Carex glareosa* associations may develop. Soils underlying these sedge associations are derived from the mature tundra and therefore highly organic. Nontidal species (e.g. tundra species) such as *Carex aquatilis*, *Eriophorum angustifolium*, *Chrysanthemum arcticum* and bryophytes such as *Campylium stellatum* and *Meesia triquetra* may be common at subsiding sites. Adjacent nontidal land is often polygonal ground dominated by *Carex aquatilis*.

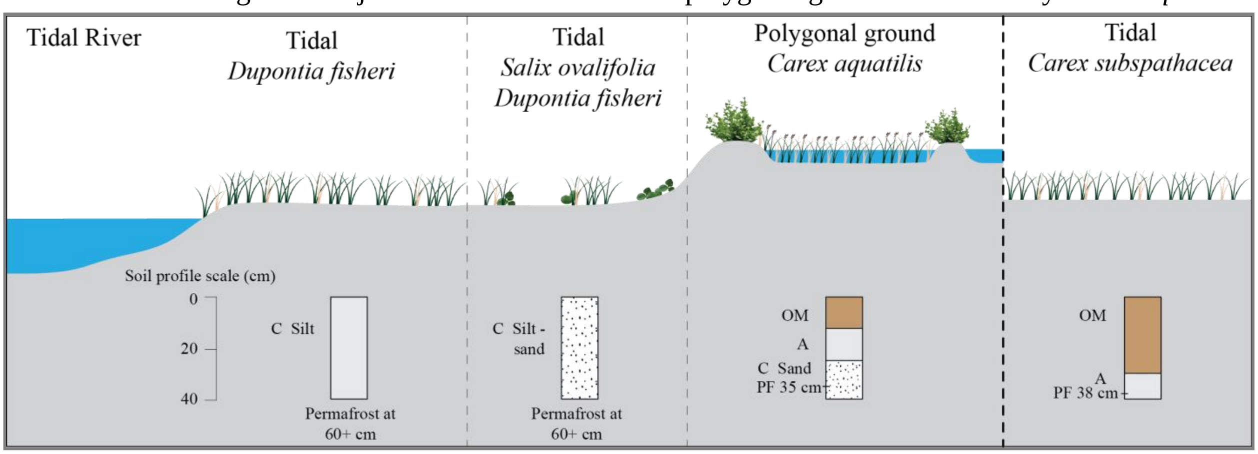

Figure 26. Schematic physiography and vegetation profile along a tidal river in Arctic Alaska.

In coastal lagoons the *Puccinellia phryganodes* association typically occurs in the lower tidal zone (Figure 27). Here, *Puccinellia phryganodes* may form a dense turf or be present only as scattered runners in more exposed sites. Species diversity is low and includes *Calamagrostis holmii, Sagina nivalis* and *Stellaria humifusa*. The *Carex subspathacea* and *Carex glareosa* associations typically occur in the mid-tidal zone on subsiding tundra; *Carex ursina* may codominate (Jorgenson et al. 1997). The *Dupontia fisheri* association also occurs in the mid-tidal zone where codominant species may include *Stellaria humifusa* or

Carex ursina. The *Carex subspathacea-Salix ovalifolia* association may also occur in the upper tidal zone on subsiding tundra. Similar to tidal rivers, adjacent nontidal land is often polygonal ground dominated by *Carex aquatilis*.

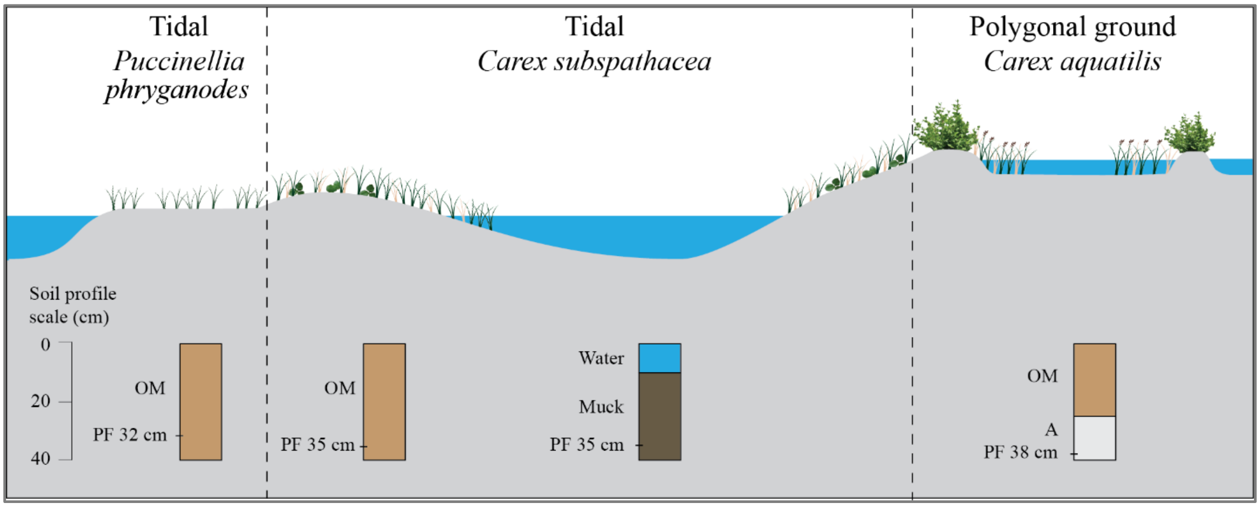

Figure 27. Schematic physiography and vegetation profile of tidal vegetation along a coastal lagoon in Arctic Alaska.

Conservation Status

Rarity: Tidal marshes are widely distributed along Alaska's Arctic Ocean coastline, but their small total area (844 km^2), threats related to climate change, and the fidelity of their component species makes this biophysical setting of one conservation concern.

Threats: The varied effects of climate change are responsible for rapid coastal erosion along the Arctic Ocean coastline (Jones et al. 2008, Ping et al. 2011, Forbes 2011). Rising ocean temperatures diminish the thickness, extent and permanence of sea ice, which in turn increase storm power (due to greater fetch). This in combination with global sea level rise and more extreme weather events pushes saltwater farther inland, at a greater frequency. Inundation serves to thaw permafrost, which promotes subsidence and thermal and mechanical erosion of coastal habitats, particularly tidal marshes (Jones et al. 2008, Ping et al. 2011, Forbes 2011). Fluctuations in winter climate causes warm spells and rain, generating crust-ice layers through thaw-freezing cycles deleteriously affecting herbivory of high Arctic small and large herbivores (Hansen et. al 2013). Due to their landscape position and proximity of oil fields, Arctic Coastal Plain tidal marshes are also highly susceptible to damage from oil spills and oil field development (Bergman et al. 1977). The degree of damage from an oil spill to nearshore waters is expected to vary with factors such as degree of tidal influx, tide level, location, ice-coverage, season, and extent and duration of the spill. Sites with high freshwater outflow are expected to be less susceptible (Crow 1977).

Trend: Coastal erosion has and will continue to reduce the total area of tidal marshes along Alaska's Arctic coastline. The average rate of shoreline change for sheltered shorelines (where tidal marshes are exclusively located) between the U.S.-Canada border and Icy Bay is -0.9 m/year (Gibbs and Richmond 2015). To some extent these losses may be offset by the inland conversion of habitat to more saline types (Arp et al. 2010) but is likely that habitat loss significantly outpaces habitat conversion. Loss of coastal habitat due to climate change is difficult to predict as projections of sea level rise must account for concurrent change in temperature, precipitation, and permafrost. It is expected that the short- and long-term impacts of climate change-induced processes will be severe and extensive in coastal areas that are low-lying, permafrost-affected and characterized by microtidal regimes areas such as along Alaska's northern coastline (Glick et al. 2010, Lawler et al. 2009).

Species of Conservation Concern

Although tidal marshes and flats occupy only a small portion of the total landscape, they are a critical staging area for wildfowl, particularly Snow Geese (*Chen caerulescens*) and Black Brant (*Branta bernicla nigricans*), and support several bird species of conservation concern, such as the Spectacled Eider (*Somateria fischeri*) and Steller's Eider (*Polysticta stelleri*). The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 15, Table 16). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 15. Mammal and bird species of conservation concern within the Arctic Tidal Marsh Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Polar bear	*Ursus maritimus*	G3G4	S2	Polar bears are known to use inland habitat for denning. Tidal marshes provide habitat between sea ice and coastal tundra.
Birds				
Black Guillemot	*Cepphus grylle*	G5	S2	Nest along beaches and in coastal cliff crevices in Northern Alaska.
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Black scoters could use inshore marine habitat during nonbreeding seasons. Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
Buff-breasted Sandpiper	*Tryngites subruficollis*	G4	S2B	Nests on tundra. Could use tidal marshes for migration.
King Eider	*Somateria spectabilis*	G5	S3BS3N	Known to nest in arctic coastal tundra. Nearshore marine waters provides wintering and migration habitat.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Breeds in tundra from near treeline to the edge of polar seas.
Spectacled Eider	*Somateria fischeri*	G2	S2B, S2N	Molting occurs in nearshore waters containing an abundance of mollusks.
Steller's Eider	*Polysticta stelleri*	G3	S2B,S3N	During molting, utilize tidal flats and deeper bays. Winter habitat includes eelgrass, intertidal sand flats, and mudflats possibly foraging on invertebrates.
Stilt Sandpiper	*Calidris himantopus*	G5	S3B	Breeding range from Canadian border to Barrow, Alaska along coastal plain at least several km inland. Suspected to use nearshore marine habitat for migration.
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Arctic tundra areas near open water are used as summer breeding grounds. Likely uses nearshore marine habitat provided by barrier islands and spits

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
				during migration and as winter habitat along Southern coastal Alaska.

Table 16. Plant species of conservation concern within the Arctic Tidal Marsh Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Eleocharis kamtschatica	G4	S2S3	Intertidal meadows.
Gentianopsis detonsa ssp. *detonsa (Gentianopsis richardsonii)*	G3G5T3T5	S1	Estuary shores, beaches, coastal marshes.
Pleuropogon sabinei	G4G5	S1S2	Found in moist to saturated soils near the coast.
Puccinellia arctica	G4G5	S1	Seashores.
Puccinellia vaginata	G4	S1/S2	Gravel beaches and edges of lagoons.
Puccinellia vahliana	G4	S3	Found in seepage meadows brackish creeks as well as other habitats.
Saxifraga rivularis ssp. *arctolitoralis*	G5T2T3	S2	Wet meadows near arctic seashores.
Symphyotrichum yukonense	G3	S3	Mud flats, gravelly, stony or silty lakeshores, sometimes saline areas in Northwest Territories, Yukon and Alaska.
Zannechellia palustris	G5	S3	Brackish water.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 17).

Table 17. Plant associations of conservation concern within the Arctic Tidal Marsh Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Carex glareosa	G3	S3	Boggs 2000
Carex subspathacea	G3	S3	Hanson 1951
Cochlearia officinalis	G3	S3	Wiggins and Thomas 1962
Cochlearia officinalis-Achillea borealis	G3	S3	Byrd 1984
Cochlearia officinalis-Phippsia algida-Stellaria humifusa	G3	S3	Webber 1978
Cochlearia officinalis-Puccinellia andersonii	G3	S3	Webber et al. 1978
Dupontia fisheri	G3	S3	Wiggins 1951
Puccinellia andersonii	G3	S3	Meyers 1985
Puccinellia phryganodes	G3	S3	Jeffries 1977
Puccinellia phryganodes-Cochlearia officinalis	G3	S3	Thomas 1951

Classification Concept Source

The classification concept for this biophysical setting is based on Jefferies (1977).

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Beringian Alpine Limestone *Dryas* Biophysical Setting

Arctic and Beringian Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The Beringian Alpine Limestone *Dryas* Biophysical Setting occurs above elevational treeline on wind-exposed landforms derived from carbonate sedimentary bedrock (limestone) and metamorphic carbonate (marble) bedrock. (Figure 28). Vegetation is comprised of dwarf shrubs, low growing herbs, and lichen, the combined cover of which can be sparse. The taxonomy of *Dryas octopetala* is currently being reviewed, as such the dominant dwarf Dryas species described within this biophysical setting should be revised if necessary upon further taxonomic clarification. Plant communities are dominated by the dwarf shrubs *Dryas integrifolia* ssp. *integrifolia* and *Dryas ajanensis* ssp. *beringensis* with the forb, *Saxifraga oppositifolia* and the sedge, *Carex nardina* further characterizing the type. The development of such plant communities on the relatively uncommon calcareous substrates of the Seward and Lisburne Peninsulas and western Brooks Range and Foothills is of particular biogeographic interest as this region was both connected to Asia by the Bering Land Bridge and, relative to adjacent inland areas, had minimal ice coverage during the late Quaternary glaciations (Sainsbury 1965, Hulten 1968, Kaufman and Hopkins 1986, Wilson et al. 2015). In combination, these calcareous substrates, a historic connection to Asia, and provision of glacial refugia provide a unique habitat for rare

Figure 28. Calcareous side slope in the western Brooks Foothills supporting *Dryas integrifolia* ssp. *integrifolia*.

taxa, regional endemics, and disjunct species (Kelso 1989). The Beringian Alpine Limestone *Dryas* Biophysical Setting is comparable to the 'Dryas Limestone Slope' and 'Bald Limestone Slope' ecological site type described by Swanson and others (1985) and the 'Alpine Alkaline Barrens' and 'Alpine Alkaline Dryas Dwarf Shrub' ecotypes described by Jorgenson and others (2009).

Distribution

The Beringian Alpine Limestone *Dryas* Biophysical Setting is geographically widespread yet uncommon. This type is restricted to carbonate substrates beyond latitudinal treeline within the Beringian floristic province of Alaska. As such, it occurs sporadically on the Seward and Lisburne Peninsulas and within the western Brooks Range and Foothills (Figure 30). The Beringian floristic province, as delineated by Raynolds and others (2006) and described by Yurtsev (1994), includes areas in northwestern and western Alaska that have remained ice-free since the last glacial maxima during which this region of Alaska was connected with northeastern Asia. Floristically, this province is distinguished by the presence of endemics, such as *Artemisia globularia*, *Papaver walpolei*, *Rumex krausei*, *Cherleria dicranoides*, *Oxytropis arctica* var. *barnebyana*, *Cardamine blaisdellii*, *Cerastium jenisejense*, *Puccinellia wrightii* ssp. *wrightii*, and *Saussurea nuda* as well as predominantly Asiatic species such as *Oxygraphis glacialis* (Ickert-Bond et al. 2017).

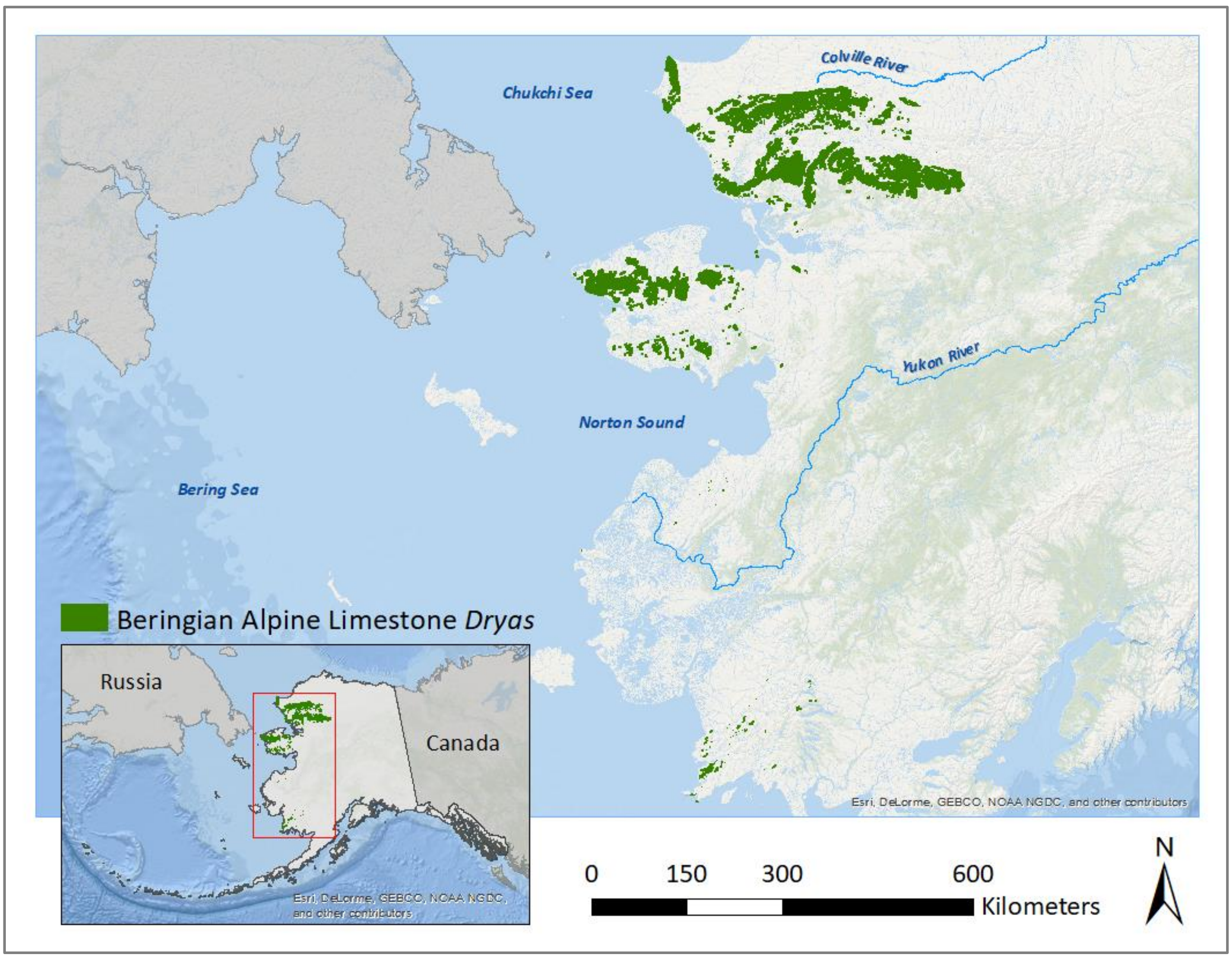

Figure 29. Distribution of the Beringian Alpine Limestone Dryas Biophysical Setting. Note that areas of occupancy in this map are buffered for greater visibility.

The Beringian Alpine Limestone *Dryas* distribution map (Figure 29) was developed from the intersection of *Dryas*-dominated landcover classes of the Alaska Vegetation Map (Boggs et al. 2015) with carbonate bedrock groups of the Geologic Map of Alaska (Wilson et al. 2015), and the Beringian Floristic Province described by Raynolds and others (2006). Landcover classes that specifically listed *Dryas octopetala* (syn. *ajanensis*) or *D. integrifolia* as dominant species (32 individual classes) and lithological units that included terms such as ‘carbonate’, ‘calcareous’, ‘limestone’, ‘dolestone’, ‘dolomite’, or ‘marble’ in their name or mentioned one of these terms as a major component in the formal description of their type (71 lithological units) were selected for inclusion.

Climate

The climate in northwest Alaska ranges from subarctic maritime near the coast to arctic continental farther inland and at higher elevations (Natural Resources Conservation Service, 2006). Summers are short and winters are long and cold with wind, fog, and precipitation decreasing away from the coast. Most of the region (excluding the Seward Peninsula) is above the Arctic Circle and consequently receives continuous sunlight for several weeks in summer and continuous twilight for several weeks in winter. The mean annual precipitation ranges from about 10 to 26 cm at lower elevations and 76 to 102 cm at higher elevations. The average annual temperature ranges from 13 to -6 ºC with a mean July temperature of 9 to 12 °C (Subzone E; Raynolds et al. 2006). Freezing temperatures can occur in any month.

Environmental Characteristics

The Beringian Alpine Limestone *Dryas* Biophysical Setting occurs in treeless areas on unglaciated carbonate substrates. This biophysical setting appears to be more strongly associated with limestone, opposed to its metamorphic correlate, marble. Limestone affinity is likely due to the lower competency of this sedimentary parent material and subsequently, the faster development of alkaline soils. Landforms are typically rounded hills, shoulders, and plateaus mantled by colluvium and talus. Elevations range from near sea level to greater than 300 m. (Swanson et al. 1985, Kelso 1989, Jorgenson et al. 2009). Exposure to high winds retards the accumulation of loess and soil development, thus soil profiles often include blocky to rubbly, weathered mineral horizons with minimal surface organics. Rocks and barren patches are common at the ground surface (Jorgenson et al. 2009). Frozen ground can be difficult to detect due to the abundance of coarse fragments and often dry soil conditions. Active layer depth at a site sampled in July, 2017 ranged from 60 to 95 cm below the ground surface (ACCS unpublished field data). Soils are alkaline due to calcium ions made available from calcium carbonate ($CaCO_3$)-rich parent material; at two sites in the western Brooks Range Foothills pH values ranged from 7.5 to 8.9 (ACCS unpublished field data).

Vegetation

In this biophysical setting vegetated cover often occupies less than 25% of the ground surface (Figure 30; Swanson et al. 1985, Kelso 1989, Jorgenson et al. 2009, Boggs et al. 2015). The dwarf (<20 cm) shrubs, *Dryas integrifolia* ssp. *integrifolia* and *Dryas ajanensis* ssp. *beringensis*, are dominant with the forb, *Saxifraga oppositifolia* and the sedge, *Carex nardina* further characterizing the type. While not obligate calciphiles, both *Dryas* species, *Carex nardina*, and *Saxifraga oppositifolia* are often associated with calcareous soils (Gjærevoll 1954, Wells & Elvander 2009). Associated dwarf shrubs include *Kalmia procumbens*, and *Salix phlebophylla*. Common forbs are *Lupinus arcticus*, *Minuartia arctica*, and *Potentilla elegans*. Lichen cover ranges up to 25% and is dominated by *Thamnolia vermicularis* with variable abundance of *Flavocetraria nivalis*, *F. cucullata*, *Cetraria islandica*, *Bryocaulon divergens*, *Alectoria ochroleuca*, *A. nigricans*, and *Stereocaulon lividum* (Swanson et al. 1985).

Plant communities developing on limestone ridges, scree slopes, cliffs, and valley meadows on the Seward Peninsula are described by Kelso (1989). While the most abundant taxa in these communities are *Dryas integrifolia* ssp. *integrifolia* and *Dryas ajanensis* ssp. *beringensis*, Beringian and Asiatic species such as *Papaver walpolei*, *Artemisia senjavinensis,* and *Oxygraphis glacialis*, are common. Additional character species are: *Anemone drummondii*, *Oxytropis bryophila*, *Phlox alaskensis*, *Carex glacialis*, *C. simpliciuscula*, and *Erigeron humilis.* Plants inhabiting limestone cracks and fissures include mat and cushion forming members of the Caryophyllaceae family such as *Silene acaulis*, ferns such as *Cystopteris fragilis*, and several species of the *Draba*, *Saxifraga*, and *Micranthes* genera. Where wind precludes the accumulation of snow, flowering begins around mid-May, several weeks before any other plant community (Kelso 1989). Vegetation succession has not been studied in this biophysical setting.

Figure 30. A series of limestone outcrops in the Darby Mountains, Seward Peninsula, Alaska (photo by J. Fulkerson).

Conservation Status

Rarity: The Beringian Alpine Limestone *Dryas* biophysical setting is widespread on the Seward and Lisburne Peninsulas and in the western Brooks Range and Foothills; yet its total area of occupancy is estimated to be only 5,500 km^2. Owing to this setting's historic connection to northeast Asia, provision of glacial refugia, and calcareous substrate, it supports a disproportionate number of rare taxa, regional endemics, and disjunct species (Kelso 1989).

Threats: The encroachment of erect shrubs into alpine and arctic tundra environments is a well-documented effect of climate change (Meyers-Smith et al. 2011). Material extraction represents a lesser, localized threat. Limestone is an essential component in cement, lime, and chemical feedstock and is a source of building and ornamental stone, however the remote location and exposure of most occurrences precludes the economic feasibility of extraction. Occurrences near roads are highest at-risk for extraction. An occurrence on the Nome-Teller Highway in the Seward Peninsula is under excavation by AK DOT. The removal of soil and rock to the bedrock have eliminated an estimated 75% of the local *Artemisia senjavinensis* population (J.R. Fulkerson pers. obs.).

Trend: Long-term decline of this alpine system due to shrub encroachment is predicted.

Table 18. Mammal and bird species of conservation concern in the Beringian Alpine Limestone *Dryas* Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alaskan hare	*Lepus othus*	G5	S3	Suspected to occur in drainages associated with Beringian Alpine Limestone *Dryas* biophysical setting.
Birds				
Arctic Peregrine Falcon	*Falco peregrinus tundrius*	G4	S3	Possible species in the mountainous areas of northwestern Alaska.
Bristle-thighed Curlew	*Numenius tahitiensis*	G2	S2B	Known to nest in the mountains of the Seward Peninsula, but likely prefers mesic tundra.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Suspected to winter in open areas near treeline.
Surfbird	*Aphriza virgata*	G5	S2N, S3B	Suspected to use Beringian Alpine Limestone *Dryas* mountainous areas for breeding.

Figure 31. The rare plants *Artemisia senjavinensis* (left; G3 S3) growing on limestone in the Darby Mountains, Alaska (photo by J. Fulkerson) and *Parrya nauruaq* (right; G2 S1S2) growing on limestone in the Moon Mountains, Alaska photo by F. Baldwin).

Species of Conservation Concern

The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 18, Table 19, Figure 31). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 19. Plant taxa of conservation concern within the Beringian Alpine Limestone *Dryas* Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Artemisia senjavinensis	G3	S2S3	A narrow Beringian endemic. On federal threatened and endangered list as status undetermined. Prefers carbonate-rich soils and scree. One occurrence of this plant growing on xeric, barren (<5%) limestone ridges and gravels at Moon Mountains.
Cardamine blaisdellii	G3G4	S3S4	Prefers moist soil and has occasionally been found associated with calcareous fellfields.
Cryptogramma stelleri	G5	S3S4	Occasionally found on limestone cliff faces.
Draba incerta	G5	S3	Found in dry limestone outcrops. The Seward Peninsula populations are disjunct by over 800 km to the main population of North America. Further work is needed to determine if the regional population is distinct taxon.
Douglasia beringensis	G2	S2	Ranked imperiled both globally and in Alaska, this species occurs on south-facing, open *Dryas* fellfield, rock outcrops and cliff ledges at Moon mountains on the western Seward Peninsula.
Erigeron porsildii	G3G4	S3S4	Found on alpine *Dryas* heath, cliffs, scree, meadows along drainages, rock outcrops and herbaceous dune meadows.
Festuca vivparoidea ssp. *viviparoidea*	G4G5	SU	Found on limestone outcrops and subalpine mesic meadows with scattered shrubs.
Oxygraphis glacialis	G4G5	S3	One population known from moist, hummocky *Dryas* fellfield in Moon Mountains of the Seward Peninsula.
Oxytropis arctica var. *barnebyana*	G4?T2Q	SU	Occasionally found on alpine limestone outcrops in Northwest Alaska but not restricted to substrate.
Oxytropis kokrinesis	G3	S3	Found on limestone outcrops in the Baird Mountains but is not restricted to substrate.
Parrya nauruaq	G2	S1S2	Found on limestone ridges and gravels, *Dryas* fellfields and scree slopes.
Ranunculus ponojensis	GNR	S2	From Russian far east and western Alaska. Found in alpine meadows and slopes, sometimes on limestone substrate.
Rumex krausei	G2	S2S3	Grows in sparsely vegetated meadows and fellfields on weathered, marbleized carbonate rock in the western Seward Peninsula.

Plant Associations of Conservation Concern

While this biophysical setting is suspected to support several plant associations of conservation concern, the associations under consideration have not been formally ranked. Plant communities associated with limestone substrates on the Seward Peninsula meriting further evaluation include the *Artemisia senjavinensis*, *Papaver walpolei*, *Parrya nudicaulis*, *Potentilla vahliana*, *Saxifraga oppositifolia* ssp.

smalliana, and *Salix rotundifolia* ssp. *dodgeana* assemblage described by Racine and Anderson (1979) as well as the *Phlox sibirica-Carex glacialis-Kobresia simpliciusula* and *Silene acaulis* - *Cystopteris fragilis* communities described by Kelso (1989). While not explicitly noted as occurring on calcareous substrate, George and others (1977) describe a *Dryas* - *Carex nardina* - *C. vaginata* – lichens plant association on the Seward Peninsula. Jorgenson and others (2009) describe both a *Dryas octopetala–Saxifraga oppositifolia* and a *Salix arctica–Minuartia arctica* association occurring on alkaline substrates throughout the Brooks Range. Outside of the Beringian Floristic Province a *Dryas octopetala* - *Kobresia simpliciuscula* association is described from limestone of the White Mountains (Gjærevoll 1954). Please note taxonomic names are taken directly from the original publications and as such, may not represent the currently-accepted nomenclature.

Classification Concept Source

The classification concept for this biophysical setting is based on Swanson and others (1985).

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Beringian Barrier Island and Spit Biophysical Setting
Beringian Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction
Barrier islands and spits are elongate, broadly-arcuate features that may be separated from each other by inlets and from the mainland by lagoons, estuaries or bays. Unlike barrier islands, spits maintain connection to the mainland and are thought to represent continuations of coastal dunes into the ocean (Figure 32; Ritter 1986). Due to similarities in landform, geomorphic process, and parent material, barrier islands and spits are treated here as a single biophysical setting. The seaward position of barrier islands and spits allows the formation of rich lagoons and estuaries (Figure 32 and Figure 33), which provide important habitat for wildlife of the region. Barrier islands and spits fronting the Bering seacoast provide shelter to shorebird populations and molting locations for the Common Eider (*Somateria mollissima*) and the King Eider (*Somateria spectabilis*). Recent sightings of the Pacific walrus on western Alaska beaches outside of their traditional haulout locations), increases the likelihood that barrier islands and spits could provide occasional coastal haulout habitat for walrus as the extent of sea ice changes (Garlich-Miller et al. 2011).Both barrier islands and spits represent dynamic ecosystems which may be subjected to threats linked to a rapidly changing climate. Because the general effects of climate change in western Alaska are not well understood, the specific impacts to barrier islands and spits are not yet defined (Macander et al. 2014).

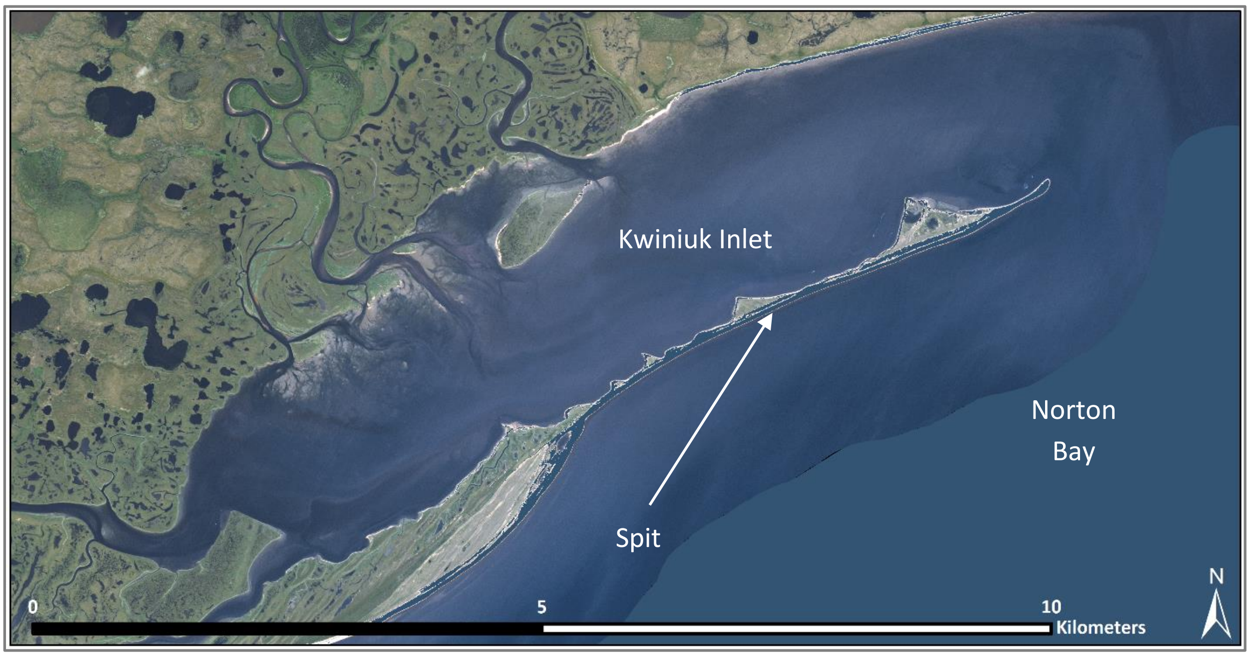

Figure 32. Aerial view of a spit near Moses Point, east of Elim, Alaska.

Distribution
Along the coastlines of the Bering Sea Islands and mainland western Alaska, barrier islands and spits are common on St. Lawrence and St. Matthew Islands, and along the coast of Bristol Bay except for the protected inlets of Nushagak Bay in the vicinity of Dillingham and Kvichak Bay in the vicinity of Naknek and King Salmon. Barrier islands and spits are not common on the Yukon-Kuskokwim Delta, presumably

due to the low terminal energy of this massive depositional environment. Further south, barrier islands and spits along the Alaska Peninsula are found near Pilot Point, Port Heiden and Port Moller.

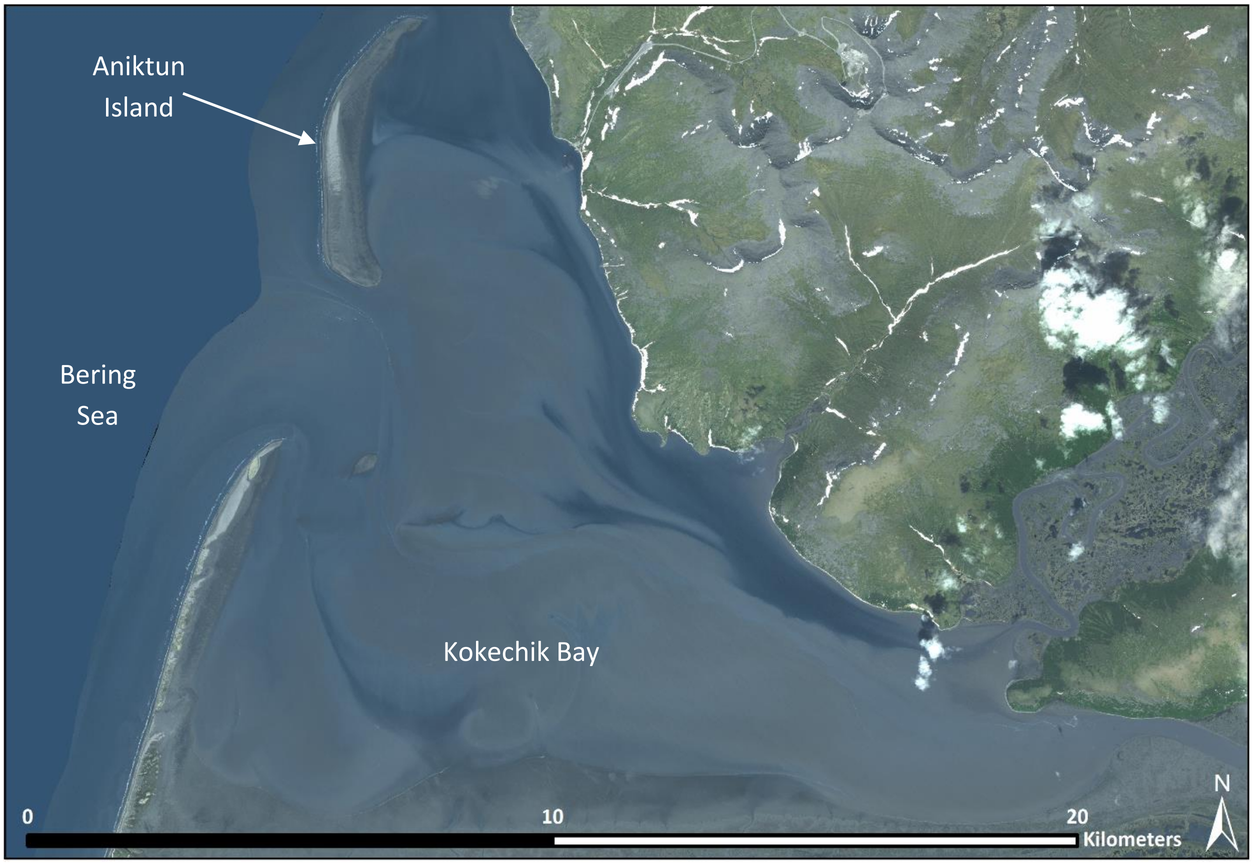

Figure 33. Barrier islands in Kokechik Bay, Western Alaska provide protected nearshore marine habitat for the common eider.

The distribution of barrier islands and spits along the Bering Sea coastline (Figure 34) was primarily developed from the estuarine and marine intertidal subsystems of the National Wetland Inventory (USFWS 2015). Because both of these classes are considered to be undermapped, and National Wetlands Inventory (NWI) coverage is not available for some portions of the mainland and all island coastlines, additional barrier islands and spits were hand-digitized from remotely-sensed imagery. Where the NWI classes corresponded to mainland beaches, the attributed polygon was removed from the distribution.

Climate

In the western Alaska region, the climate ranges from maritime near the coast to subarctic continental away from the coast and at the higher elevations (Natural Resources Conservation Service, 2006). In the northern part of the region, the winter climate becomes more continental as the icepack forms in the Bering Sea. Summers are short and warm and cloudy along the coast, and winters are long and cold. The annual precipitation ranges from about 33 to 203 cm millimeters with the lowest precipitation in lowland areas and the Nulato Hills and the highest at the higher elevations of the Ahklun and Alaska Peninsula Mountains. The average annual temperature ranges from -4 to 2^{o} C. Frost may occur in any month at higher elevations, strong winds are common, and snow covers the ground for approximately 7 to 9 months each year. Further south, climate is strongly maritime near the coast of Bristol Bay and along the Alaska Peninsula. Summers are short, and cloudy conditions and rain are common (Moore et al. 2004).

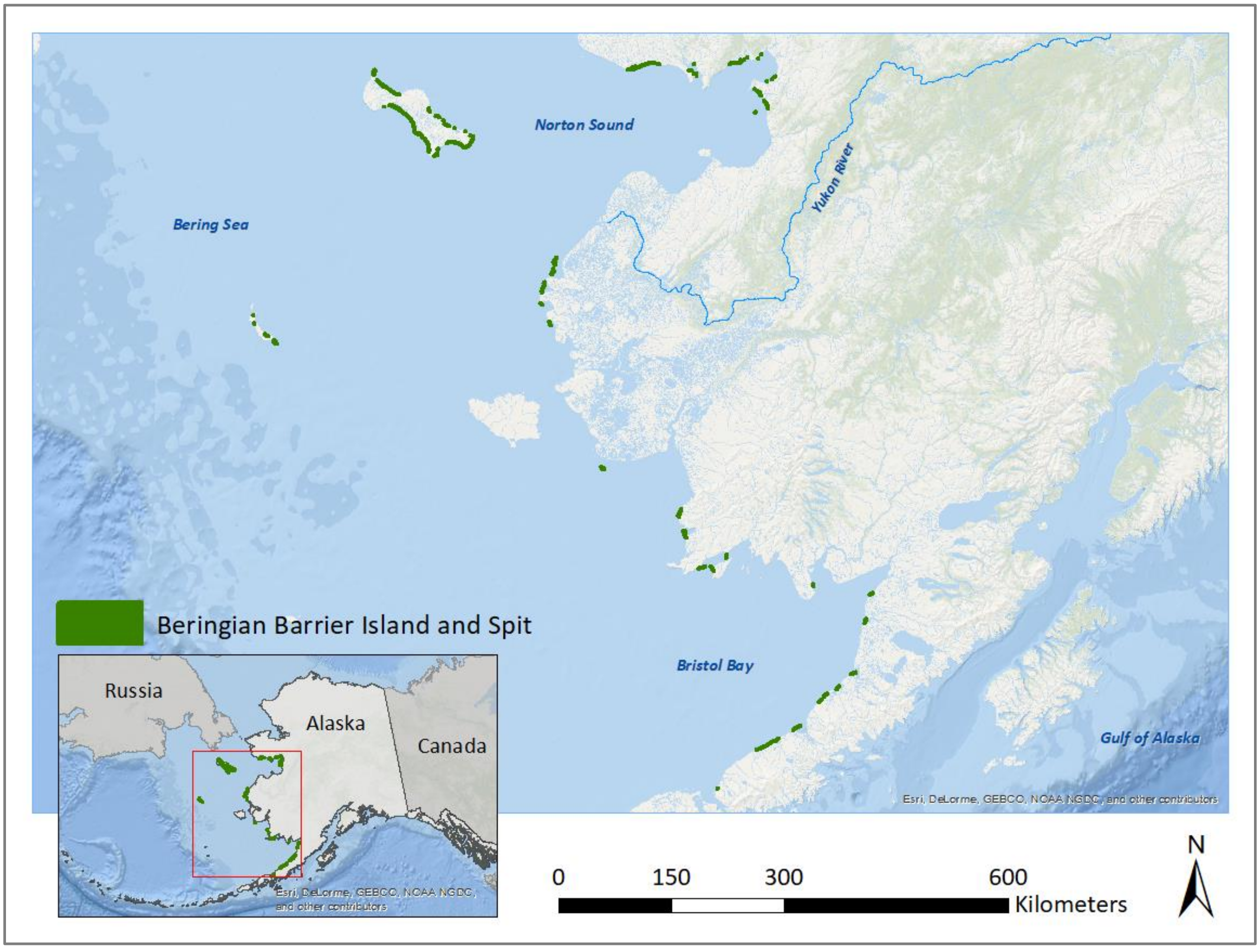

Figure 34. Distribution of the Beringian Barrier Island and Spit Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Environmental Characteristics

Barrier islands and spits are dynamic ecosystems that are driven by multiple processes. They are temporary in location and shape with their geomorphology controlled by the amount and type of sediment, the magnitude of natural processes and the stability of sea level (Dolan 1980). Most islands and spits fully enclose lagoons with only small tidal outlets. In western Alaska they range in length from less than 1 km to greater than 30 km long and up to more than 3 km wide (Figure 32). Along western Alaska's Bering Sea coast, sediment is sourced from eroding bluffs and coastline, major rivers, and the shallow continental shelf (Hopkins and Hartz 1978, Morack and Rogers 1981, Ritter 1986). Sediment is delivered by wind and waves and subsequently transported by continual longshore drift and episodic storm surges (Hopkins and Hartz 1978, Morack and Rogers 1981, Ritter 1986). Where waves land at angles oblique to the shore, sediment can be transported considerable distances by longshore currents; however storm events are principally responsible for the sculpting and migration of barrier island complexes (Dolan 1980). Storm surges frequently breach low-relief barrier islands and spits and transport material from the high-energy erosive environment on the windward side to the low-energy depositional environment on the leeward side. This forms a pattern of gravel beaches backed by sandy dunes that grade to fine-sand beaches and washover fans across the barrier island or spit.

Figure 35. The Nunathloogagamiutbingoi dunes form a series of spits on the south side of Nunivak Island, Bering Sea, Alaska.

The lagoons and estuaries that form between barrier islands and the mainland grade to tidal flats and marshes landward. The multiple, recurved spits attendant to most barrier islands and sections of the mainland coast may be deposited and shaped by single storm events that extend the terminus of an island past a previously-formed spit (Hopkins and Hartz 1978, Short 1979). These repeated cycles of erosion and deposition result in the migration of barrier islands and spits with little net loss of mass (Hopkins and Hartz 1978). Rafted ice may scour vegetated surfaces and dredge sediment shoreward across barrier islands and spits creating furrows tens of meters long and ridges up to a meter high (Hopkins and Hartz 1978, Martin et al. 2009).

On a broader scale, the formation of barrier islands and spits is promoted by rise in global sea level. Where the flooding of inland topography results in shallow embayments with local sediment source, the coastline may be straightened by barrier island construction (Gilbert 1885, Leontyev 1965). Many modern barrier island systems, including those in western Alaska, initially formed during sea level rise in the Holocene (7,000 - 5,000 ybp; Woodroffe 2003) at the end of which sea level approached its present day level. At Cape Krusenstern, a complex of over 150 barrier beach ridges, each marking a former coastline position and collectively representing a chronosequence of several thousand years have been delineated (Lawler et al. 2009). Here, relict vegetated ridges are separated by shallow backshore swales that may support ponds or remain dry much of the year. Farther inland, extensive lagoon systems supporting tidal marshes and mud flats may develop. or remain dry much of the year. Farther inland, extensive lagoon systems supporting tidal marshes and mud flats may develop.

Vegetation

While barrier islands and spits are largely devoid of vegetation, sparse cover may develop in protected dune areas that are older than 30 years (Hopkins and Hartz 1978, Short 1979). Pioneer species tolerant of salt and sand accumulation are the first to establish. The beachgrass, *Leymus mollis* and forb, *Lathyrus maritimus* are most common on topographic highs, with the succulent, halophytic forb, *Honckenya peploides* occurring on lower, often tidal substrates. Due to the challenges of germination posed by wind and desiccation in a dune environment, most species reproduce vegetatively and quickly develop to clonal stands (Carter 1988, Howard et al. 1977). On early seral sites the unstable soils are sandy, well drained and circumneutral with no organic horizon. While permafrost overlain by a deep active layer (>80 cm) is present on these early seral sites in northwestern Alaska, its presence is intermittent to the south and absent on dunes of Nunivak Island (Bos 1967, Jorgenson et al. 2004, Swanson et al. 1985).

Figure 36. An *Empetrum nigrum* dominated back dune east of Nome, Alaska.

More stable dunes may support monocultures of *Leymus mollis*, or a mixture of the grasses *Leymus mollis, Calamagrostis lapponica, Festuca rubra, Poa* spp., and the forbs *Achillea borealis, Artemisia arctica, Cnidium ajanense, Conioselinum benthami* and *Lathyrus maritimus* (Bos 1967, Jorgenson et al. 2004; Figure 35). Minor associates include *Artemisia tilesii, Chrysanthemum bipinnatum* and *Deschampsia caespitosa*.

Inactive older dunes support a mixture of a dwarf shrubs including *Arctostaphylos rubra, Betula nana,* and *Empetrum nigrum.* (Bos 1967, Jorgenson et al. 2004; Figure 36). Other vascular species may include

Chamerion latifolium, Lathyrus maritimus, Leymus mollis, Trisetum spp., and. *Salix ovalifolia.* Nonvascular species may include *Cladina arbuscula, Flavocetraria nivalis, Rhytidium rugosum, Stereocaulon* species and *Thamnolia vermicularis*. These late-seral soils are sandy with some organics, well-drained, circumneutral, with a thin surface organic layer (Jorgenson et al. 2004).

Conservation Status

Rarity: Barrier islands and spits are uncommon in southern Alaska, occupying a total area of 118 km^2.

Threats: The combined effects of rising sea level, declining sea ice, increasing summer ocean temperature and increasing storm power have dramatic effect on Alaska's northern and western coastlines (Jones et al. 2008, Ping et al. 2011, Forbes 2011). The ice-free season in the Bering Sea is projected to increase from its current average of five and a half months to about eight and a half months by the end of the century (Meehan et al. 2012, which will prolong the exposure of thawed beach sediments to erosive forces. Also, greater fetch across the Bering Sea is likely to increase wave and storm surge energy, which will accelerate the rate of barrier islands and spit migration. In addition to the effects of climate change, barrier islands and spits are threatened by human activity. Barrier islands and spits are heavily used corridors for travel during the summer by all-terrain vehicles (Lawler et al. 2009). The lagoons and islands also receive some fishing and hunting pressure, respectively.

Trend: In general, barrier islands represent dynamic habitats capable of repositioning, growing and shrinking in response to changing conditions. It is not known if the area of barrier islands and spits along Alaska's Bering seacoast are stable, increasing or decreasing (Macander et al. 2014).

Species of Conservation Concern

Wildlife: Barrier islands, spits and their associated dunes, swales, lagoons, estuaries and bays provide a wide variety of habitats. Some barrier islands and spits such as those near Nelson Lagoon are a stopover for hundreds of thousands of shorebirds including dunlins (*Calidris alpine,* Figure 37), western sandpipers (*Calidris mauri*), rock sandpipers (*Calidris ptilocnemis*), ruddy turnstones (*Arenaria interpres*) and black turnstones (*Arenaria melanocephala*). Barrier islands also support glaucous-winged gull (*Larus glaucescens*) colonies, and haulouts for harbor seals (*Phoca vitulina*). Some islands such as Walrus Island in Nelson Lagoon serve as molting locations for the Common Eider (*Somateria mollissima*); the Port Clarence spit area on the Seward Peninsula provides stopover habitat for the endangered Steller's Eider (*Polysticta stelleri*) during migration. Backdune swales (Figure 35) are especially important as breeding grounds for shorebirds and terns and also support populations of various microtine rodents, which are preyed upon by foxes and predatory birds such as short-eared owls and northern harriers (Lawler et al. 2009). Coastal dunes are a preferred habitat for muskox (*Ovibos moschatus*; Bos 1967; Figure 38).

The mammal, bird and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 20, Table 21). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Figure 37. Nelson Lagoon is a migration stopover for thousands of shorebirds, including dunlins pictured above.

Table 20. Mammals and bird species of conservation concern within the Beringian Barrier Island and Spit Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Pacific walrus	*Odobenus rosmarus*	G4	S3	Known to use barrier islands and spits as haulouts in the western ecoregion of Alaska.
Birds				
Aleutian Tern	*Sterna aleutica*	G4	S3B	Nests usually on sand spits, sandbar islands, sand dunes, and flat vegetated summits of more rugged islands; on low wet coastal marsh and tundra in some areas.
Bering Sea Rock Sandpiper	*Calidris ptilocnemis tschuktschorum*	GNR	S2N, S3B	Nests on tundra of Bering Sea islands. Likely winters along rocky coasts of Aleutian Islands.
Beringian Marbled Godwit	*Limosa fedoa beringiae*	G5T2T3	S2B	The entire breeding population is thought to move to intertidal and estuarine habitats of the Alaska Peninsula after breeding.
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Black scoters could use inshore marine habitat during nonbreeding seasons. Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
Bristle-thighed Curlew	*Numenius tahitiensis*	G2	S2B	Known to nest in the low mountainous regions of the Yukon-Kuskokwim delta. Tidal flats and beaches provide migration habitat.
Emperor Goose	*Chen canagica*	G3G4	S3S4	Nest on marshy edges of ponds, lakes, and potholes. Brood rearing areas include sloughs and rivers (with Carex rariflora) and tidal marshes.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
King Eider	*Somateria spectabilis*	G5	S3B,S3N	Known to nest in arctic coastal tundra. Nearshore marine waters provide wintering and migration habitat.
Osprey	*Pandion haliaetus*	G5	S3S4B	Ospreys are known to use mature spruce tree habitat along major river systems in Interior Alaska (Hughes 1990). Known to occur in the Bristol Bay region.
Peale's Peregrine Falcon	*Falco peregrinus pealei*	G4T3	S2	Utilizes coastal beaches, tidal flats, islands, marshes, estuaries, and lagoons. Nests primarily on ledges of vertical rocky cliffs in the vicinity of seabird colonies.
Rock Sandpiper	*Calidris ptilocnemis*	G5	S3N, S4B	Winters on rocky seacoasts, breakwaters, and mudflats. Nests in the open on the ground, prefers grassy or mossy tundra in coastal or montane areas (AOU 1983).
Spectacled Eider	*Somateria fischeri*	G2	S2B, S2N	Molting occurs in nearshore waters containing an abundance of mollusks.
Slaty-backed Gull	*Larus schistisagus*	G5	S2B	Uncommon to rare along coastal Alaska. Mostly found along rocky sea coasts. Nests on cliffs and rocky islands, occasionally on flat sandy shores with scattered bushes (AOU 1983).
Steller’s Eider	*Polysticta stelleri*	G3	S2B,S3N	During molting, utilize tidal flats and deeper bays. Winter habitat includes eelgrass, intertidal sand flats, and mudflats possibly foraging on invertebrates.
White Wagtail	*Motacilla alba*	G5	S3B	Usually found along the coast, this Eurasian species is suspected to use crevices near or on the ground, and grassy dune banks.
Whimbrel	*Numenius phaeopus*	G5	S3S4B	Feeds on sandy beaches and spits during breeding season. Nests in nearby dwarf shrub tundra.
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Arctic tundra areas near open water are used as summer breeding grounds. Likely uses nearshore marine habitat provided by barrier islands and spits during migration.

Figure 38. Muskox and ecologist on a coastal dune of Nunivak Island (photo by T. Bowman).

Table 21. Plant species of conservation concern within the Beringian Barrier Islands and Spit Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Koeleria asiatica	G4	S3	Amphiberingian species of sand dunes, river banks and bluffs.
Potentilla fragiformis	G4	S1S2	Gravel beaches, inner lagoons, and old beach ridges.
Ranunculus camissonis	GNR	S3	Alpine slopes, seepage slopes, rock outcrops, beach ridges, alluvial fans, wet meadows, frost boils.
Trisetum sibiricum var. *litorale*	G5T4Q	S3	Occurs in habitats such as river and stream banks, beach terraces, wet meadows, and brackish mires.

Plant Associations of Conservation Concern

Barrier islands and spits support a variety of plant associations; however, they are not listed here because they are common (G4-G5) in other biophysical settings.

Classification Concept Source

The classification concept for this biophysical setting is based on Bos (1967).

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Beringian Dwarf Shrub-Lichen Peatland Plateau Biophysical Setting

Beringian Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Peatland plateaus are landforms comprised of thick organic deposits that have been uplifted by permafrost aggradation and subsequently colonized by dwarf shrub and lichen species (Tande and Jennings 1986, Kincheloe and Stehn 1991, Babcock and Ely 1994, Collett 1991, Jorgenson 2000, Ducks Unlimited, Inc. 2011). In the more stable areas of the Yukon -Kuskokwim Delta, this unique biophysical setting develops when deep peat deposits insulate the underlying permafrost and thus facilitate its aggradation. The subsequent uplift slightly above the surface of basins and other wet environments improves drainage and facilitates the growth and eventual dominance of lichen and dwarf shrubs (Figure 39; Ducks Unlimited, Inc. 2011). Over time, this less-insulating vegetative cover allows the underlying permafrost to degrade, which initiates subsidence, and the eventual development of wetland habitat. The resultant mosaic of peatland plateaus, thaw-ponds and adjoining tidal marshes provides critical habitat for millions of migrating shorebirds, geese and swans. Due to their sensitivity to soil temperature and water levels, and their location in regions of discontinuous permafrost, peatland plateaus are thought to be highly susceptible to climate change.

Figure 39. Peatland plateaus mosaicked with thaw ponds on the Yukon-Kuskokwim Delta, Alaska.

Distribution

Dwarf shrub-lichen peatland plateaus are common on the Yukon-Kuskokwim Delta where they extend more than 160 km inland. This system is uncommon in the rest of Alaska. The distribution of these peatland plateaus was developed from the following landcover classes of the Alaska Vegetation Map: Dwarf Shrub, Dwarf Shrub-Lichen, Dwarf Shrub-Lichen-Sphagnum (Peatland Plateau) and Dwarf Shrub-Sphagnum (Peatland Plateau) (Boggs et al. 2015). To ensure that upland and alpine dwarf shrub tundra was not included in the distribution of this ecosystem, dwarf shrub classes that occurred above 30 m elevation were excluded from the geographical range of peatland plateaus (Figure 40).

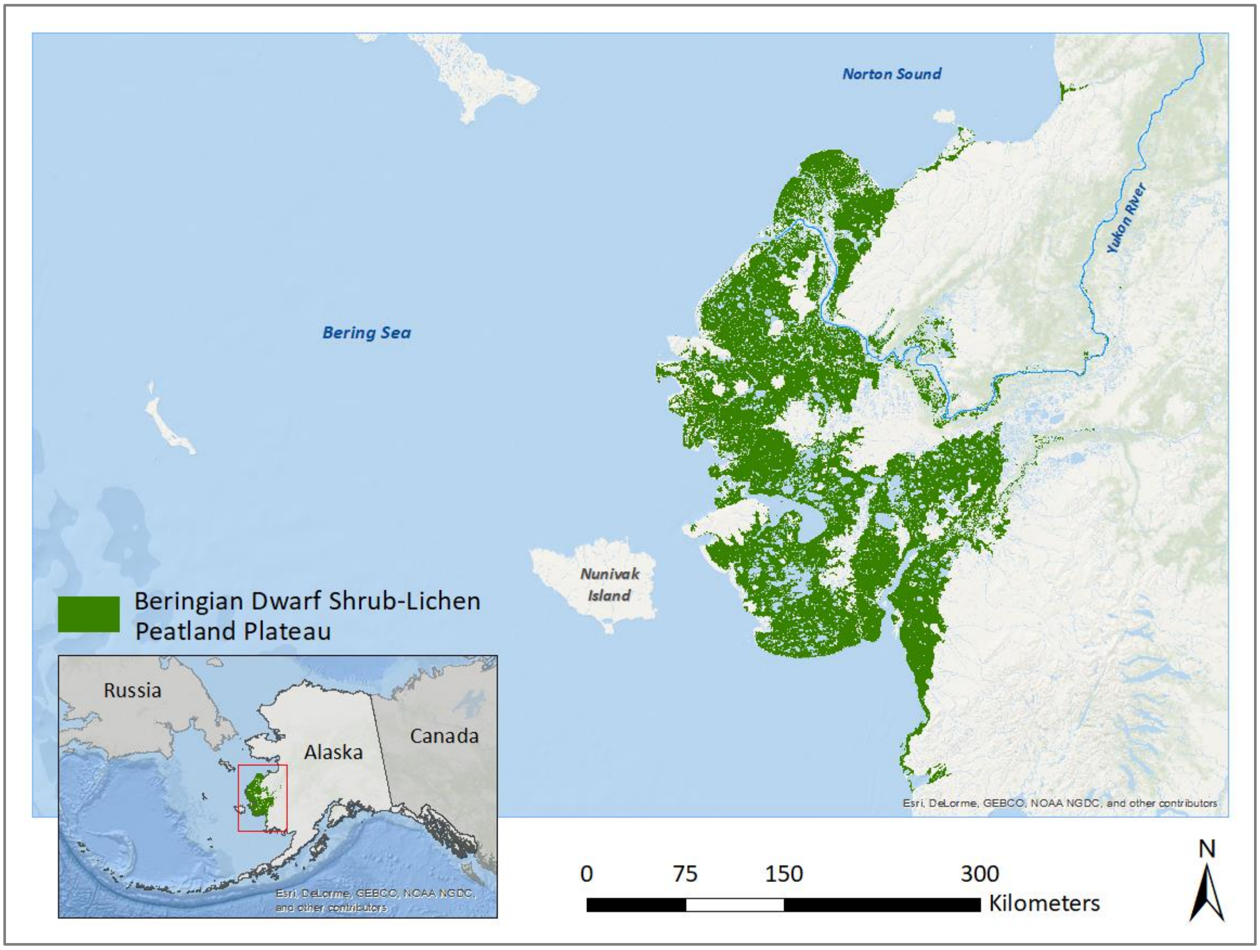

Figure 40. Distribution of the Beringian Dwarf Shrub-Lichen Peatland Plateau Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Climate in the Yukon-Kuskokwim Delta is transitional between maritime and continental conditions (Natural Resources Conservation Service 2004). In general, the southern delta has warmer temperatures and receives more precipitation than the northern delta. Average annual precipitation varies from 25 cm around Kotzebue Sound to 50 cm in the Yukon-Kuskokwim lowlands. Annual snowfall is approximately 100 cm in the north and ranges from 105 cm to 150 cm in the south. Winter temperatures range from average daily lows of -25 °C in the north and -20 °C to -15°C in the south, to average daily maximums of -16°C in the north and -10°C in the south. July and August are usually frost-free throughout most of the region. Average daily minimum temperatures in summer range from 6°C in the north to 8°C in the south. Average summer daily maximum temperatures range from 13°C to 17°C in both the north and south, generally increasing inland from the coast.

Environmental Characteristics

The Yukon and Kuskokwim Rivers have created one of the most expansive deltas in the world. Much of the delta is a flat wetland and tundra complex dotted with lakes and ponds, lakes intersecting with meandering rivers. Many streams and sloughs are former tributaries of the two major rivers. The relatively flat topography of the region extends tidal influence more than 32 km inland and allows for expansive spring floods. Within this terrestrial-aquatic complex, peatland plateaus are areas of thick organic peat (20-60 cm) that have been uplifted slightly above the surface of basins and other wet environments by permafrost aggradation (Tande and Jennings 1986, Kincheloe and Stehn 1991, Babcock and Ely 1994, Collett 1991, Jorgenson 2000, Ducks Unlimited, Inc. 2011). This uplift improves drainage and facilitates the growth and eventual dominance of lichen and dwarf shrubs. Peat typically overlies deltaic and abandoned floodplain deposits (Jorgenson 2000).

Vegetation and Succession

Several vegetation studies and maps describe vegetation and site conditions on the peatland plateaus of the Yukon-Kuskokwim Delta (Tande and Jennings 1986, Kincheloe and Stehn 1991, Babcock and Ely 1994, Collett 1991, Jorgenson 2000, Ducks Unlimited, Inc. 2011). Succession on peatland plateaus follows the thaw-pond cycle; however, succession is not necessarily unidirectional as described below, and other seral trajectories occur (Figure 41 and Figure 42).

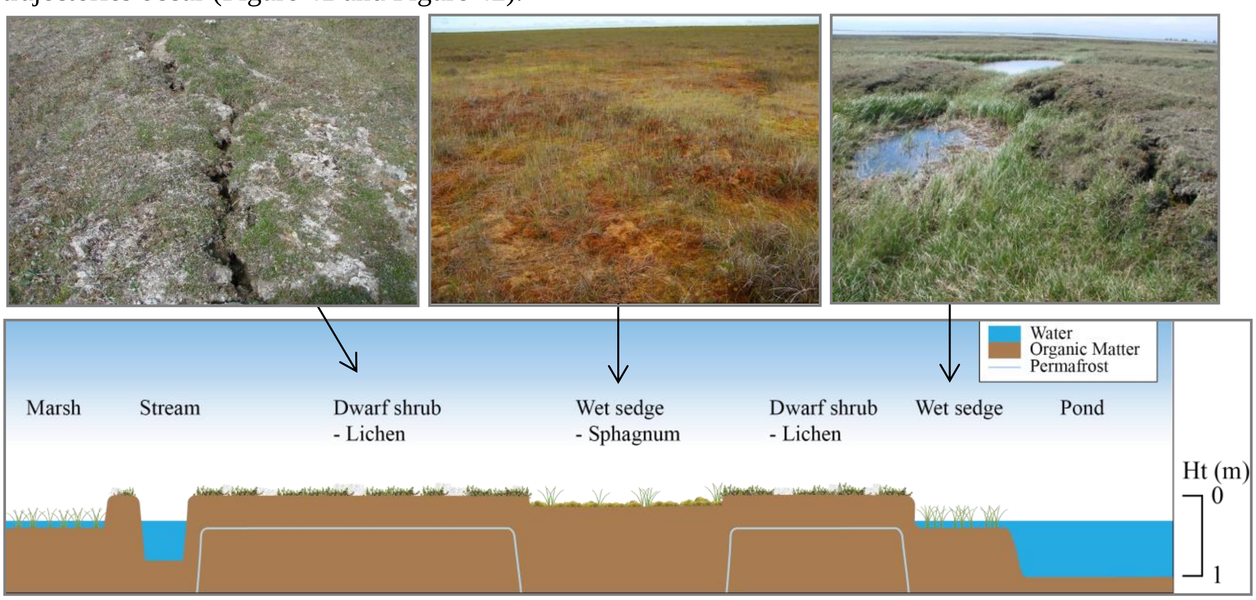

Figure 41. Schematic physiography and vegetation profile of a peatland plateau east of Scammon Bay, Alaska.

The thaw-pond cycle is initiated with the collapse of a plateau, resulting in a wet depression often filled with standing water. Marsh, wet sedge or wet sedge-*Sphagnum* associations develop in the wet depression or on the edge of newly formed lakes. Marshes are dominated by *Carex utriculata* and *Arctophila fulva* associations with subdominant *Comarum palustre, Menyanthes trifoliata, Equisetum fluviatile, Hippuris tetraphylla,* and *Sparganium hyperboreum*. Wet sedge meadows are dominated by *Carex aquatilis* with *C. rariflora, Eriophorum russeolum, E. angustifolium* and *Salix fuscescens* occurring as minor associates; moss comprises less than 50% of the total cover. The wet sedge-*Sphagnum* seral stage is dominated by *Sphagnum*, while herbaceous species may occupy >25% of ground cover. The dominant vascular species is typically *Carex aquatilis,* but other subordinate, codominant or dominant species may include *Comarum palustris, Carex rariflora, C. lyngbyei, Eriophorum* species, *Equisetum fluviatile, Menyanthes trifoliata, Salix fuscescens* and *Empetrum nigrum*.

Wet sedge-*Sphagnum* associations that are uplifted by permafrost aggradation or organic matter accumulation are colonized by dwarf shrubs. The dwarf shrub mid-seral stage has similar species composition as the late-seral dwarf shrub-lichen stage but with less than 20% lichen. It primarily occurs in areas too wet or moist to support lichen, such as periodically flooded floodplain basins, watertracks, snow accumulation areas and mounds or palsas. As the surface continues to lift above the wetter adjacent environments, lichen establish, and a dwarf shrub-lichen peatland plateau association eventually develops. These late-seral associations are characterized by codominance of the lichens *Cladina rangiferina* and other *Cladonia* species, as well as mosses of the genera *Dicranum* and *Sphagnum*, with the shrubs *Betula nana* and *Ledum palustre* ssp. *decumbens*. Other shrubs include *Arctostaphylos* species, *Chamaedaphne calyculata*, *Empetrum nigrum*, *Rubus chamaemorus*, *Salix pulchra*, *Spiraea stevenii*, *Vaccinium uliginosum* and *Vaccinium vitis-idaea*.

In areas of subsidence due to permafrost degradation or organic matter reduction, this successional trajectory is broadly reversed. The length of time required for a thaw pond to develop is not well known but may take hundreds of years. The rate of this succession is likely related to permafrost thickness, with successional change occurring rapidly in areas of discontinuous and thin permafrost and more slowly in areas of thick, continuous permafrost (Camill and Clark 1998, Camill 1999, Jorgenson 2000).

Conservation Status

Rarity: Dwarf shrub lichen peatland plateaus are a dominant biophysical setting on the Yukon-Kuskokwim Delta (total area 10,000 km^2) but are rare elsewhere in Alaska.

Threats: Climate change represents the greatest threat to peatland plateaus. Climate-induced increases in storm power and frequency as well as permafrost thaw is expected to further the inland extent of saltwater inundation and cause significant thermokarst in the ice-rich peat that supports these plateaus.

Trend: Both short- and long-term declines are predicted for this system. It is expected that thermokarst and saltwater flooding will lead to a significant reduction in the late-seral dwarf shrub-lichen stage. However, declines may be offset by increased productivity and organic matter accumulation in a warming climate.

Figure 42. Peatland plateaus on the Yukon-Kuskokwim Delta, Alaska.

Species of Conservation Concern

Concern for habitats worldwide in the context of a changing climate are heightened for coastal tundra ecosystems in Alaska owing to their biodiversity, high productivity and abundance of migrant bird populations that serve as important subsistence resources (Sedinger et al. 1994, Sedinger and Newbury 1998, Fienup-Riordan 1999, Jorgenson 2000). The wetland mosaics characteristic of the Yukon-Kuskokwim Delta supports one of the world's largest nesting aggregations of ducks, geese and other waterfowl and is considered one of the most important shorebird nesting areas in the United States in terms of both density and species diversity (Figure 43).

The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 22, Table 23). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 22. Mammal and bird species of conservation concern within the Beringian Dwarf Shrub-Lichen Peatland Plateau Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alaskan hare	*Lepus othus*	G3G4	S3S4	Habitat includes tundra, alluvial plains, coastal lowlands, alder thickets, sedge flats, wet meadows; open tundra, but use brush when available.
Birds				
Aleutian Tern	*Sterna aleutica*	G4	S3B	Nests usually on sand spits, sandbar islands, sand dunes, and flat vegetated summits of more rugged islands; on low wet coastal marsh and tundra in some areas.
Bar-tailed Godwit	*Limosa lapponica*	G5	S3B	Nests in sedge meadows and coastal tundra. Staging in nearshore estuarine areas and beaches.
Bering Sea Rock Sandpiper	*Calidris ptilocnemis tschuktschorum*	GNR	S2N, S3B	Breeds in coastal mountains and uplands in eastern Russian (Chukotka Peninsula) and western AK. (from n. Seward Peninsula south throughout Alaska Peninsula) (Gill et al. 2002).
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Black scoters could use inshore marine habitat during nonbreeding seasons. Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
Black Turnstone	*Arenaria melanocephala*	G5	S3N, S4B	Nonbreeding: rocky seacoasts and offshore islets, less frequently in seaweed on sandy beaches and tidal mudflats (AOU 1983). Nests mainly in salt-grass tundra; breeds along the coast or on offshore islands.
Bristle-thighed Curlew	*Numenius tahitiensis*	G2	S2B	Known to nest in the low mountainous regions of the Yukon-Kuskokwim delta. Tidal flats and beaches provide migration habitat.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Emperor Goose	*Chen canagica*	G3G4	S3S4	Nest on marshy edges of ponds, lakes, and potholes. Brood rearing areas include sloughs and rivers (with Carex rariflora) and tidal marshes.
Eurasian Wigeon	*Anas penelope*	G5	S3N	Winters primarily in freshwater (marshes, lakes) and brackish situations in coastal areas but migrates through inland regions. Rare in Southcoastal Alaska.
King Eider	*Somateria spectabilis*	G5	S3B,S3N	Known to nest in Arctic coastal tundra in northern Alaska and the Seward and Alaska Peninsulas. Nearshore marine waters provides wintering and migration habitat.
Rock Sandpiper	*Calidris ptilocnemis*	G5	S3N, S4B	Winters on rocky seacoasts, breakwaters, and mudflats. Nests in the open on the ground, prefers grassy or mossy tundra in coastal or montane areas (AOU 1983).
Slaty-backed Gull	*Larus schistisagus*	G5	S2B	Uncommon to rare along coastal Alaska. Mostly found along rocky sea coasts. Nests on cliffs and rocky islands, occasionally on flat sandy shores with scattered bushes (AOU 1983).
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Breeds in tundra from near treeline to the edge of polar seas.
Spectacled Eider	*Somateria fischeri*	G2	S2B	Molting occurs in nearshore waters containing an abundance of mollusks. Nests primarily in lowland wetlands on coastal tundra.

Table 23. Plant species of conservation concern with the Beringian Dwarf Shrub-Lichen Peatland Plateau Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Potamogeton subsibiricus	G3G4	S3S4	Found growing at or below the surface of wet meadow ponds.
Limosella aquatica	G5	S3	Grows along pond margins in wet mud.
Micranthes nudicaulis	G3G4Q	S3	Found in vicinity of snowmelt saturated tundra and wet meadows.

Figure 43. Emperor goose on the Yukon-Kuskokwim Delta (photo by T. Bowman).

Plant Associations of Conservation Concern

Peatland plateaus support a variety of plant associations; however, they are not listed here because they are common (G4-G5) in other biophysical settings.

Classification Concept Source

The classification concept for this biophysical setting is based on Tande and Jennings (1986).

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Beringian Tidal Marsh Biophysical Setting

Beringian Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Tidal marshes develop where relatively flat land receives periodic input of tidal waters (Frohne 1953). As an interface between the ocean and land, tidal marshes combine aquatic and terrestrial habitats, anoxic and oxic conditions, as well as saline and fresh waters (Stone 1984). This dynamic environment supports life highly-adapted to saturation and saline conditions. Tidal marshes along the Bering Sea coastline range from small marshes forming in protected topographic pockets of the harsh coast, to large lagoon systems forming behind barrier beaches, to extensive inland complexes lining the tidally-influenced waters of the Yukon-Kuskokwim Delta (Figure 44). Although tidal marshes only occupy a small percentage of the total landscape, the plant species they support are often obligate and they provide a critical staging area for migrating shorebirds, geese and swans, many of which are species of conservation concern. Tidal marshes in Beringian Alaska are described separately from those found along the Arctic Ocean coastline. Although both regions share an arctic climate and are underlain by permafrost, arctic tidal marshes support several species that are uncommon in western Alaska, including *Carex ursina*, *Dupontia fischeri*, *Puccinellia andersonii* and *Puccinellia arctica* (Bergman et al. 1977, Chapman 1960, Jefferies 1977, Taylor 1981). The dominant sedge in Beringian (and Cook Inlet) tidal marshes is generally *Carex ramenskii* (Batten et al. 1978).

Figure 44. Tidal marsh on the outer coast of the Yukon-Kuskokwim Delta, Alaska (photo by T. Boucher).

Distribution

Tidal marshes occur as a narrow band along the Bering Sea coastline (Figure 45). The Beringian Tidal Marsh distribution map was developed from select tidal marsh landcover classes of the Alaska Vegetation Map (Boggs et al. 2015).

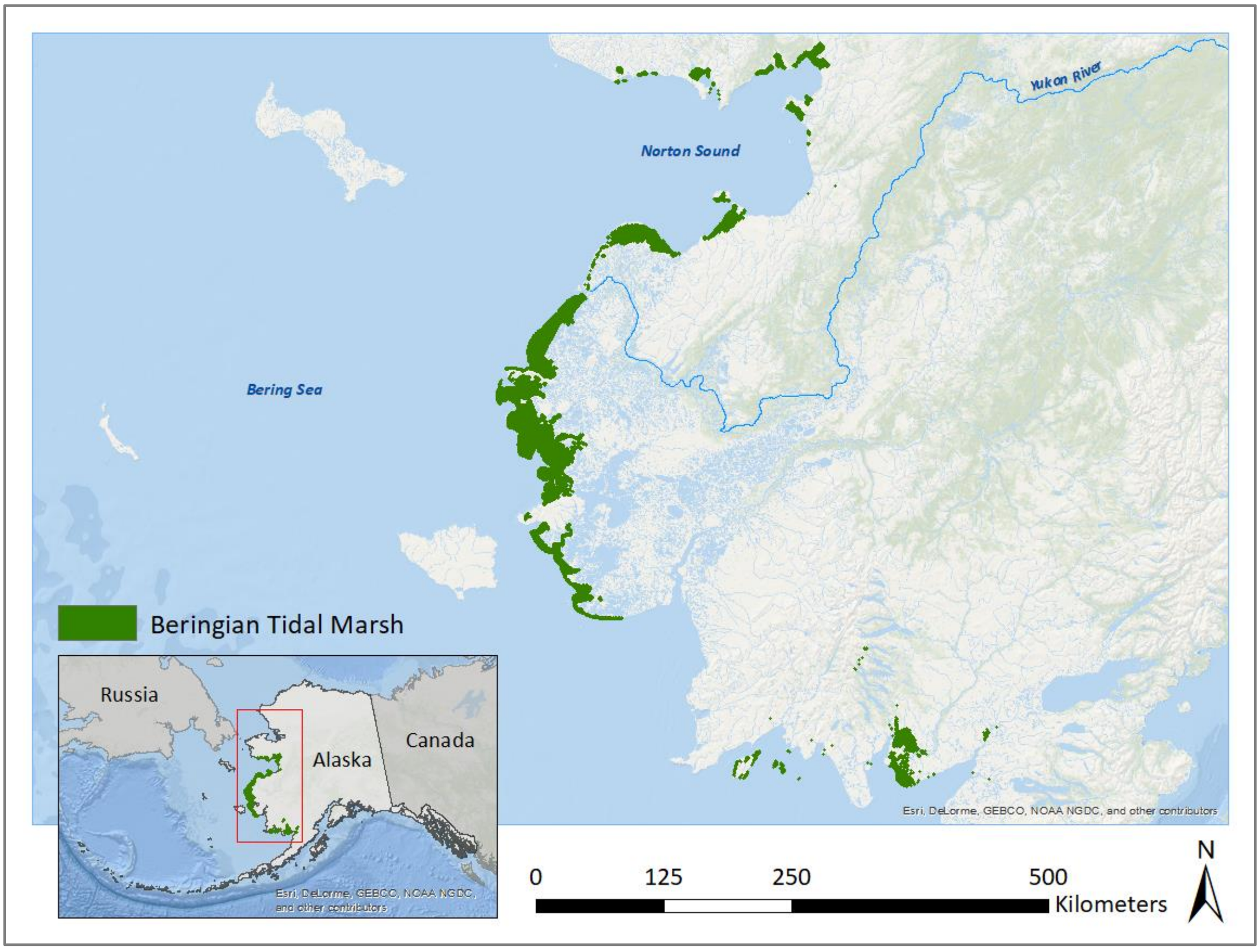

Figure 45. Distribution of the Beringian Tidal Marsh Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

In the western Alaska region, the climate is maritime near the coast to subarctic continental away from the coast and at the higher elevations (Natural Resources Conservation Service 2006). In the northern part of the region, the winter climate becomes more continental as the icepack forms in the Bering Sea. Summers are short and warm and cloudy along the coast, and winters are long and cold. The annual precipitation ranges from about 33 to 203 cm with the lowest precipitation in lowland areas and the Nulato Hills and the highest at the higher elevations of the Ahklun and Alaska Peninsula Mountains. The average annual temperature ranges from -4 to 2 ^{o}C Frost may occur in any month, strong winds are common, and snow covers the ground for approximately 7 to 9 months each year.

Environmental Characteristics

Tidal marshes occur wherever there is flat land at sea level (Frohne 1953); however, three elements are required for their formation: 1) the input of tidal waters that ranges from the twice daily inundation of mudflats to the occasional exposure of upper marsh habitats to storm surges; 2) sediment deposition from rivers depositing their sediment load on deltas, or sediment imported from adjacent coastlines via long-shore drift; there is commonly a concurrent organic matter buildup; and 3) protection from ocean wave and ocean-current erosion. This protection is critical for marsh development and is provided by topography (e.g. barrier islands, spits, peninsulas, shallow bays) or, at a smaller scale, by established vegetation which effectively slows the water current or wave energy (Chapman 1960).

The bathymetry is generally shallow in the Bering Sea on the adjacent upland terrain is often low angle (Lawler et al. 2009). On the Yukon-Kuskokwim Delta, which often rises less than 1 m over several kilometers (Kincheloe and Stehn 1991), tidally-influenced water can reach up to 55 km inland (Tande and Jennings 1986; Figure 46).

Coastal regions in arctic and subarctic Alaska are subject to flooding in the spring by meltwater and in the fall by storm surges (Bergman et al. 1977, Byrd and Ronsse 1983). River and sea ice may remain frozen from approximately October to June (Kincheloe and Stehn 1991). The seven to nine month ice cover limits fetch and wave size and thus decreases the wave erosion and sea ice scour through much of the year (Kincheloe and Stehn 1991). However, fall storms are capable of drastically reworking the coastal environment. A combination of wind, water and ice can cause erosion, redeposition and flooding. Ice blocks rafted by storm waves both scour the land and, on melting, deposit any ocean floor sediment that may have been incorporated to the block (Hanson 1951, Meyers 1985).

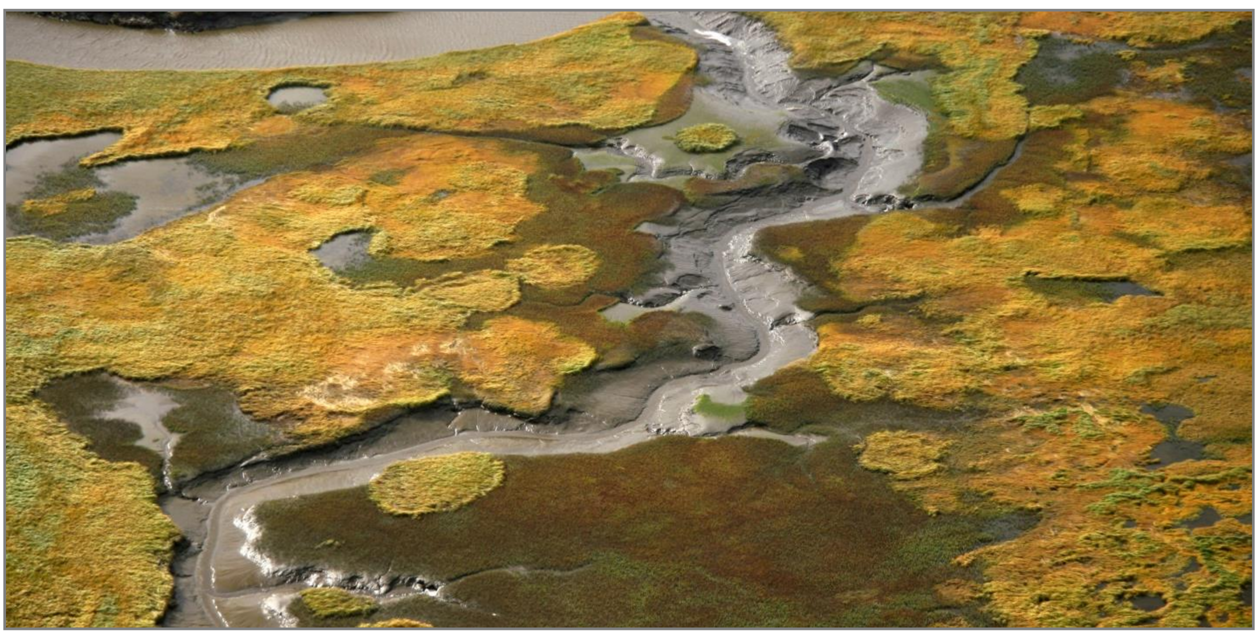

Figure 46. Inland tidal mudflats and meadows dominated by Puccinellia and Carex species on the Yukon-Kuskokwim Delta, Western Alaska (photo by T. Boucher).

Permafrost occurs within the top 1 m of the soil profile in tidal marshes on the Seward Peninsula (Jorgenson et al. 2004, 2009), and is encountered at a mean depth of 1.65 m in similar habitats on the Yukon-Kuskokwim Delta (Jorgenson 2000) but may be absent or discontinuous in the southern portion of its range. In all areas underlain by permafrost, the depth of thaw increases with proximity to water bodies due to the warming effects of water (Bergman et al. 1977, Hanson 1951, Kincheloe and Stehn 1991). Shallow permafrost also promotes the inundation of tidal marshes by restricting drainage (Bergman et al. 1977, Meyers 1985).

Vegetation Patterns and Floristics

The zonation of vegetation within tidal marshes is conspicuous both globally (Vince and Snow 1984) and in Alaska (Hanson 1951). Vegetation patterns are ultimately related to elevation in so far that it directs the frequency and duration of tidal inundation as well as soil salinity and drainage (Stephens and Billings 1967, Batten et al. 1978, Dupre 1980, Byrd and Ronsse 1983, Kincheloe and Stehn 1991, Viereck et al. 1992). Where shoreline topography rises uniformly from the water, elongated zones of tidal marsh vegetation are common (e.g. Cook Inlet Basin; Hanson 1951). However, where permafrost produces an intricate topography, tidal marsh vegetation is often mosaicked such as the Kotzebue vicinity and the Yukon-Kuskokwim Delta (Figure 44 and Figure 47; Hanson 1951, Kincheloe and Stehn 1991).

General patterns of vegetation are recognizable and predictable within Beringian tidal marshes. The lowest elevations are often barren mudflats to those sparsely vegetated by halophytic graminoids such as *Puccinellia phryganodes* and *Carex subspathacea* (Kincheloe and Stehn 1991, Jorgenson et al. 2004, 2009; Figure 46). These mudflats and sparsely vegetated sites also occur on the banks of tidal rivers, sloughs and margins of tidal ponds. The riverbanks and slough margins initially support *Puccinellia phryganodes* and *Carex subspathacea* that transitions upriver to *Arctophila fulva* and *Carex lyngbyei* as conditions become less saline (Kincheloe and Stehn 1991). Levees also support unique associations such as *Potentilla egedii-Leymus arenarius-Triglochin palustris-Stellaria humifusa* or *Festuca rubra-Ligusticum scoticum-Potentilla egedii-Calamagrostis deschampsioides-Salix ovalifolia* (Kincheloe and Stehn 1991, Jorgenson et al. 2009).

Moving inland from the coastline, extensive tidal meadows occur (Figure 47). As the elevation rises, the dominant associations gradually shift from *Carex ramenskii* or *Carex ramenskii-Dupontia fischeri*, to *Carex rariflora-Calamagrostis deschampsioides*, and eventually *Carex rariflora-Salix ovalifolia*-mosses or *Salix ovalifolia-Deschampsia caespitosa* (Kincheloe and Stehn 1991, Jorgenson et al. 2009). *Hippuris tetraphylla* or *Carex ramenskii* may dominate pond edges.

Figure 47. Coastal brackish meadows on the Yukon-Kuskokwim Delta (photo by T. Boucher).

On the Beaufort Sea Coast and in the Yukon-Kuskokwim Delta there is some evidence that the boundaries of the *Puccinellia phryganodes, Carex subspathacea* and *Carex ramenskii* communities are maintained in part by grazing geese such as black brant (Bergman et al. 1977, Kincheloe and Stehn 1991, Person and Ruess 2003).

Conservation Status

Rarity: Tidal marshes are widely distributed along Alaska's western coastline, but the fidelity of their component species and threats related to climate change makes this biophysical setting of one conservation concern.

Threats: The varied effects of climate change are responsible for extensive and increasing coastal erosion along Alaska's western coastline. Rising ocean temperatures diminish the thickness, extent and permanence of sea ice, which in turn increase storm power (due to greater fetch). This in combination with global sea level rise and more extreme weather events pushes saltwater farther inland, at a greater frequency. Inundation serves to thaw permafrost, which promotes subsidence and thermal and mechanical erosion of coastal habitats, particularly tidal marshes (Jones et al. 2008, Ping et al. 2011, Forbes 2011).

Trend: Loss of coastal habitat due to climate change is difficult to predict as projections must account for concurrent change in temperature, precipitation, permafrost and vegetation. The eustatic rate of sea level rise is 0.18 cm annually (Pendelton et al. 2006) and a rise in sea levels of 0.5 m is predicted for the Bering Sea by 2100 (Houghton et al. 1996). It is expected that the short- and long-term impacts of climate change-induced processes will be severe and extensive in coastal areas that are low-lying, permafrost-affected and characterized by microtidal regimes areas such as along Alaska's western coastline (Glick et al. 2010, Lawler et al. 2009).

Species of Conservation Concern

Although tidal marshes only occupy a small percentage of the total landscape, they are critical staging areas for migrating shorebirds, sea ducks, geese and swans. The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 24, Table 25). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 24. Mammal and bird species of conservation concern within the Beringian Tidal Marsh Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alaskan hare	*Lepus othus*	G3G4	S3S4	Habitat includes tundra, alluvial plains, coastal lowlands, alder thickets, sedge flats, wet meadows; open tundra, but use brush when available.
Birds				
Aleutian Tern	*Sterna aleutica*	G4	S3B	Nests usually on sand spits, sandbar islands, sand dunes, and flat vegetated summits of more rugged islands; on low wet coastal marsh and tundra in some areas.
Bar-tailed Godwit	*Limosa lapponica*	G5	S3B	Nests in sedge meadows and coastal tundra. Staging in nearshore estuarine areas and beaches.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Black scoters could use inshore marine habitat during nonbreeding seasons. Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
Black Turnstone	*Arenaria melanocephala*	G5	S3NS4B	Nonbreeding: rocky seacoasts and offshore islets, less frequently in seaweed on sandy beaches and tidal mudflats (AOU 1983). Nests mainly in salt-grass tundra; breeds along the coast or on offshore islands.
Bristle-thighed Curlew	*Numenius tahitiensis*	G2	S2B	Known to nest in the low mountainous regions of the Yukon-Kuskokwim delta. Tidal flats and beaches provide migration habitat.
Emperor Goose	*Chen canagica*	G3G4	S3S4	Nest on marshy edges of ponds, lakes, and potholes. Brood rearing areas include sloughs and rivers (with *Carex rariflora*) and tidal marshes.
King Eider	*Somateria spectabilis*	G5	S3B, S3N	Known to nest in arctic coastal tundra. Nearshore marine waters provides wintering and migration habitat.
McKay's Bunting	*Plectrophenax hyperboreus*	GU	S3	The McKay's bunting may use coastal habitat in the Bering Sea including tidal marshes during migration. This species is only known to breed on St. Matthews and Hall islands in rocky areas and beaches.
Osprey	*Pandion haliaetus*	G5	S3S4B	Ospreys are known to use mature spruce tree habitat along major river systems in Interior Alaska (Hughes 1990). Known to occur in the Bristol Bay region.
Rock Sandpiper	*Calidris ptilocnemis*	G5	S3N, S4B	Winters on rocky seacoasts, breakwaters, and mudflats. Nests in the open on the ground, prefers grassy or mossy tundra in coastal or montane areas (AOU 1983).
Sanderling	*Calidris alba*	G5	S2B	Breeds in small area of high arctic tundra on the Arctic Coastal Plain near Barrow. Likely uses tidal marshes for migration. Winters along tidal marshes.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Suspected to winter in open areas near shorelines. Breeds in tundra from near treeline to the edge of polar seas.
Spectacled Eider	*Somateria fischeri*	G2	S2B, S2N	Molting occurs in nearshore waters containing an abundance of mollusks.
Steller's Eider	*Polysticta stelleri*	G3	S2B, S3N	During molting, utilize tidal flats and deeper bays. Winter habitat includes eelgrass, intertidal sand flats, and mudflats possibly foraging on invertebrates.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Whimbrel	*Numenius phaeopus*	G5	S3S4B	Feeds on sandy beaches and spits during breeding season. Nests in nearby dwarf shrub tundra. Uses nearshore marine waters in Southcoastal Alaska during migration.
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Suspected to use nearshore protected seawater habitat for migration and molting. Nests on tundra near lakes and coastal areas.

Table 25. Plant species of conservation concern within the Beringian Tidal Marsh Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Eleocharis kamtschatica	G4	S2S3	Intertidal meadows.
Gentianopsis richardsonii	G3G5T3T5	S1	Estuary shores, beaches, coastal marshes. Known from a few seashore localities at Kotzebue Sound.
Plagiobothrys orientalis	G3G4	S3	Estuaries and lagoons at or above tidal zone, lake shores, river bars; also in disturbed sites such as airstrips and ATV tracks.
Puccinellia arctica	G4G5	S1	Grows along arctic seashores, with occurrences on the Seward Peninsula.
Puccinellia vaginata	G4	S1	Gravel beaches and edges of lagoons.
Puccinellia vahliana	G4	S3	Found in seepage meadows brackish creeks as well as other habitats.
Saxifraga rivularis ssp. *arctolitoralis*	G5T2T3	S2	Occurs in wet meadows near arctic seashores.
Zannichellia palustris	G5	S3	Brackish water.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 26).

Table 26. Plant associations of conservation concern within the Beringian Tidal Marsh Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Agropyron trachycaulum- Festuca rubra-Achillea borealis-Lathyrus palustris	G3	S3	Hanson 1951
Carex glareosa	G3	S3	Boggs 2000
Carex lyngbyei – Cicuta mackenziana	G3	S3	Crow 1968
Carex subspathacea	G3	S3	Hanson 1951
Carex subspathacea-Salix ovalifolia	G3	S3	Boggs et al. 2015
Cochlearia officinalis	G3	S3	Wiggins and Thomas 1962
Cochlearia officinalis- Achillea borealis	G3	S3	Byrd 1984
Cochlearia officinalis – Lathyrus maritimus	G3	S3	Bank 1951
Cochlearia officinalis – Phippsia algida-Stellaria humifusa	G3	S3	Webber 1978
Deschampsia caespitosa	G4	S3	DeVelice et al. 1999
Puccinellia borealis – Potentilla egedii	G4G5	S2	Hanson 1953
Puccinellia phryganodes	G3	S3	Jeffries 1977
Puccinellia phryganodes-Cochlearia officinalis	G3	S3	Thomas 1951

Name	Global Rank	State Rank	Concept Source
Salix arctica – Carex lyngbyei	G3	S3	Boggs 2000, DeVelice et al. 1999

Classification Concept Source

The classification concept for this biophysical setting is based on Hanson (1951).

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Luzula confusa-Poa arctica Plant Association

Northern Woodrush-Arctic Bluegrass Plant Association

Arctic Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Luzula confusa-Poa arctica* (northern woodrush-Arctic bluegrass) Plant Association is a graminoid-dominated type that occurs on acidic coastal tundra (Figure 48). It may represent the typical vegetation type in coastal habitats of northern Alaska, but it does not occur widely and is poorly characterized (Webber 1978). This type is distinguished from the *Luzula confusa-Sphaerophorus globosus* plant association by its greater abundance of graminoids, particularly rushes and grasses and it's somewhat moister, more organic-rich soils.

Distribution

This plant association is known from Barrow and is estimated to occur within only a small portion of the larger region. Due to its patchiness and small area of occupancy, this distribution of this association is difficult to map at the landscape scale. A preliminary distribution of this association was derived from herbarium records (40) and bioclimatic information. The distribution of the *Luzula confusa-Poa arctica* plant association (Figure 49) was developed from locations where both *Luzula confusa* and *Poa arctica* were collected (Consortium of Pacifc Northwest Herbaria 2016) within (or near) the wetland landcover class subunit "W.1" of Subzone C of the Arctic Alaska Tundra Vegetation Map (Raynolds et al. 2006).

Figure 48. The *Luzula confusa-Poa arctica* plant association on a high-centered polygon at Barrow, Alaska (photo by D.A. Walker).

Climate

In the northern Alaska region, the arctic climate is dry and cold, characterized by very short summers and long winters (Natural Resources Conservation Service 2006). The mean annual precipitation ranges from about 10 to 26 cm. Annual precipitation mostly falls as snow during the long winter season. The average annual temperature ranges from -13 to -6 ºC, and freezing temperatures can occur in any month. Summers are frequently foggy because of close proximity to the Arctic Ocean. June, July and August annually receive the highest average precipitation, with August receiving an average of 3.3 cm precipitation. The average annual temperature ranges from -13 to -6 ºC, and freezing temperatures can occur in any month. Summers are frequently foggy because of close proximity to the Arctic Ocean. The northern part of the Arctic Coastal Plain, is classified as bioclimatic Subzone C, which has a mean July temperature of 7ºC (Walker et al. 2005).

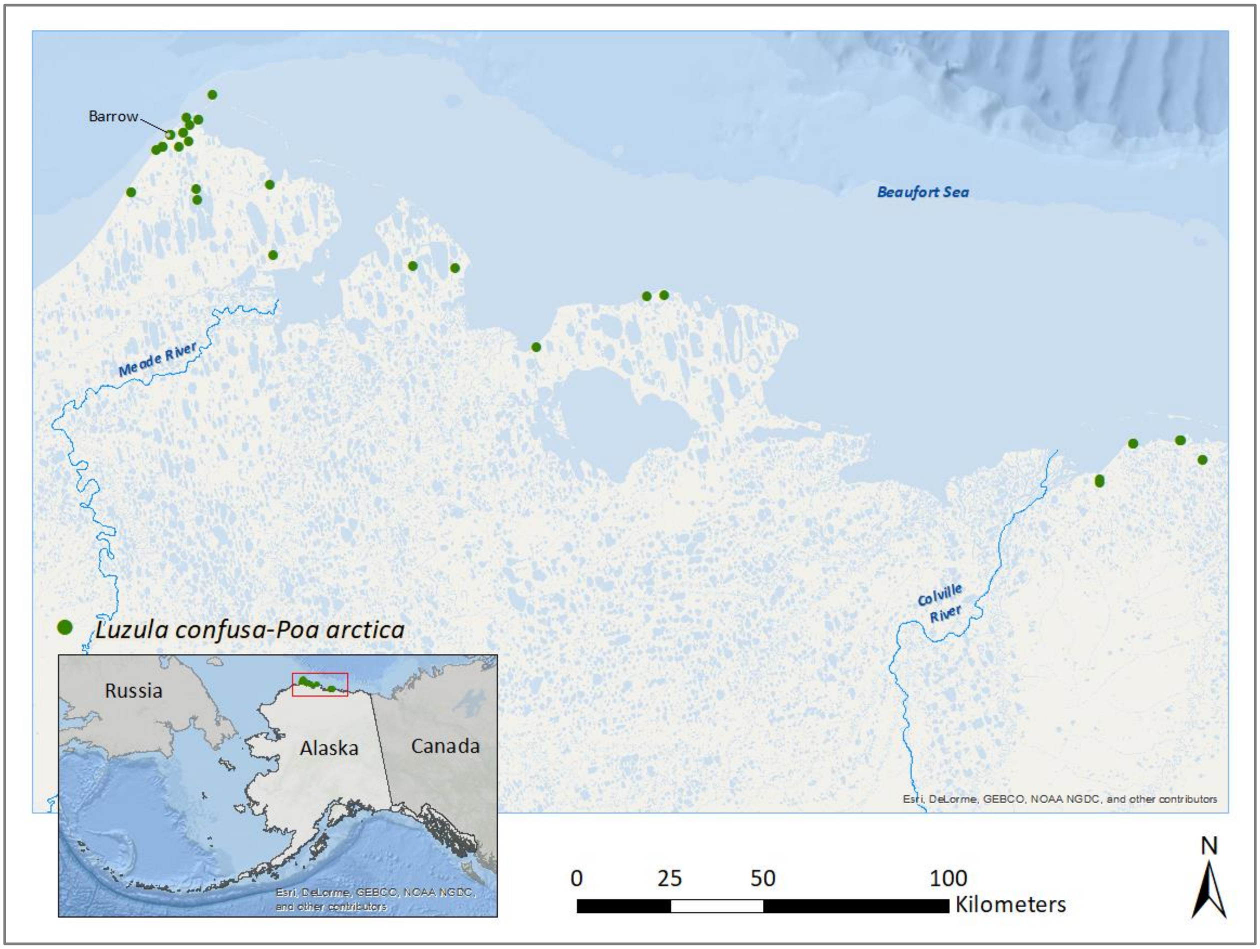

Figure 49. Distribution of Luzula confusa -Poa arctica Plant Association. Note that point occurrences in this map are buffered for greater visibility.

Environmental Characteristics

This plant association occurs on mesic, organic-rich acidic coastal tundra (Figure 48). Those associations with high cover of the crustose lichen *Ochrolechia frigida,* occur mainly on organic-rich, high-centered polygons, low-centered polygon rims, and other somewhat elevated microsites in ice wedge polygon complexes (Figure 51 and Figure 50). Sites may have a lumpy microtopography due to hummocks of the moss *Dicranum elongatum* covered by *Ochrolechia* species.

Vegetation

This plant association is characterized by an abundance of the rushes *Luzula confusa* and *L. arctica*, the grasses *Poa arctica*, *Dupontia fisheri* and *Anthoxanthum monticola* and lichens. Lichen species include *Sphaerophorus globosus*, *Dactylina arctica*, *Alectoria nigricans*, *Cladonia* species and locally abundant *Ochrolechia frigida* (Figure 51 and Figure 50). Bryophyte species include *Polytrichastrum alpinum*, *Dicranum elongatum*, *Polytrichum strictum* and *Sarmenthypnum sarmentosum.* At Prudhoe Bay and Barter Island this subtype is replaced by a similar community with abundant *Dryas integrifolia* and *Ochrolechia frigida*.

Conservation Status

Rarity: While multiple occurrences of this association are documented, they appear to be restricted to the high-arctic climate of the Barrow region.

Threats: Threats include climate change in so far that warming could thaw the presumably ice-rich soils that support this association and shift the bioclimate that typifies its range beyond the extent of land. Additional threats include anthropogenic disturbances such as village and oil and gas development as well as snow machine and all-terrain vehicle traffic.

Trend: Short-term declines related to coastal erosion and thermokarst are expected for this association. In the long-term, loss of habitat may be exacerbated by the northward shift of bioclimatic zones.

Figure 50. The *Luzula confusa-Poa arctica* Plant Association showing *Ochrolechia frigida* covering hummocks of the moss *Dicranum elongatum* (photo by D.A. Walker).

Species of Conservation Concern

The bird and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this plant association (Table 27, Table 28). More research is needed to better understand which mammals of conservation concern are supported by the *Luzula confusa – Poa arctica* plant association. Please visit the Alaska Center for Conservation Science webpage for species descriptions (ACCS 2016).

Figure 51. The *Luzula confusa-Poa arctica* Plant Association showing abundant *Ochrolechia frigida* on rims of low centered polygons (photo by D.A. Walker).

Classification Concept Source

The classification concept for this plant association is based on the dry *Luzula confusa* heath described by Webber (1978). The similar associations of *Luzula confusa, Alectoria nigricans, Polytrichum juniperinum* and *Sphaerophorus globosus-Luzula confusa,* subtype *Saxifraga foliolosa* are described by Walker (1977) and Elias et al. (1996), respectively.

Table 27. Bird species of conservation concern within the *Luzula confusa – Poa arctica* Plant Association.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Suspected to winter in open areas near shorelines. Breeds in tundra from near treeline to the edge of polar seas.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Smith's Longspur	*Calcarius pictus*	G5	S3S4B	Breeds in dry tundra and is known to nest in the Brooks Range foothills.

Table 28. Plant species of conservation concern within the *Luzula confusa-Poa arctica* Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Draba micropetala	GNR	S1S2	Creek and stream banks, beach ridges.
Draba pauciflora	G4	S2	Beach ridges, boulder slopes, high-center polygons, broad troughs, seepage slopes.
Draba subcapitata	G4	S1S2	Occurs in graminoid-herbaceous meadows and ericaceous heath of coastal bluffs, river bars, pingos, and hummocks.
Papaver gorodkovii	G3	S2S3	Associated with sparsely vegetated habitats on river floodplains, gravel bars, rock outcrops, and polygon tundra.
Ranunculus sabinei	G4	S1	Tundra slopes, hummocks, estuary banks; all occurrences near coast.
Saxifraga rivularis ssp. *arctolitoralis*	G5T2T3	S2	Occurs in wet meadows near arctic seashores.

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Luzula confusa-Sphaerophorus globosus Plant Association

Northern Woodrush-Globe Ball Lichen Plant Association

Arctic Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Luzula confusa-Sphaerophorus globosus* (northern woodrush-globe ball lichen) Plant Associationis a type codominated by rushes and lichens that also supports a high diversity of arctic plant species. It is common on dry to moist acidic sands and gravels of marine terraces at Barrow but appears to be uncommon elsewhere in Alaska (Webber 1978) (Figure 52). This type is distinguished from the *Luzula confusa-Poa arctica* plant association by its greater abundance of lichens and its somewhat drier, mineral soils.

Distribution

This plant association is described from the Barrow area where it is common along the well-drained, sloping creek banks and marine terraces of Footprint Creek and similar habitats. While it occupies 7% of the International Biological Program (IBP) study area, (Walker and Webber 1974) it is thought to cover only a small portion of the larger region. Due to its patchiness and small area of occupancy, the distribution of this association is difficult to map at the landscape scale. A preliminary distribution of this association was derived from herbarium records and bioclimatic information. Collection locations of either *Luzula confusa* or *Sphaerophorus globosus* (CPNW Herbaria 2016) were compared to remotely-sensed imagery to decide if the occurrence of the species was representative of the association. The intersection of these representative locations with Subzone C of the Circumpolar Arctic Vegetation Map (Raynolds et al. 2006) was used to develop the final distribution map (Figure 53).

Figure 52. The *Luzula confusa-Sphaerophorus globosus* Plant Association on a gravelly marine terrace at Barrow, Alaska (photo by D.A. Walker).

Climate

In the northern Alaska region, the arctic climate is dry and cold, characterized by very short summers and long winters (Natural Resources Conservation Service 2006). The mean annual precipitation ranges from about 10 to 26 cm. Annual precipitation mostly falls as snow during the long winter season. The average annual temperature ranges from -13 to -6 ^{o}C, and freezing temperatures can occur in any month. Summers are frequently foggy because of close proximity to the Arctic Ocean. June, July and August annually receive the highest average precipitation, with August receiving an average of 3.3 cm precipitation. The average annual temperature ranges from -13 to -6 ^{o}C, and freezing temperatures can occur in any month. Summers are frequently foggy because of close proximity to the Arctic Ocean. The northern part of the Arctic Coastal Plain, is classified as bioclimatic Subzone C, which has a mean July temperature of 7^{o}C (Walker et al. 2005), which limits the growth of shrubs hemiprostrate forms. (Raynolds et al. 2006).

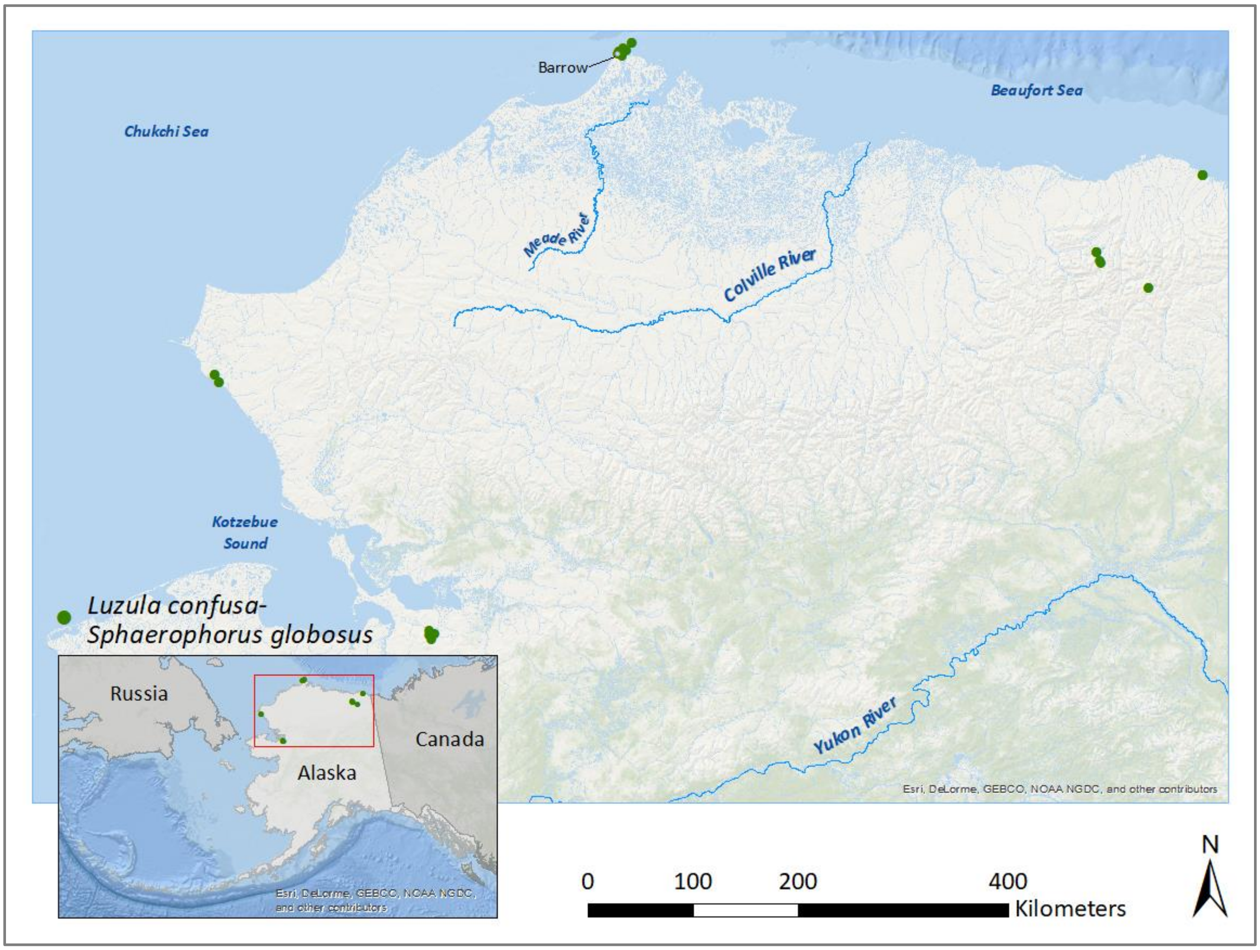

Figure 53. Distribution of the *Luzula confusa-Sphaerophorus globosus* Plant Association. Note that point occurrences in this map have been buffered for greater visibility.

Environmental Characteristics

This plant association occurs on dry, exposed sites typically along well-drained, sloping creek banks and marine terraces. Soils are acidic, gravelly or sandy coastal tundra.

Vegetation

This plant association has high cover of lichens and sparse vascular plant cover (Figure 54). Common lichens include *Alectoria nigricans, Sphaerophorus globosus, Bryocaulon divergens, Dactylina arctica, Cladonia, Cetraria* and *Ochrolechia* species as well as *Thamnolia vermicularis.* Vascular cover is characterized by high constancy of the rushes *Luzula confusa* and *L. arctica*, the grasses *Arctagrostis latifolia* and *Anthoxanthum monticola* and a diversity of forbs such as *Potentilla hyparctica, Pedicularis lanata, Saxifraga nelsoniana, Draba* species, *Eutrema edwardsii, Papaver macounii, Polygonum viviparum, Rumex arcticum* and *Senecio atropurpureus*. The dwarf shrub *Salix rotundifolia* is usually abundant (Figure 55). Bryophyte species include *Dicranum elongatum*, *Brachythecium* species, *Drepanocladus uncinatus*, *Gymnomitrion corallioides*, *Pogonatum alpinum* and *Polytrichum strictum*. The community has high richness ranging from 70 to 82 species (Webber 1978, Elias et al. 1996).

Figure 54. The *Luzula confusa-Sphaerophorus globosus* Plant Association showing the lichen covered surface and forbs, including *Papaver hultenii* and *Potentilla hyparctica* (photo by D.A. Walker).

Conservation Status

Rarity: The *Luzula confusa-Sphaerophorus globosus* association is common in the Barrow area and similar habitats elsewhere in northwestern Alaska; 29 possible occurrences have been documented.

Threats: Threats include climate change in so far that warming could thaw the presumably ice-rich soils that support this association. Additional threats include anthropogenic disturbances such as village and oil and gas development as well as snow machine and all-terrain vehicle traffic.

Trend: Short-and long-term declines related to thermokarst and coastal erosion (for nearshore locations) are expected for this association.

Figure 55. The *Luzula confusa-Sphaerophorus globosus* Plant Association showing the dwarf shrub, *Salix rotundifolia*, abundant lichens, the forb *Pedicularis lanata*, and graminoids Arctagrostis latifolia, and *Luzula confusa* (photo by D.A. Walker).

Species of Conservation Concern

The bird, mammal, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this plant association (Table 29, Table 30). Please visit the Alaska Center for Conservation Science webpage for species descriptions (ACCS 2016).

Table 29. Mammal and bird species of conservation concern within the *Luzula confusa – Sphaerophorus globosus* Plant Association.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Polar bear	*Ursus maritimus*	G3G4	S2	Polar bears are known to use inland habitat for denning. Coastal areas of this plant association likely provide seasonal habitat for polar bears.
Birds				
Bar-tailed Godwit	*Limosa lapponica*	G5	S3B	Nests in sedge meadows and coastal tundra. Staging in nearshore estuarine areas and beaches.
Buff-breasted Sandpiper	*Tryngites subruficollis*	G4	S2B	Nests on tundra. Rare Arctic coastal breeder.
Hudsonian Godwit	*Limosa haemastica*	G4	S2S3B	Nests on grassy tundra, near water – bogs, marshes, coastal or riverine areas. Nonbreeding habitat includes marshes, beaches, flooded fields, and tidal mudflats (AOU 1983); lake and pond shores, inlets.
King Eider	*Somateria spectabilis*	G5	S3B, S3N	Known to nest in arctic coastal tundra.
Red Knot	*Calidris canutus*	G5	S2S3B	Nests on ground of barren tundra and well vegetated moist tundra in Northwest Alaska including the Seward Peninsula and less commonly near Point Barrow.
Red-necked Stint	*Calidris ruficollis*	G5	S3B	Breeds on swampy or mossy tundra, especially with scattered willow scrub (AOU 1983).
Sanderling	*Calidris alba*	G5	S2B	Breeds in small area of high arctic tundra on the Arctic Coastal Plain near Barrow.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Breeds in tundra from near treeline to the edge of polar seas.
Spectacled Eider	*Somateria fischeri*	G2	S2B	Molting occurs in nearshore waters containing an abundance of mollusks. Nests primarily in lowland wetlands on coastal tundra.
Steller's Eider	*Polysticta stelleri*	G3	S2B, S3N	During molting, utilize tidal flats and deeper bays. Winter habitat includes eelgrass, intertidal sand flats, and mudflats possibly foraging on invertebrates.
Stilt Sandpiper	*Calidris himantopus*	G5	S3B	Breeding range from Canadian border to Barrow, Alaska along coastal plain at least several km inland. Suspected to use nearshore marine habitat for migration.
White-rumped Sandpiper	*Calidris fuscicollis*	G5	S3B	Grassy or mossy tundra, often not far from water; wet tundra, with nest sites on tops of hummocks.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Nearshore protected seawater habitat used for migration and molting. Nests on tundra near lakes and coastal areas.

Table 30. Plant species of conservation concern within the *Luzula confusa-Sphaerophorus globosus* Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Cardamine microphylla	G3G4	S2	Floodplains, stream banks, river bars, river terraces, bog shores, alpine slopes.
Draba micropetala	GNR	S1S2	Creek and stream banks, beach ridges.
Draba pauciflora	G4	S2	Beach ridges, boulder slopes, high-center polygons, broad troughs, seepage slopes.
Draba subcapitata	G4	S1S2	Occurs in graminoid-herbaceous meadows and ericaceous heath of coastal bluffs, river bars, pingos, and hummocks.
Papaver gorodkovii	G3	S2S3	Associated with sparsely vegetated habitats on river floodplains, gravel bars, volcanic scree, basalt bedrock and polygon tundra.
Ranunculus sabinei	G4	S1	Tundra slopes, hummocks, estuary banks; all occurrences near coast.
Saxifraga rivularis ssp. *arctolitoralis*	G5T2T3	S2	Occurs in wet meadows near arctic seashores.

Classification Concept Source

The classification concept for this plant association is based on the Mesic *Salix rotundifolia* heath described by Webber (1978). The similar associations of *Salix rotundifolia, Arctagrostis latifolia, Alectoria nigricans*, and the *Sphaerophorus globosus-Luzula confusa*, subtype *Salix rotundifolia* are described by Walker (1977) and Elias and others (1996), respectively.

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Papaver gorodkovii Volcanic Scree Plant Association

Arctic Poppy Volcanic Scree Plant Association

Beringian Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

The *Papaver gorodkovii* (Arctic poppy) Volcanic Scree plant association occurs on nearly barren volcanic scree slopes supporting a sparse vegetation cover dominated by the rare plant *Papaver gorodkovii* (Figure 56). As a species, *Papaver gorodkovii* is endemic to western and northern Alaska and eastern Siberia where it typically occurs on sparsely vegetated coastal back dunes, river gravel bars, and limestone talus (Nawrocki et al. 2013). Its occurrence on volcanic scree slopes has only been observed on Nunivak and St. Lawrence islands.

Figure 56. *Papaver gorodkovii* growing on volcanic scree, Nunivak Island, Bering Sea, Alaska.

Distribution

This association is documented from Nunivak and St. Lawrence islands only, but is suspected to occur on volcanic scree in western mainland Alaska. *Papaver gorodkovii* is a Beringian species endemic to coastal areas of western and northern Alaska, Wrangel Island in northeast Siberia, and has been reported but not confirmed from the Canadian Arctic Archipelago (Nawrocki et al. 2013). The distribution of this association was developed from the intersection of herbarium records (ACCS 2016) of *Papaver gorodkovii* with the 'young volcanic scree and shallow intrusive rocks' group of the Geologic Map of Alaska (Wilson et al. 2015) (Figure 57).

Climate

In western Alaska, the climate is maritime near the coast to subarctic continental away from the coast and at the higher elevations (NRCS 2004). In the northern part of the region, the winter climate becomes more continental as the icepack forms in the Bering Sea. Summers are short and warm and cloudy along the coast, and winters are long and cold. The annual precipitation ranges from about 33 to 203 cm with the lowest precipitation in lowland areas and the highest at the higher elevations of the Ahklun and Alaska Peninsula. The average annual temperature ranges from -4 to 2 ^{o}C. Frost may occur in any month, strong winds are common, and snow covers the ground for approximately 7 to 9 months each year. The climate of St. Lawrence Island is maritime arctic and much cooler than its modest latitude of 63 ^{o}N would suggest (Carlson et al. 2018).

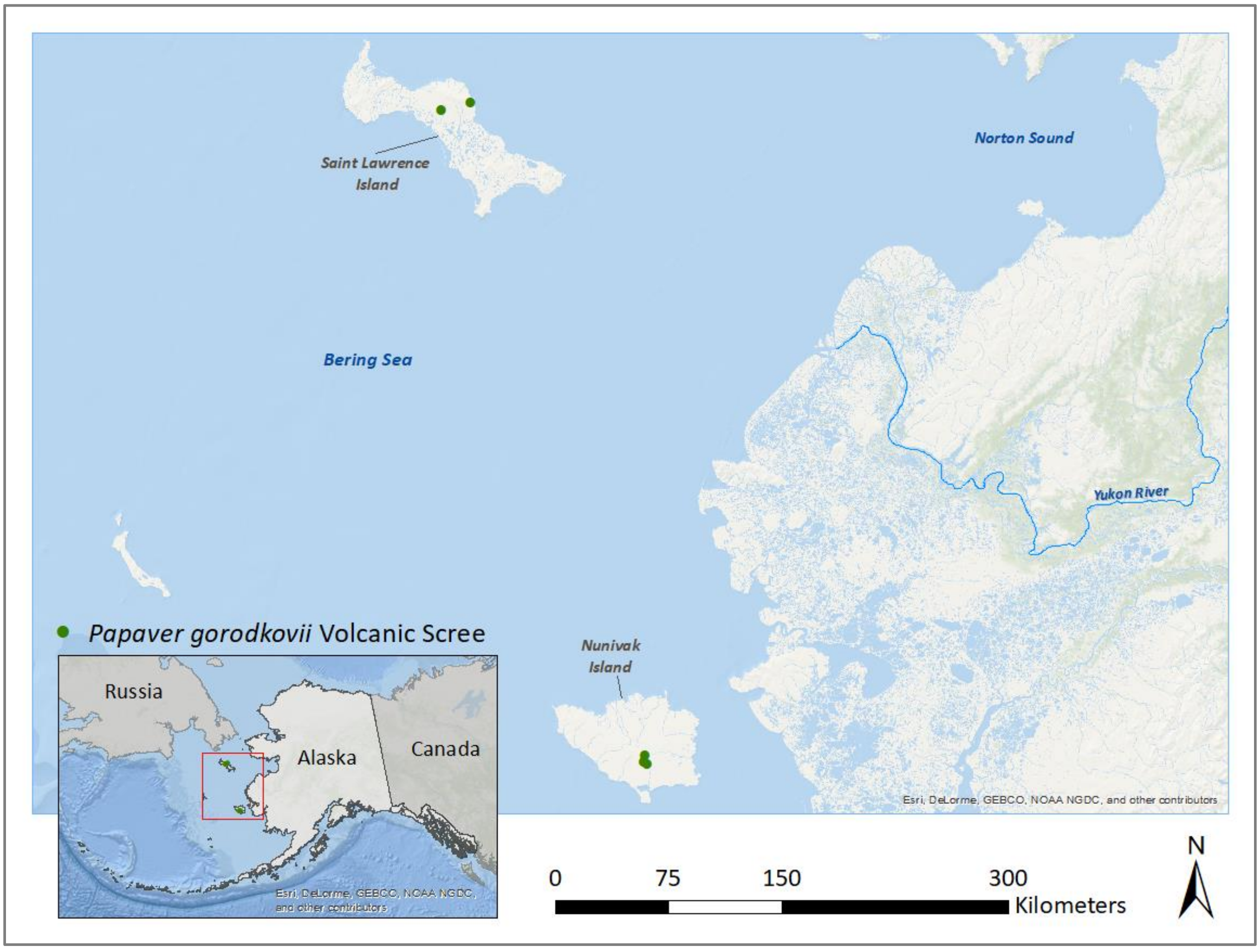

Figure 57. Distribution of the *Papaver gorodkovii* Volcanic Scree Plant Association on the Bering Sea Islands, Alaska. Note that point occurrences in this map are buffered for greater visibility.

Environmental Characteristics

This plant association occurs from 100 m to 500 m on moderate to steep (10 to 20 degree) volcanic scree slopes of the Nunivak and St. Lawrence Islands. Soils are mesic to dry and comprised of gravel or small volcanic rocks (lapilli) overlying fine-grained mineral soil. Biological crusts often develop on finer-grained surface soils.

The central part of St. Lawrence Island is dominated by the Kookooligit Mountains, a large Quaternary shield volcano with abundant, thin pahoehoe lava flows, smaller alkali basalt lava flows, cinder cones, and maars (Wood and Kienle 1990, Hoare et al. 1968). Volcanic deposits are underlain by Cretaceous sedimentary rock. On both Nunivak and St. Lawrence islands, this plant association occurs on eroding basalt bedrock slopes with fine, loose lapilli. In areas of basalt bedrock, *Papaver gorodkovii* occurs in patches of unstable gravel (Figure 58, Figure 59, Figure 60).

Figure 58. The rare plant *Papaver gorodkovii* (G3 S2S3) growing on weathered basalt, Nunivak Island, Alaska.

Vegetation and Succession

Papaver gorodkovii dominates this sparsely-vegetated type, minor associates include *Cassiope tetragona* ssp. *tetragona*, *Chamerion latifolium*, *Chrysosplenium wrightii*, *Corydalis arctica*, *Poa arctica*, *Poa pratensis* var. *colpodea*, *Ranunculus nivalis*, *Racomitrium* spp., *Salix ovalifolia* var. *glacialis*, and *Thamnolia vermicularis*. *Papaver gorodkovii* is a perennial forb that is presumably insect-pollinated, and likely to be long-lived based on extensive caudexes with persistent leaf bases.

No vegetation successional studies have been conducted. Based on observations, the *Papaver gorodkovii* plant association is an early seral colonizer of active volcanic scree surfaces (Bos 1967). Primary succession on volcanic surfaces may be limited by direct climatic effects rather than by nutrients (del Moral and Wood 1993).

Conservation Status

Rarity: The *Papaver gorodkovii* volcanic scree plant association is known from only five locations on volcanic cones of Nunivak Island (Figure 59) and St. Lawrence Island. Further survey is needed to determine if it occurs elsewhere in Western Alaska. A few herbarium records of *Papaver gorodkovii* occur

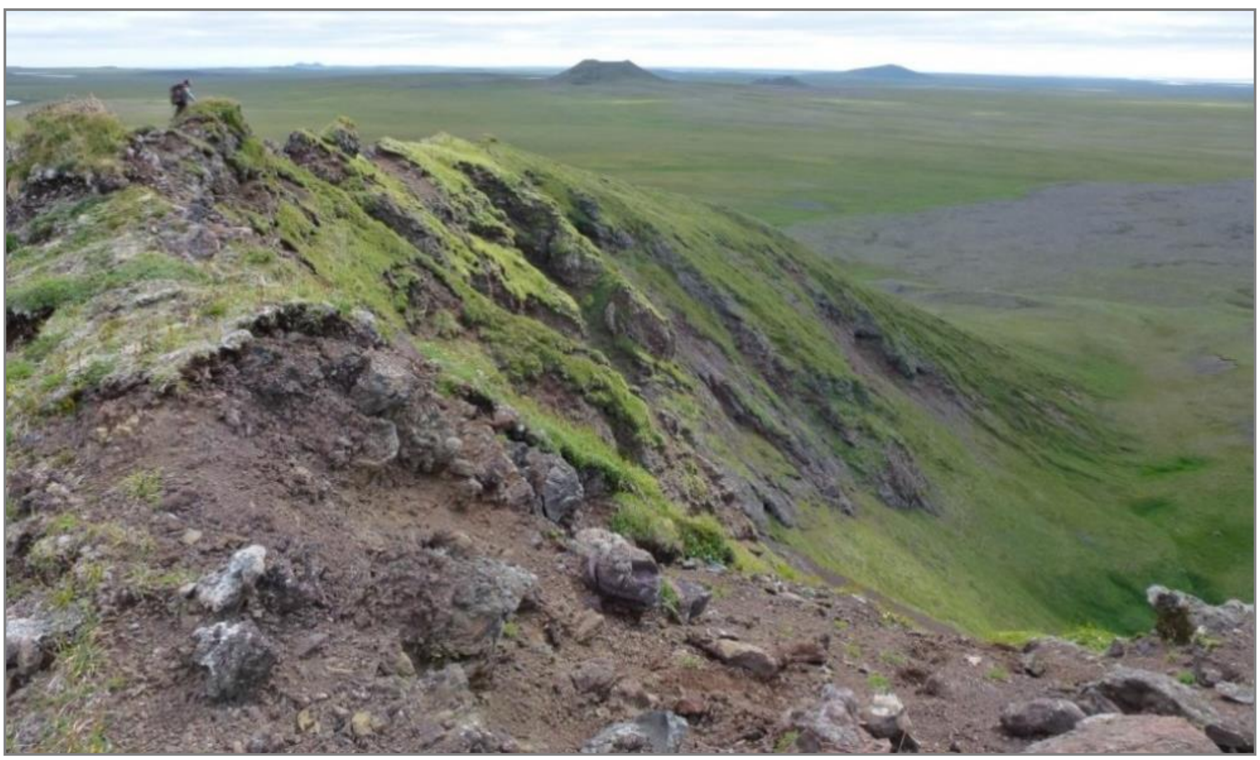

Figure 59. View from an alkali basalt cone on Nunivak Island, Alaska.

in the Northern Alaska ecoregion including records from Point Barrow, Prudhoe Bay, Canning River vicinity, Point Hope, and Cape Lisburne (CPNWH 2017).

Threats: While no nonnative plants are known from regions around this plant association, establishment of invasive species could pose a threat. Remote areas of other islands in Alaska (e.g. Camp Island on Kodiak) have been invaded by invasive species, such as orange hawkweed (AKEPIC 2016). Additionally, the rapidly changing climate poses a potential threat to the persistence of the species composing this plant association, tracking suitable climate envelopes for insular species is particularly problematic (Carlson and Cortes-Burns 2013).

Trend: The extent and condition of this association is not expected to change in the short- or long-term

Species of Conservation Concern

Papaver gorodkovii is the only plant species of concern so far identified in this plant association. This plant is considered globally vulnerable (ranked G3, S2S3) as there are only 20 known locations in eastern Russia and northern Alaska. It is also considered a sensitive species requiring special management consideration to promote its conservation by the BLM in Alaska. Please visit the Alaska Center for Conservation Science website for a full species description (ACCS 2016). The bird species listed below is designated vulnerable within Alaska (S1-S3) and is suspected to occur in this plant association (Table 31). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

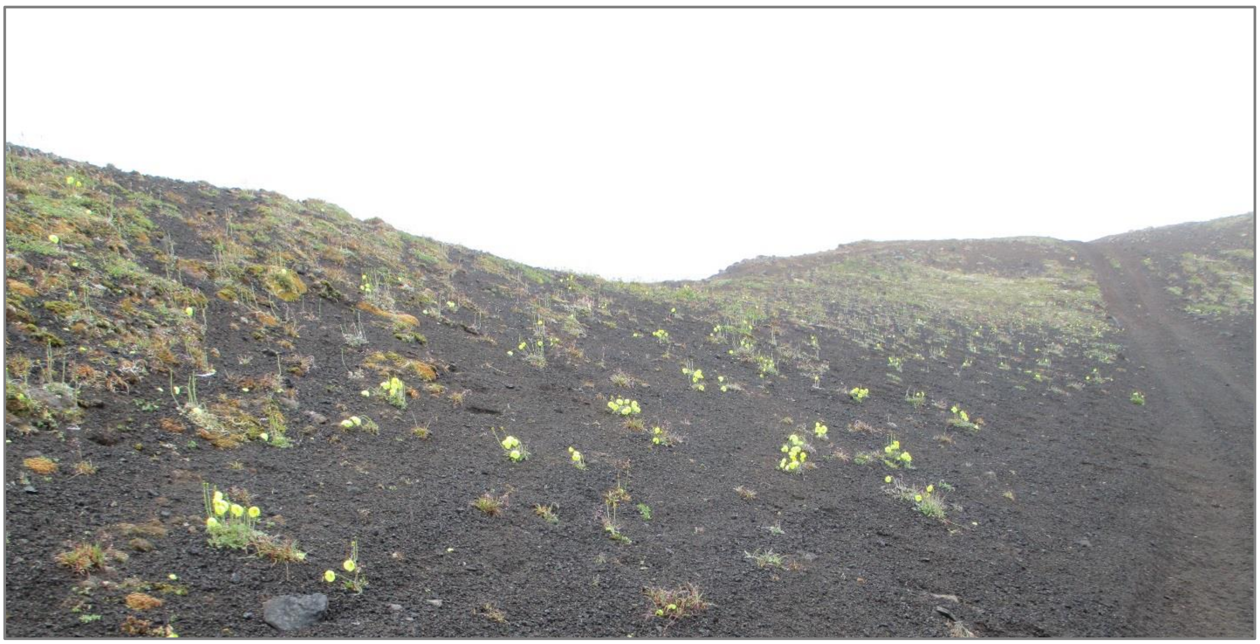

Figure 60. The *Papaver gorodkovii* Plant Association on weathered basalt, St. Lawrence Island.

Table 31. Bird species of conservation concern within the *Papaver gorodkovii* Plant Association.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Birds				
McKay's Bunting	*Plectrophenax hyperboreus*	GU	S3	May use coastal habitat in the Bering Sea including Nunivak Island during migration. This species is only known to breed on St. Matthews and Hall islands in rocky areas and beaches but could also use rocky areas and crevices within this plant association on Nunivak Island.

Classification Concept Source

This publication represents the first description of the *Papaver gorodkovii* volcanic scree plant association.

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Artemisia alaskana – Dianthus repens Gravel Bar Plant Association

Boreal Alaska

Conservation Status Rank: S2 (apparently secure)

Introduction

The *Artemisia alaskana – Dianthus repens* (Alaska wormwood - boreal carnation) Gravel Bar Plant Association is an herbaceous-moss community occurring on well-drained substrates derived from ultramafic parent materials (Figure 61). This association has been formally described from two river bars in subarctic, continental Alaska (Lipkin 2007). The unusual cooccurrence of its dominant species, *Artemisia alaskana* and *Dianthus repens* have not been documented on similar landforms elsewhere in Alaska.

Figure 61. The *Artemisia alaskana – Dianthus repens* Gravel Bar Plant Association along the Kanuti Kilolitna River in Kanuti National Wildlife Refuge, Alaska.

Distribution

The *Artemisia alaskana – Dianthus repens* Gravel Bar Plant Association has been described from two locations in Kanuti National Wildlife Refuge, Alaska (Lipkin 2007). Both sites are located on the Kanuti Kilolitna River, between its confluence with the Kanuti River to the north and the Ray Mountains at the southern boundary of the refuge (Figure 62). While additional occurrences of the *Artemisia alaskana – Dianthus repens* association have not been confirmed, Lipkin (2007) states that similar habitat, along the same stretch of the Kanuti Kilolitna River is evident in remotely-sensed imagery. Based on this suggestion, areas of potential occupancy were hand delineated along the Kanuti Kilolitna River on remotely-sensed imagery.

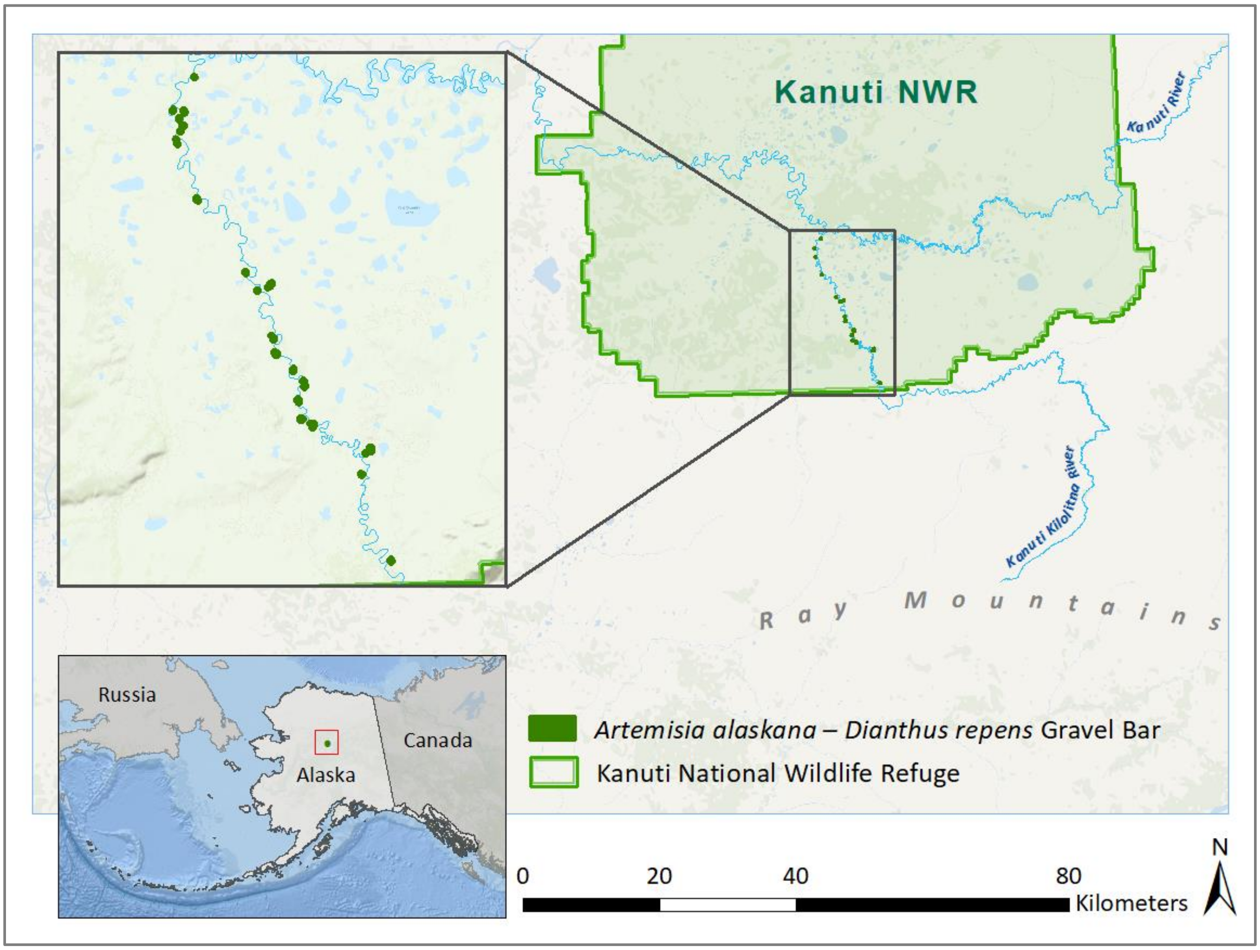

Figure 62. Distribution of the *Artemisia alaskana – Dianthus repens* Gravel Bar Plant Association. Note that areas of occupancy in this map are buffered for greater visibility.

Hand delineation targeted flat terrain located in the inactive floodplain with relatively continuous, low-stature vegetation. Vegetation with a blue-green signature in true-color imagery, typical of the Artemisia genus, was prioritized with care taken to exclude floodplain willow thickets and spruce lichen woodland, both of which can also appear blue-green in imagery. Areas of potential occurrence became less common downstream as distance from ultramafic outcrops increased and the river became more channelized.

Cooccurrence of the dominant species, *Artemisia alaskana and Dianthus repens* is documented by herbarium specimens collected above the headwaters of the Alatna River in the Brooks Range (Murray 1973a, b, c). Plants were collected from steep, high-elevation, south- and east-facing slopes or cliff edges and have little topographic affinity to the gravel bar association described here.

Climate

Short, warm summers and long, cold winters characterize the subarctic continental interior of Alaska where this plant association occurs. Climate data for Bettles, Alaska located approximately 35 miles north of the northern border of Kanuti National Wildlife Refuge show July average minimum and maximum temperatures to be 9.8 ºC and 21 ºC. January average temperatures reach a low of -27 ºC and high of -19 ºC. Average annual temperature is -4.75 ºC and precipitation is moderate with an average annual rain and snowfall of 21 cm and 2.1 m, respectively (NCDC 2012). The average frost-free period is 60 to 100 days with the temperature remaining above freezing from June through mid-September (NRCS 2004).

Environmental Characteristics

This association occurs on gravel bars along older river channels that are located back from active point bars, but remain subject to seasonal flooding. Both sites sampled were unburned and moist, despite proximity of the 2005 Old Dummy Fire (Lipkin 2007). Similar to all floodplain systems, terraces become progressively drier with increasing vertical and horizontal distance from the active channels.

Soils supporting the *Artemisia alaskana - Dianthus repens* association have not been described, however they are thought to be derived in part, from upgradient ultramafic deposits. Broadly, ultramafic rocks are low in silica and high in magnesium and iron. They occur in igneous form as peridotite and dunite, or as the metamorphic derivative, serpentinite (Kruckeberg 1967). The Kanuti ultramafic complex is exposed along more than 125 km of the Kanuti River drainage and at the southern edge of the Kanuti National Wildlife Refuge and is comprised of unaltered peridotite and dunite as well as serpentine derivatives (Patton et al. 1989, Lipkin 2007, Wilson et al. 2015).

Soils derived from ultramafic parent materials are generally basic (average pH of 6.1) with an availability of nutrients (Fe, Mg, Cr, Ni, Mn, and Co) that is different from soils derived from calcareous or siliceous rock types (Bockheim 2014). Due to frequent alluvial disturbance, soils in the active floodplain show little development and are often classified as inceptisols or entisols whereas older sites may support spodisols. (Martin et al. 1995).

Vegetation and Succession

This herbaceous-moss community is dominated by the forbs *Artemisia alaskana* and *Dianthus repens* and the grasses *Bromopsis pumpellianus* and *Calamagrostis purpurascens* and includes a very high cover of bryophytes. *Artemisia alaskana* is the dominant vascular plant with foliar cover exceeding 25%. *Dianthus repens* and *Lupinus arcticus* are frequent to abundant forbs, and *Bromopsis pumpellianus*, *Calamagrostis purpurascens*, *Festuca richardsonii*, *Poa glauca*, and species of *Elymus* are the most common grasses. While the taxonomic identities of component bryophytes have not been documented, we suspect early-seral types such as *Ceratodon purpureus*, *Dicranella crispa*, and *Polytrichum juniperinum* are well-represented.

Both *Dianthus repens* and *Festuca saximontana*, which was collected on one of the two gravel bar sites, represent disjunct populations. Globally, *Dianthus repens* has a Beringian distribution ranging from north-central Siberia east to the Alaska-Yukon border. In North America, it ranges from Cape Thompson, Alaska, in the northwest to the Richardson Mountains in northern Yukon and through interior Alaska south to Kachemak Bay (Lipkin 2007). The *Festuca saximontana* collection discussed here represents a range extension of over 200 km to the northwest from the nearest sites in the Tanana Valley. Disjunct occurrences have also been documented north to Toolik Lake and west to Kotzebue (Lipkin 2007).

Although *Artemisia alaskana* occurs as a minor element on some gravel bars in interior and northern Alaska, rarely is it the dominant member of the community, particularly in combination with *Dianthus repens* and *Calamagrostis purpurascens*. As such, the *Artemisia alaskana – Dianthus repens* association may represent a variant of either the open low scrub Sagebrush-Grass community, which includes steppic associations characterized by bunch grasses in the *Bromopsis* genus and *Calamagrostis purpurascens*, and one or more species of *Artemisia,* or the dry graminoid herbaceous Midgrass-Shrub community (types II.C.2.n and III.A.1.c, respectively) proposed by Viereck and others (1992). However, the association described here differs from these previously-described types in being located on a gravel bar rather than a steep, south-facing bluff and in having a high percentage cover of moss, the unusual combination of *Artemisia alaskana* and *Dianthus repens* as dominant species, and less than 25% shrub cover, (Lipkin 2007).

The *Artemisia alaskana* - *Dianthus repens* Gravel Bar Plant Association appears to be an early-seral type developing after the colonization of alluvium by bryophytes. The lush growth of mosses characteristic of this association is thought to produce a humic layer that facilitates the establishment of herbaceous and ultimately, woody species. While the successional status of the *Artemisia alaskana* - *Dianthus repens* association has not been specifically addressed, floodplain succession in interior Alaska is well-documented (Boggs and Sturdy 2005, Van Cleve et al. 1993, Viereck 1970, Walker et al. 1986, Yarie 1983). Primary succession along the meandering rivers that are so typical of this region begins with the deposition of alluvium deposited on the inner, point bank the river channel (Leopold et al. 1964). Among other pioneers, light-seeded herbs and shrubs in the *Salix* (willow) genus are well-represented on these newly-created substrates (Viereck 1970). Under conditions of low sedimentation, and good soil aeration, *Alnus incana* ssp. *tenuifolia* may be an important pioneer shrub. Within five years, willow and *Populus balsamifera* (balsam poplar) seedlings are abundant. During this stage, *Alnus incana* ssp. *tenuifolia* (thinleaf alder) and *Picea glauca* (white spruce) seedlings are often present in lesser abundance. Within 10 to 15 years, the *Populus balsamifera* saplings overtop the *Salix* species, which are gradually replaced by *Rosa acicularis* (prickly rose) and *Viburnum edule* (highbush cranberry) shrubs in the understory. (Walker et al. 1986, Boggs and Sturdy 2005).

Conservation Status

Rarity: This association is uncommon in Alaska where only two occurrences have been documented (Lipkin 2007).

Threats: This plant association could be impacted by the natural processes of wildfire, flooding, and/or succession. Climate change may also have direct and indirect impacts on the components of this association.

Trend: Short- and long-term change in extent and condition is not expected.

Species of Conservation Concern

The plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this plant association (Table 32). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016). Additional study is required to evaluate whether this plant association supports animal species of conservation concern.

Table 32. Plant species of conservation concern within the *Artemisia alaskana - Dianthus repens* Gravel Bar Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Alyssum obovatum	G5	S2S3	Steep, dry, south facing stony slopes, usually on calcareous or ultramafic substrates
Koeleria asiatica	G4	S3	Dry, sandy sites, ultramafic substrates

Classification Concept Source

The classification concept for this plant association is based on Lipkin (2007).

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Boreal Forested Glacial Ablation Plain Biophysical Setting

Boreal Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Forested glacial ablation plains are represented by mature trees and associated understory species growing in a periglacial environment on ice-cored deposits. Through various geomorphic processes, glaciers may accumulate rock, gravel and sand on their upper surfaces. Where this debris reaches a depth sufficient to insulate roots, plants may colonize and a vegetated glacial ablation plain may develop (Figure 63). Areas that are not subject to continual erosion or deposition of material will usually exhibit greater soil development and in Alaska may eventually support mature conifer forests (USFS 2004). In boreal ecoregions, seres occurring in this unique environment transition from pioneer *Hedysarum alpinum-Chamerion latifolium* (alpine sweetvetch-dwarf fireweed) associations to mid-seral stands of *Populus balsamifera* to mature *Picea glauca-Betula neoalaskana* forests (Figure 64; Molnia 2006, Rampton 1970, Birks 1980). Additional study is required to evaluate whether these plant associations support unique vegetation, rare plants, and/or wildlife habitat. Many of the ice-cored ablation plains may last 550 years, ample time to allow forests to mature and even for secondary succession to occur (Rampton 1970, Birks 1980). However, in a rapidly warming climate, the melt processes that have produced these stable ablation plains become a liability to their existence (Tarr and Martin 1914).

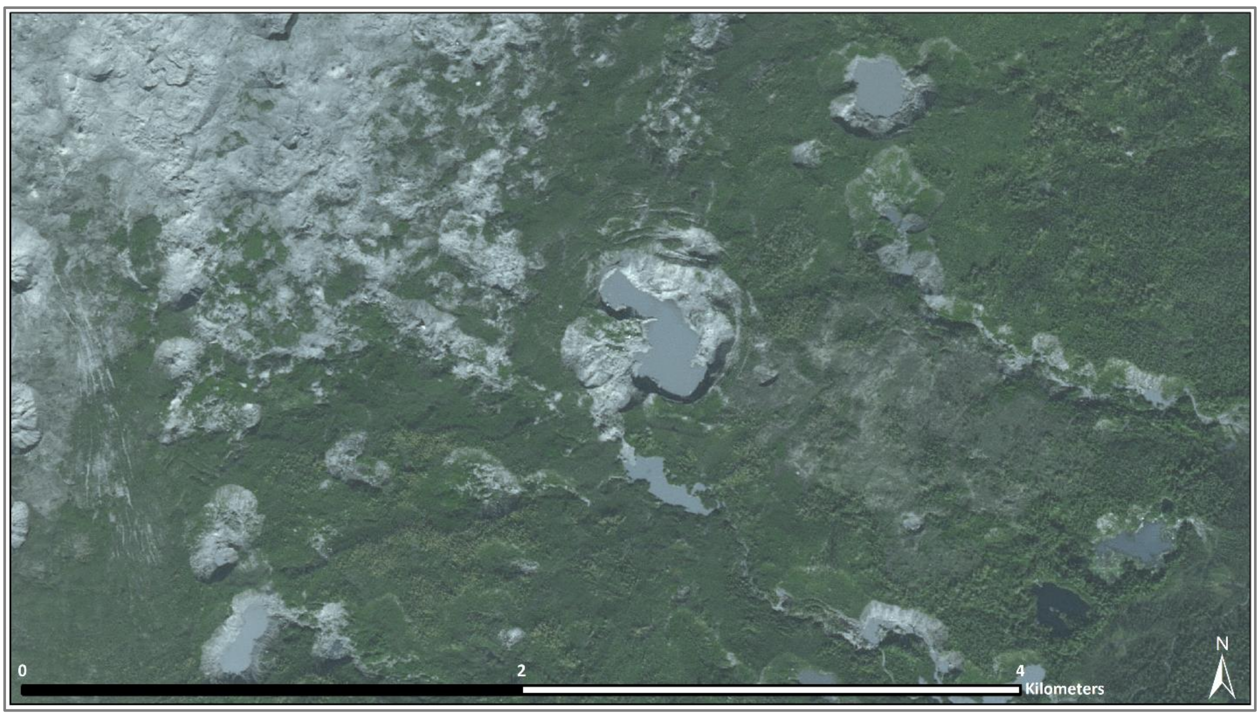

Figure 63. Ruth Glacier ablation plain showing barren supraglacial debris (upper left) transitioning to forest (lower right). Note the occurrence of craters and small lakes that occur across the plain.

Distribution

Mature forests dominated or codominated by *Picea glauca* and *Betula neoalaskana* on ablation plains are rare and occur as isolated pockets on the lower elevations of glaciers in the Alaska Range, Chugach

Mountains, Wrangell Mountains, and the St. Elias Mountains of the Yukon Territory, Canada. Younger seral-stages occur on additional ablation plains, and are more common than the mature forests.

The distribution of forested glacial ablation plains in boreal Alaska (Figure 64) was developed from the intersection of glacial ice (GLIMS 2005) with *Picea glauca*-dominated landcover classes of the Alaska Vegetation Map (Boggs et al. 2016). Selected *Picea glauca* landcover classes include: White Spruce or Black Spruce (Open-Closed), White Spruce or Black Spruce (Woodland), White Spruce or Black Spruce-Deciduous (Open-Closed), and White Spruce or Black Spruce/Lichen (Woodland-Open).

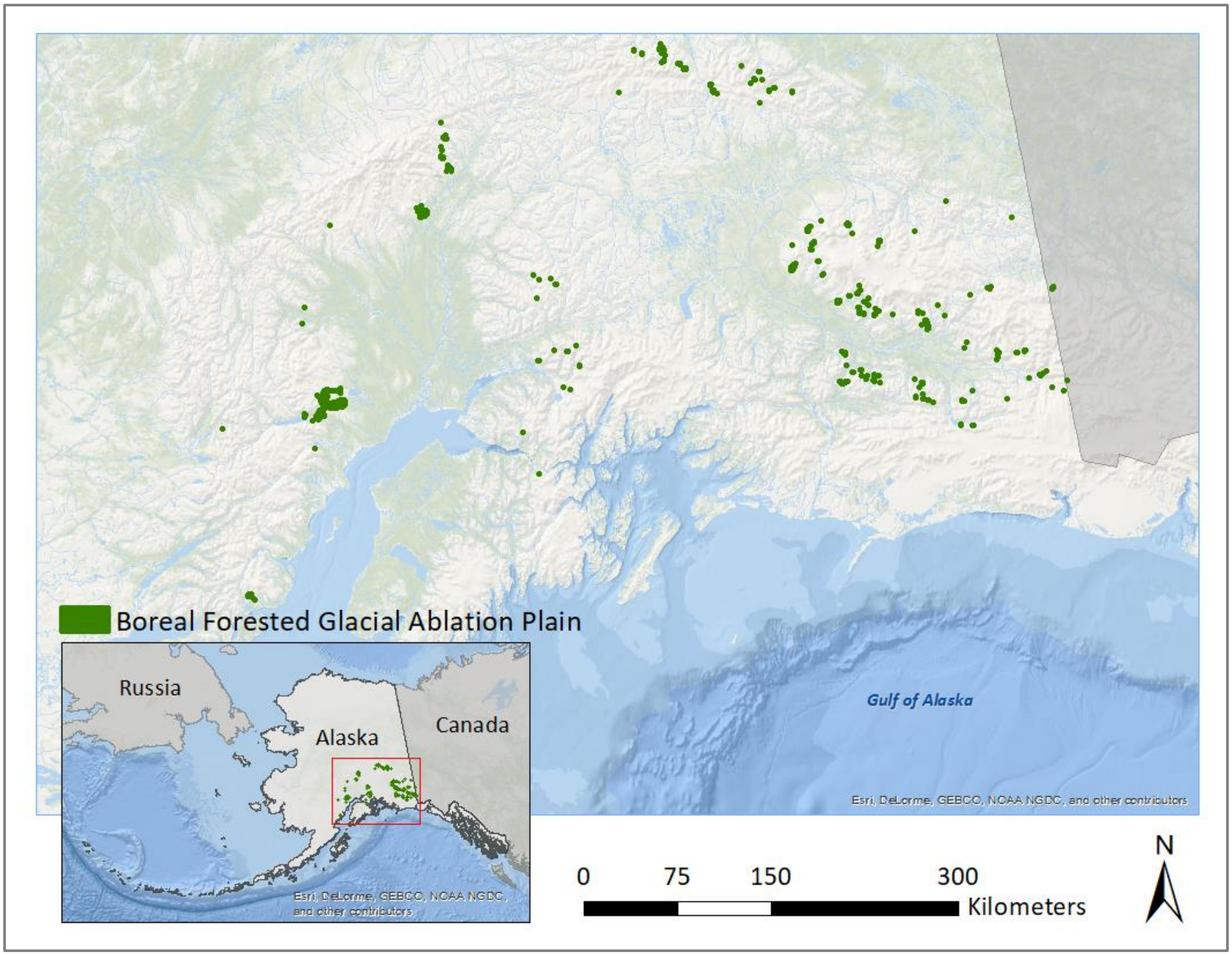

Figure 64. Distribution of the Boreal Forested Glacier Ablation Plain Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Interior Alaska has short, warm summers and long, cold winters. The average annual precipitation ranges from 25 to 51 cm in valley bottoms and basins. Most precipitation falls as rain between the months of May and September. Average annual snowfall ranges from 165 to 203 cm, and average annual temperature ranges from -6.7 to -5.6 °C. The typical frost-free period ranges from less than 30 to 90 days. Normally, the temperature remains above freezing in river valleys and basins from mid-June through August (Moore et al. 2004).

Figure 65. The Matanuska Glacier flowing from bottom to top of the image. Note the widening of the medial and lateral moraines as they enter the ablation plain (source: Google Earth, accessed September 2, 2015).

Figure 66. Melt across steep ice faces can initiate small landslides, which expose glacial ice; Matanuska Glacier, Alaska.

Environmental Characteristics

Supraglacial debris is largely derived from medial and lateral moraines or landslides to the glacier surface (Fickert et al. 2007); lesser sources may include alluvial or aeolian sediment transport and solifluction, as well as thrusting of bed-derived sediment from the bottom of a glacier to its surface (Alley et al. 1997). Depending on the energy of the depositional process, debris may include boulders 2 to 3 m in diameter and may reach thicknesses exceeding 0.5 m (Rampton 1970, Birks 1980). Of these varied sources, medial and lateral moraines are thought to be the dominant sources of supraglacial debris (Figure 65). Medial and lateral moraines form as narrow strips of debris, but increase in width and relief as they move downgradient past the equilibrium line to the ablation zone. In the ablation zone, where ice melt exceeds accumulation, debris is most commonly reworked by meltwater into outwash plains and ice may be degraded by above-freezing temperatures, stream erosion, or the exposure of ice by removal of sediment (Figure 67). Melt across steep ice faces can initiate small soil-vegetation slides, forming a chaotic accumulation of debris and vegetation (Russell 1891; Figure 66). Slides across slopes of craters may form bluffs 8 m high littered with standing, leaning and fallen dead trees.

Figure 67. Supraglacial debris on the Matanuska Glacier supporting early-seral communities (left) and late-seral, *Picea glauca*-dominated forest (right).

Under less rapid melt conditions debris may build over ice allowing vegetation to establish (Figure 68). Due to the insulation provided to the underlying ice by supraglacial debris, the thermodynamics of 'dirty' glaciers differ from those of 'clean' glaciers. Supraglacial debris can reduce glacial ablation rates, allowing the glacier to extend further down valley than meteorology alone would suggest (Anderson 2000). Research on the vegetation communities on glacier ablation plains have shown that the lifespan of supraglacial trees is mainly controlled by glacier surface displacements and by the occurrence of backwasting and downwasting processes, whereas tree germination was associated with fine debris presence (Pelfini et al. 2012).

Vegetation and Soil Succession

Vegetation succession has been described on ice-cored moraines of the Klutlan and Natazhat Glaciers, located in the extreme southwest of the Yukon Territory, Canada (Rampton 1970, Birks 1980). Nine major vegetation types are listed: *Crepis nana, Dryas drummondii, Hedysarum mackenzii, Hedysarum-Salix, Salix-Shepherdia canadensis, Picea glauca-Salix, Picea glauca-Arctostaphylos, Picea glauca-Ledum*, and *Picea glauca-Rhytidium*. Their estimated ages, based on shrub and tree ring counts, are 2-6, 9-23, 10-20, 24-30, 32-58, 58-80, 96-178, 177-240, and 163 to greater than 339 years, respectively. These major vegetation types reflect a succession of vegetation related to moraine age and stability, with the *Crepis nana* type invading the youngest, most disturbed moraines and the *Picea glauca-Rhytidium* type occupying the oldest, most stable moraines. Soil development and humus accumulation parallel assembly of the plant community. Soil nutrient levels are poor and nitrogen available to plants is primarily from atmospheric based nitrogen (N_2). A symbiotic relationship between actinobacteria *Frankia* and known N_2-fixing plant species including those from the genera *Alnus, Dryas, Hedysarum,* and *Sheperdia* facilitate nitrogen uptake by early colonizing plants (Matthews 1992; Kohls et al. 2003).

During a field visit in July 2014 by the authors to the ablation plain of the Matanuska Glacier, a similar chronosequence was observed and sampled. Here, the youngest sites are pioneered by *Hedysarum alpinum-Chamerion latifolium* with a mixture of young *Salix niphoclada* and *Populus trichocarpa* (Figure 68). Common pioneer bryophytes are *Ceratodon purpureus* and *Leptobryum pyriforme*. The substrate is comprised of rock, sand and silt with a pH of 7.7 at 10 cm depth and no evidence of soil development. Older sites support 1 to 2 m tall *Populus trichocarpa*, *Salix niphoclada,* and *Salix alaskana* over *Hedysarum alpinum* and *Chamerion latifolium*, or *Alnus viridis* ssp. *fruticosa*. The bryophyte *Ceratodon purpureus* persists in occurrence with *Sanionia uncinata* and *Brachythecium albicans* with the foliose lichen, *Peltigera canina* is also present. Soil development is minimal, multiple surface cracks expose glacial ice and initiate the slumping of soil and vegetation.

The oldest sites sampled supported mature *Picea glauca-Betula neoalaskana* forests 25 m in height with 20-30% cover and an understory of *Salix glauca*, *Alnus viridis* ssp. *fruticosa*, *Shepherdia canadensis* and *Linnaea borealis* (Figure 68); *Brachythecium albicans* is the most common bryophyte. The forest soil had a 4 cm organic layer over a 10 cm thick B horizon comprised of 5% rock and 95% sand, with a pH of 6.7 at 10 cm depth. Here, soil cracks and active side slope slumps indicate the active melt of ground ice. Substrate disturbance caused by subsurface melting creates a dynamic, early-seral vegetation community that transitions to a more stable ablation plain with soil development.

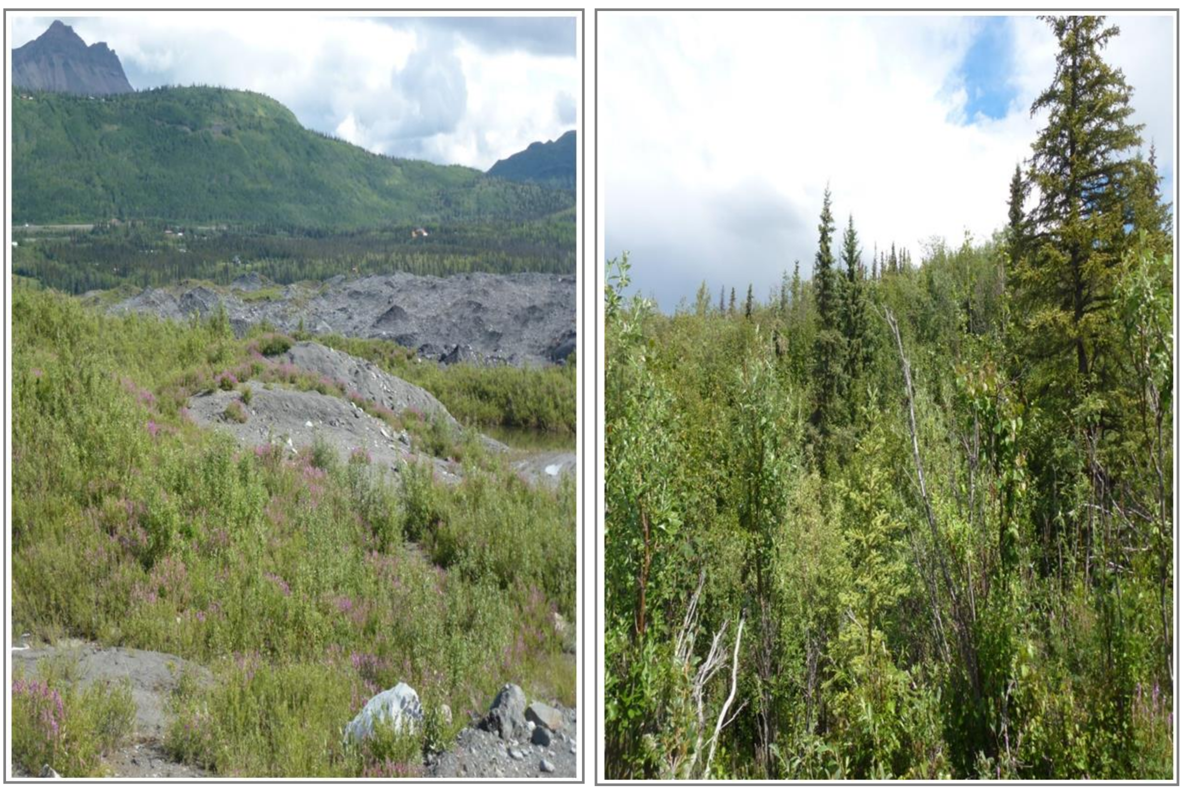

Figure 68. Supraglacial debris on the Matanuska Glacier supporting early-seral *Hedysarum alpinum-Chamerion latifolium* plant association (left) and a late-seral *Picea glauca/Salix* forest association (right).

Conservation Status

Rarity: Mature forests dominated by *Picea glauca* or *Betula neoalaskana* rarely develop on glacial ablation plains and are only documented from five periglacial environments in Interior Alaska. Their estimated area of occupancy is less than 7 km^2.

Threats: Change in glacier movement threatens this system. In a rapidly warming climate, the melt processes that have produced these stable ablation plains become a liability to their further existence (Tarr and Martin 1914, Stephens 1969). In contrast, it is unclear as to whether advancing glaciers would support an ablation plain stable enough to allow the development of forests.

Trend: Ice-cored ablation plains are estimated to last well beyond the time required for forests to mature and even for secondary forest succession to occur (600 years; Rampton 1970, Birks 1980). Thus in the absence of significant glacier recession or advance, change in the extent and condition of this system in not expected. It is not known how increased ablation rates due to a warming climate will affect the maintenance of this system.

Species of Conservation Concern

No animal or plant species of conservation concern are known or suspected to occur within this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports species of conservation concern.

Plant Associations of Conservation Concern

No plant associations of conservation concern are known or suspected to occur within this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports plant associations of conservation concern.

Classification Concept Source

The classification concept for this biophysical setting is based on Russell (1891).

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Boreal Inland Dune Biophysical Setting

Boreal Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Active inland dunes occur in areas where wind-deposited silts and sands form expansive deposits. In boreal Alaska and western boreal Canada inland dunes represent remnants of larger dunes systems and sand sheets that developed in the late Pleistocene. Most of these relict sand deposits have been stabilized by vegetation, but areas of active transport and deposition still exist. In Alaska, the Great Kobuk Sand Dunes, Little Kobuk Sand Dunes, and Nogahabara Dunes persist as isolated, active remnants of these extensive sand sheets (Figure 69). These and the western Canada boreal dune fields are strongly linked by their shared floristics, Quaternary origins, and geomorphic processes and landforms. In addition to several plant species of conservation concern, an abundance of Beringian endemics, and disjunct species are known from active inland dunes. This biophysical setting differs from the Arctic Inland Dune biophysical setting as it is not underlain by continuous permafrost. Inland dune systems do not include coastal dune settings such as back beaches, barrier islands, and spits.

Figure 69. The Great Kobuk Sand Dunes, Alaska (photo provided by Kobuk Valley National Park).

Distribution

In boreal Alaska, inland dunes are represented by the Nogahabara Dunes (65 km^2), which exist in a designated wilderness area in the Koyukok River lowlands and Great Kobuk Sand Dunes (62 km^2) (Figure 71) and Little Kobuk Sand Dunes (8 km^2), which are protected National Park and Fish and Wildlife Service lands. The Boreal Inland Dunes distribution map (Figure 70) was developed from bare ground landcover classes of the Alaska Vegetation Map within the areas of interest (Boggs et al. 2016).

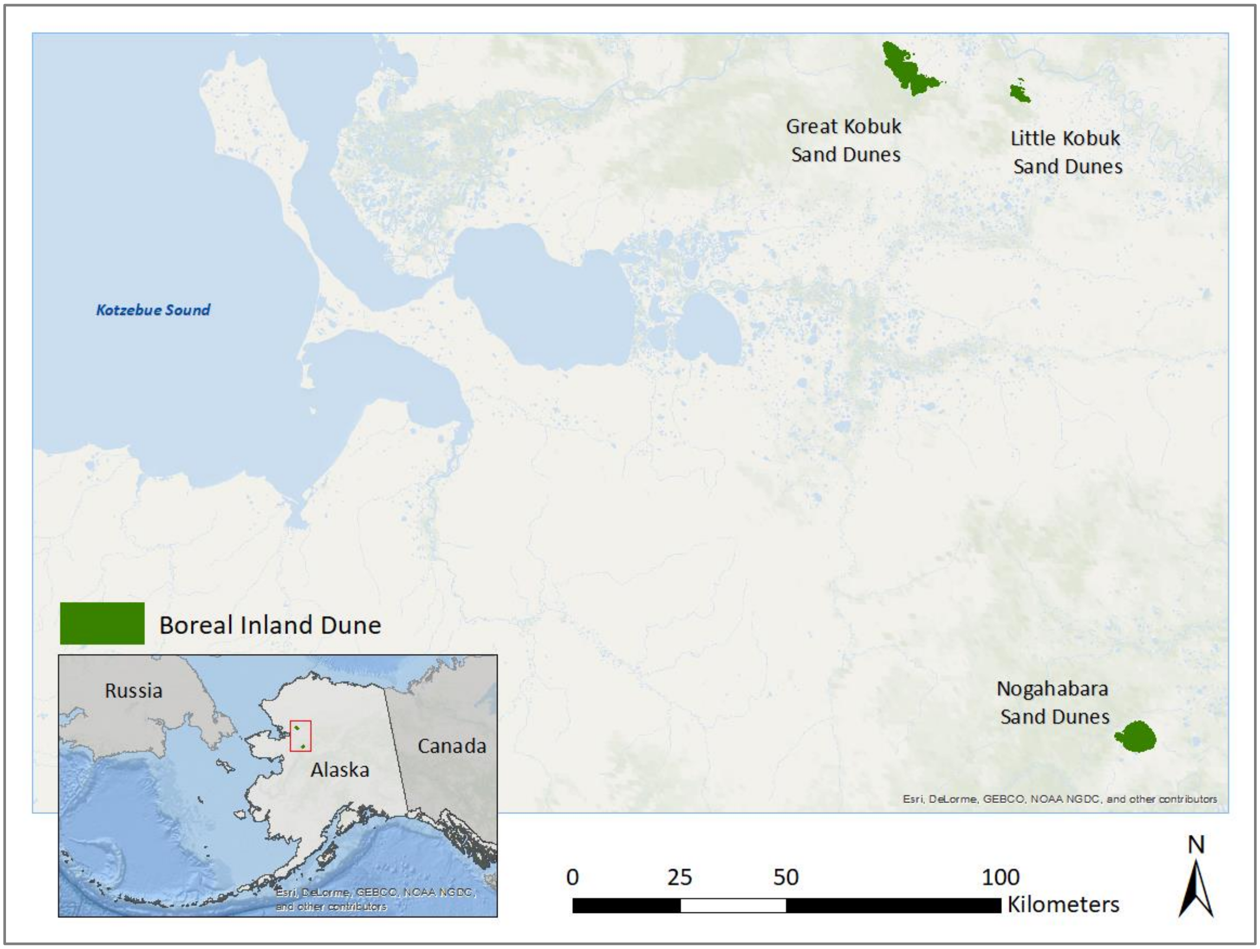

Figure 70. Distribution of the Boreal Inland Dune Biophysical Setting. Note that areas of occupancy in this map are buffered for greater visibility.

Figure 71. The Great Kobuk dunes, Alaska (photo by Kobuk Valley National Park).

Climate

Interior Alaska has short, warm summers and long, cold winters. The average annual precipitation ranges from 25 to 51 cm in valley bottoms and basins. Most precipitation falls as rain between the months of May and September. Average annual snowfall ranges from 165 to 203 cm, and average annual temperature ranges from -6.7 to -5.6 °C. The typical frost-free period ranges from less than 30 to 90 days. Normally, the temperature remains above freezing in river valleys and basins from mid-June through August (NRCS 2004).

Environmental Characteristics

Inland dunes develop from concentrations of glaciofluvial silts and sands that have been deposited by wind. Source material for the three active dune systems in boreal Alaska is derived from sand sheets and dunes that covered over 30,000 km^2 of northern Alaska during the last glacial period (Carter 1981, Hopkins 1982, Lea and Waythomas 1990). The parent material of the sand composing the Kobuk Valley dunes is quartzose bedrock in the Brooks Range that, during the Pleistocene glaciations, was eroded and transported by glaciers and outwash streams into the Kobuk Valley (Fernald 1964, Hamilton 1984, Hamilton et al. 1987). These sands are fine-grained and moderately well-sorted (Dijkmans et al. 1988). Quartz and feldspar are the dominant minerals (78%), accompanied by heavy minerals (10%), and carbonate (7%; Dijkmans et al. 1986). Carbonate grains in the dune sands are a mixture of detrital grains derived from bedrock and calcite precipitated as secondary carbonates within the dune field. Secondary carbonates are widespread in the Great Kobuk Sand Dunes, where they accumulate in frost cracks, around springs and in interdune basins (Cox and Lawrence 1983, Koster et al. 1986, Galloway et al. 1990). Calcretes (carbonate-cemented crusts) also occur and are formed in the Kobuk Valley Dunes primarily by the exposure of cold, carbonate-rich groundwater to warm surface conditions with lower partial pressures of CO_2 (Dijkmans et al. 1986). Calcretes found in the Nogahabara Dunes contain microfeatures that suggest fluvial influences (shallow surface waters) were greater than aeolian or glacial influences prior to concretion (Galloway et al.1990). Very fine sand and silt may be carried beyond the dunes and eventually deposited within the surrounding tundra and forest. This material rains on vegetated surfaces, where it becomes interstratified with soil organic horizons (Mann et al. 2002).

The Great Kobuk Dunes contain a diverse assemblage of aeolian landforms, including parabolic, transverse, longitudinal, and barchanoid dunes, along with sand sheets, blowouts and precipitation ridges (Koster and Dijkmans 1988, Dijkmans and Koster 1990). Precipitation ridges form at the dune field perimeter where bordering forests cause wind speed to drop, resulting in the deposition of sand along a linear crest (Cooper 1967, Raup and Argus 1982, Mann et al. 2002). The Little Kobuk Dunes (8 km^2) are an elongate patch of blowouts and parabolic dunes with barchanoid dunes at their western extremity (Kuhry-Helmens et al. 1985, Hamilton et al.1987). Comparable active dunes outside of boreal Alaska include the Athabasca Sand Dunes in northern Saskatchewan and Carcross dunes in southwestern Yukon.

Vegetation and Succession

The main disturbance process is the erosion, transport and deposition of sand. Sand accumulates at the crest of a dune until the lee slope exceeds the angle of repose and layers slide. Repetition of this process causes migration of the dune. Establishment of plants slows dune migration and leads to stabilization. Vegetation on the lee side of the dune is gradually buried in sand, while vegetation reestablishing on the windward side is subject to excavation. Creeks and interdune depressions, also referred to as slacks, sometimes support wetland and riparian plant communities. Black or white spruce (*Picea mariana* or *P. glauca*) forests surround the dune fields (Racine 1976).

Figure 72. *Oxytropis kobukensis* along the Kobuk River (photo by Rob Lipkin).

The Great Kobuk Sand Dunes are largely barren, supporting widely scattered plants of the grasses *Bromus pumpellianus* and *Festuca rubra*, the willow, *Salix alaxensis*, and the forbs *Artemisia borealis*, *Oxytropis kobukensis*, and *Plantago canescens* (Figure 72). Dune margins are sometimes stabilized by the grasses *Festuca rubra* and *Leymus mollis*, although cover rarely exceeds 10%. Here, dead leaves of *Leymus* accumulate at the base of the stem and radiate out from it, providing increased cover along the sand surface. Windblown plant and lichen fragments are trapped providing germination sites for additional plants. In time, lichens begin to replace the grasses, and other vascular species, including the forbs, *Plantago canescens* and *Dianthus repens*, become established and may increase plant cover to about 40% in gently sloped areas. Coverage and diversity of lichens and other plants, including the forb, *Silene acaulis* and the dwarf shrub *Dryas integrifolia*, continues to increase. When cover reaches about 90%, spruce may colonize and gradually develop into woodland with widely-spaced trees, a lichen understory and few vascular plants. On well-drained sites within 50–100 m of the active dunes, this forest is dominated by 10–20 m tall *Picea glauca* with subordinate *Betula neoalaskana* and *Populus tremuloides*. Farther from the active dunes, well-drained, stabilized dunes are covered by forest woodlands of *Picea glauca*, *Betula neoalaskana*, *Populus tremuloides*, *Salix* species and *Alnus viridis* ssp. *crispa*, with a ground layer of ericaceous shrubs and foliose lichens (Young and Racine 1977). Lichens identified from the sand dunes and surrounding habitats comprise 63 genera and 160 species, many with circumpolar arctic-alpine and amphiberingian distributions (Dillman et al. 2001).

Active sand may advance on spruce forests, killing them and resetting the successional pattern (Bowers 1982). Fire may also return forest- or tundra-stabilized dunes to activity (Mann et al. 2002). Animals also cause disturbance to dunes; grazing, trampling or burrowing by caribou (*Rangifer tarandus*) or ground squirrels (*Spermophilus parryi*) disturbs vegetation, thereby facilitating erosion and blowouts (Peterson and Billings 1978).

Conservation Status

Rarity: Cold-climate dune fields in North America, Europe and Asia are estimated to cover an area of over 100,000 km^2 (Koster 1988). Although large systems of dunes and sand sheets developed in Alaska during the late Pleistocene, most deposits have since been stabilized by vegetation. Today active inland dune fields are rare on the landscape; only three large active dune fields: the Great Kobuk, Little Kobuk and Nogahabara Sand Dunes, comprising approximately 100 km^2 are known from boreal Alaska.

Threats: Foot traffic may prevent plants from establishing or persisting in the sandy soil. Thus increased subsistence or recreational use of the dunes could potentially impact the dunes. However, these threats are expected to be minimal due to low human population densities that is concentrated around local villages. Also, the introduction of nonnative plant species could affect establishment of native plants in dune field stabilization.

Trend: A period of dune-field stabilization occurred at Great Kobuk Sand Dunes between 7,000 and 5,000 ybp (years before present). Following this period of stabilization, episodes of dune field expansion occurred at 400 to 1,500 year intervals. Specifically, the Great Kobuk dunes expanded during the Medieval Warm Period (ca. AD 900–1,400), were relatively inactive early in the Little Ice Age (AD 1,400–1,800), and expanded briefly late in the Little Ice Age prior to AD 1,900. The dune field has contracted over the last 80–100 years. Moisture balance appears to be the major control of aeolian (wind driven) activity at dune fields within boreal forests, with increased moisture leading to contraction of the dune fields (Mann et al. 2002, Wolfe et al. 2000). Because vegetation colonization of active dunes is so closely tied to moisture regimes, active dunes currently exist at a threshold wherein a minor change in climate could impact their future direction more strongly than human activity (Parker and Mann 2000).

Species of Conservation Concern

The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 33, Table 34). The Alaska tiny shrew (*Sorex yukonicus*) has been documented to occur at Kobuk Valley National Park, between the Great Kobuk and Little Kobuk dunes (UAM 2015). It primarily inhabits riparian scrub areas, but has also been observed in wetlands and bogs, and at forests and shrub tussock tundra at dune margins. Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 33. Mammal and bird species of conservation concern within the Boreal Inland Dune Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alaska tiny shrew	*Sorex yukonicus*	GU	S3	Suspected to occur at Great Kobuk Sand Dunes. Primarily occurs in riparian scrub, and also forests, wetlands, bogs, and shrub tussock tundra.
Birds				
Rusty Blackbird	*Euphagus carolinus*	G4	S3	Documented occurrence in Nogahabara Sand Dunes (Bodony et al. 2011).
Fox Sparrow	*Passerella iliaca*	G5	S3	Suspected to occur within edge habitat of Kobuk Sand Dunes, primarily in wooded understory.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Peregrine Falcon	*Falco peregrinus*	G4	S3	Suspected to occur nearby to the Great Kobuk Sand Dunes- primarily in mountainous cliffs, hunting wetlands nearby the Dunes.
Sharp-shinned Hawk	*Accipiter striatus*	G5	S3	Suspected to occur within edge habitat of Kobuk Sand Dunes, primarily in wooded cover.

Table 34. Plant species of conservation concern within the Boreal Inland Dune Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Carex sabulosa ssp. *leiophylla*	G5	S1	Riverine sand exposures and dune fields in Yukon and Alaska. Also occurs in Kazakhstan, Mongolia, and Russia. Known from less than six sites in North America, this sedge is uncommon at Nogahabara Sand Dunes.
Lupinus kuschei	G3G4	S2	Occurs on sand dunes and glacial rivers. Most of the global population is in southwestern Yukon Territory, with additional occurrences in British Columbia and Alaska.
Oxytropis kobukensis	G2	S2	Narrowly endemic to a small stretch of the middle Kobuk River, where it grows on sparsely vegetated sand on active dunes, in dune slacks and on sheltered dune slopes.
Symphyotrichum yukonense	G3	S3	Known to occur in the Great Kobuk Sand Dunes in damp, sandy dune depressions and creek floodplains.

Plant Associations of Conservation Concern

Of the plant associations that occur at dune field margins, all have a high fidelity for this biophysical setting. However, there are no plant associations of conservation concern (S1-S3) known or suspected to occur within this biophysical setting.

Classification Concept Source

The classification concept for this biophysical setting is based on Racine (1976).

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Larix laricina Wetland Biophysical Setting

Tamarack Wetland Biophysical Setting

Boreal Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

The *Larix laricina* (Tamarack) Wetland Biophysical Setting is represented by open forests dominated by *Larix laricina* and *Picea mariana* (black spruce) occurring on wet lowlands in interior Alaska (Viereck and Little 1972, Heebner 1982, Viereck et al. 1992, Juday 2001, Boggs et al. 2001). Trees are small and stunted and the understory is comprised of species commonly found in *Picea mariana* forested bogs (Viereck et al. 1992; Figure 73). *Larix laricina* as a species is of conservation concern due to both the drastic population reductions caused by infestations of larch sawfly (*Pristiphora erichsonii*) and the geographic and potentially genetic separation of the Alaska population from to the North American population. Published descriptions of the plant associations and successional processes of *Larix laricina* wetlands are limited and thus threats and trend of the greater biophysical setting are not fully understood.

Figure 73. *Larix laricina* Wetland Biophysical Setting at Denali National Park, Alaska.

Distribution

Larix laricina is a disjunct species restricted to drainages between the Brooks and Alaska Ranges. It is locally abundant along the Tanana River but scattered along the Yukon, Kuskokwim and Koyukuk Rivers (Viereck and Little 2007). The *Larix laricina* Wetland distribution map (Figure 74) was developed from manual digitization of the *Larix laricina* range in Alaska (Viereck and Little 2007). Occurrence records of *Larix laricina* were developed from herbarium specimens that explicitly noted collection from a wetland habitat (CPNWH 2016).

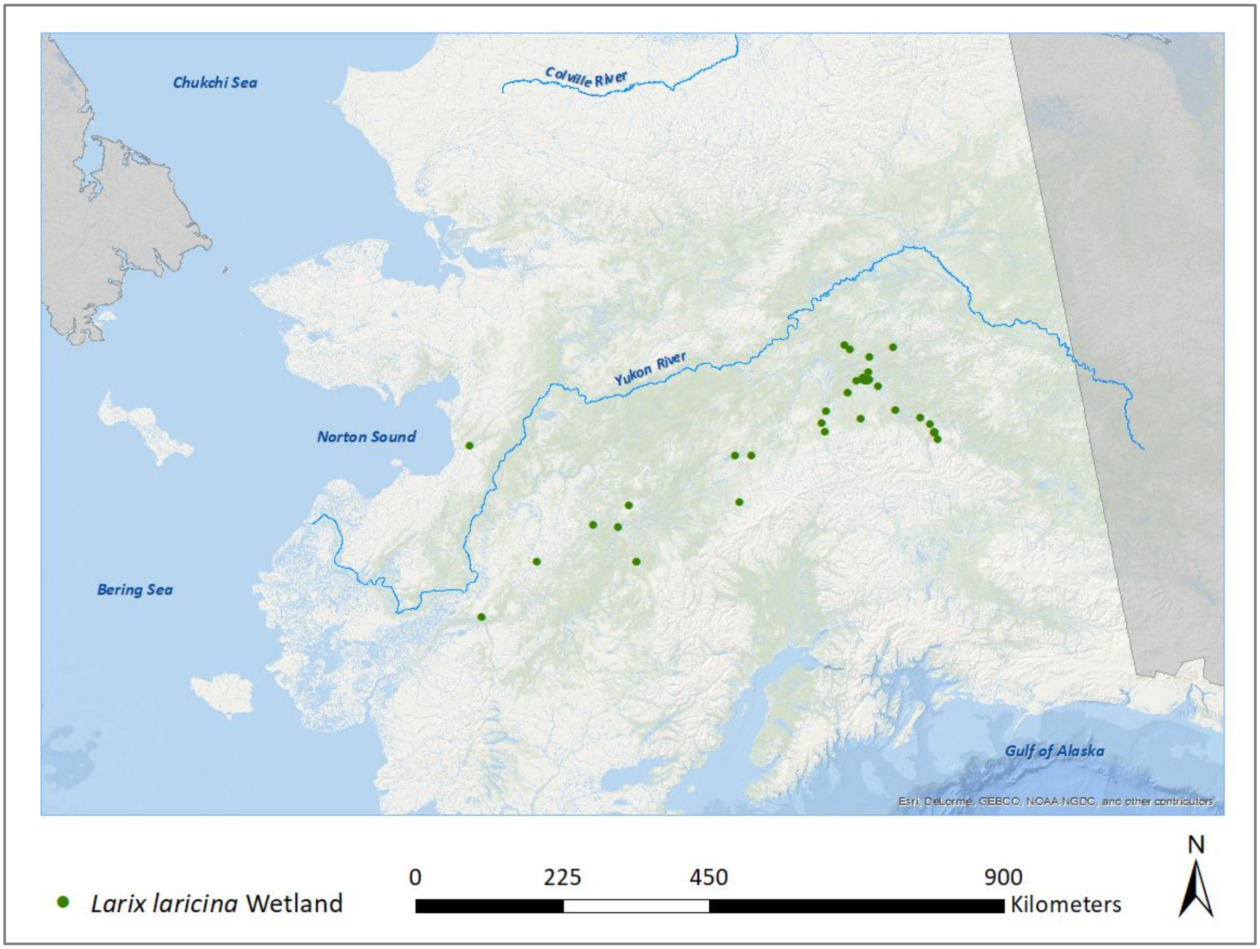

Figure 74. Distribution of the *Larix laricina* Wetland Biophysical Setting. Note only small patches of mature *Larix laricina* forest occur within its range and point occurrences shown in the map are buffered for greater visibility.

Climate

Interior Alaska has short, warm summers and long, cold winters. The subarctic continental climate is dry and cold (Natural Resources Conservation Service 2006). Mean annual precipitation ranges from about 15 cm in the northwest lowlands to over 254 cm in the Alaska Range. In summer, afternoon thunderstorms are common in valleys and lower mountain slopes. The mean annual temperature ranges from -13 to -2 ºC and freezing temperatures may occur in any month in most of the region.

Environmental Characteristics

The *Larix laricina* Wetland Biophysical Setting is generally restricted to wet and cold sites underlain by shallow permafrost (Figure 75; Brown et al. 1988, Viereck and Little 2007). Site slopes range from 0 to 6 degrees and elevations range from 198 to 479 m (Heebner 1982, Boggs et al. 2001). This biophysical setting occurs on both nutrient-poor, acidic peatlands (Damman and French 1987, Johnston 1990) and nutrient rich nonacidic peatlands (Juday 2001).

Vegetation, Succession and Disturbance

On wet sites, *Larix laricina* trees are typically stunted, achieving heights of only 3 m and diameters of 8 cm; sites with better drainage support mature trees 9-18 m tall and 10-25 cm in diameter (Johnston 1990, Viereck and Little 2007). The maximum age for *Larix laricina* is about 180 years. In wetland habitats, the

Figure 75. Stand of *Larix laricina* near Fairbanks, Alaska.

overstory is dominated by *Larix laricina*, with *Picea mariana* and *Betula neoalaskana* present as codominants or minor associates; total canopy cover ranges from 10-30%. Understory shrubs include *Andromeda polifolia*, *Betula nana*, *Chamaedaphne calyculata*, *Ledum palustre* ssp. *decumbens*, *Rubus chamaemorus*, *Vaccinium uliginosum*, and *V. vitis-idaea* (Heebner 1982, Boggs et al. 2001). The herbaceous layer may include *Eriophorum vaginatum*, *Equisetum fluviatile*, *Drosera rotundifolia*, *Carex bigelowii*, *C. rhynchophysa*, *Sparganium angustifolium*, *Menyanthes trifoliata* and *Comarum palustre*. Cover of peat mosses in the *Sphagnum* genus is often high (Heebner 1982, Boggs et al. 2001).

In interior Alaska, the thawing of permafrost under a tree canopy may result in pond formation (Drury 1956). As plants colonize and peat accumulates in the pond, *Larix laricina* communities will develop. *Larix laricina* is a pioneer or early seral species that commonly establishes in the wettest portions of a wetland. It is the first tree to colonize floating *Sphagnum* mats and may also invade bogs during the sedge mat, or ericaceous shrub stages (Beeftink 1951, Brown et al. 1988, Gates 1942). *Larix laricina* is extremely intolerant of shade and is eventually replaced by *Picea mariana*.

Several folivorous insects infest *Larix laricina* stands in interior Alaska. These include the larch sawfly (*Pristiphora erichsonii*), larch casebearer (*Coleophora laricella*), larch bud moth (*Zieraphera* sp.) and eastern larch beetle (*Dendroctonus simplex*; Johnson 1990, Werner 1980, Werner 1986). Repeated larch sawfly infestations from 1993 through 1999 killed most populations of *Larix laricina* across an estimated 651,100 ha area of interior Alaska (U.S. Department of Agriculture 1999). Female sawflies deposit eggs in new shoots near the branch tips. The hatched larvae feed on needles for 3–4 weeks, generally in late June and early July with several consecutive years of heavy defoliation leading to tree death. Outbreaks of the larch casebearer (*Coleophora laricella*) have also caused extensive mortality in some areas (Johnston 1990).

Larix laricina is susceptible to damage from flooding and disruptions in groundwater movements. Trees have been killed over large areas where newly-constructed roads or beaver dams impede water movement (Johnston 1990).

Conservation Status

Rarity: This biophysical setting is widespread in interior Alaska, but limited in total area with only 41 occurrences documented. The Alaska population is of conservation concern because it is isolated from the remaining North American population (Figure 74). *Larix laricina* is thought to have entered Alaska along the Mackenzie River corridor and became isolated from the Yukon Territory populations when the climate subsequently cooled (pers. comm. Glenn Juday). At one time, the Alaska population was also considered either a distinct species or as a variety of *Larix laricina* on the basis of narrower cone scale and bracts (Figure 76); however the variability is now generally recognized as within the range of other populations of the species (Johnston 1990, Parker and Dickinson 1990, United States Department of Agriculture, 2015).

Figure 76. *Larix laricina* cones and needles, near Fairbanks Alaska.

Threats: Threats include infestations of larch sawfly (*Pristiphora erichsonii*) and eastern larch beetle (*Dendroctonus simplex*) as well as forest fire and climate change. A warming climate will likely affect the range of this biophysical setting in Alaska as wet, interior lowlands dry and permafrost-supported ecosystems shift north.

Trend: *Larix laricina* as a species is of conservation concern because of drastic population reductions caused by infestations of larch sawfly (*Pristiphora erichsonii*) in stands across the northern United States and Canada. In Alaska it is estimated that over 2,800 km2 of larch forest were impacted since the beginning of the infestation in 1999 (Burnside et al. 2007). In the Nowitna National Wildlife Refuge *Larix laricina* trees that established following the sawfly damage of 1998-2000 are now producing cones (pers. comm. Karin Bodony, USFWS). Short-term declines related to climate warming and drying, which is expected to decrease the fire return interval and potentially compromise permafrost-supported wetland systems are predicted. In the long-term, declines related to future larch sawfly and eastern larch beetle infestations are predicted.

Species of Conservation Concern

The mammal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 35, Table 36). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016). Additional study is required to evaluate whether this biophysical setting supports other mammal or bird species of conservation concern. Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 35. Mammal species of conservation concern within the *Larix laricina* Wetland Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alaska tiny shrew	*Sorex yukonicus*	GU	S3	The tiny shrew is a habitat generalist that will use Larix laricina wetland habitat when present.

Table 36. Plant species of conservation concern within the *Larix laricina* Wetland Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Circuta bulbifera	G5	S3	Uncommon in wet sedge meadows and pond margins.
Sphagnum balticum	G2G4	S4	Abundant in hollows and floating mats in raised bogs and poor fens.
Splachnum luteum	G3	S4	Grows on dung in fens and bogs across the boreal forest.
Splachnum rubrum	G3	S2	Grows on dung in fens and bogs across the boreal forest.
Warnstorfia pseudostraminea	G3	S3	Found in mineral-poor and acid habitats (disturbed), slightly sloping poor fens, ditches, periodically water-filled depressions.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 37).

Table 37. Plant associations of conservation concern within the *Larix laricina* Wetland Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Larix laricina/Chamaedaphne calyculata/Sphagnum spp.	G3	S3	Boggs et al. 2001
Picea mariana-Larix laricina/Andromeda polifolia-Eriophorum vaginatum/Sphagnum spp.	G3	S3	Heebner 1982
Picea mariana-Larix laricina/Empetrum nigrum/Sphagnum spp.	G3	S3	Heebner 1982
Picea mariana-Larix laricina/Ledum palustre ssp. decumbens-Vaccinium uliginosum/Hylocomium splendens	G3	S3	Heebner 1982
Picea mariana-Larix laricina/Ledum palustre ssp. *decumbens/Sphagnum* spp.	G3	S3	Heebner 1982

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Picea glauca Floodplain Old-growth Forest Biophysical Setting

White Spruce Floodplain Old-growth Forest Biophysical Setting

Boreal Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Picea glauca* (white spruce) Floodplain Old-growth Forest biophysical setting is characterized by a closed canopy of mature *Picea glauca* and an abundance of snags and downed wood in a floodplain environment (Figure 77). Definitions of old growth forests vary as they reflect the inherent patterns and dynamics of the regional forest (USFS 2003). On floodplains in boreal Alaska *Picea glauca* tree age averages 150 years but may be less as some stands of old growth contain patches of younger growth (Juday et al. 2015). Old-growth forests are valued as unique habitats in North America that function to filter sediment and nutrient-laden floodwaters, stabilize bank sediments and regulate temperature through shading (Waring and Franklin 1979, Juday and Zasada 1984, Alaback 1991). In Alaska, mature *Picea glauca* forests also provide important habitat to a variety of bird and mammal species, particularly cavity nesters such as the Boreal Owl (*Aegolius funereus*), Hawk Owl (*Surnia ulula*), Northern Flying Squirrel (*Glaucomys sabrinus*) and Hairy Woodpecker (*Picoides villosus*) (Scott et al. 1977). Marten (*Martes americana*) utilize large tree cavities for denning and resting and thus reach peak abundance in old-growth forests (Bailey 1981). Old growth systems are dynamic with disturbance affecting their growth, amount of large woody debris, and landscape patch mosaic The spruce bark beetle (*Dendroctonus rufipennis*) has killed large areas of mature *Picea glauca* and forests were widely exploited during the gold rush and settlement periods of the early 1900s (USFS 2003).

Figure 77. Small patches of *Picea glauca* forests on floodplains of the Yukon River in Yukon-Charley Rivers National Preserve, Alaska.

Distribution

Old-growth *Picea glauca* floodplain forests occur on moderate to large floodplains in interior Alaska flanking the Yukon, Kuskokwim, Koyukuk, and Tanana Rivers. These forests have not been mapped as a distinct class in most of Alaska, however a small portion of the total 45,900,000 ha of boreal forest in interior Alaska occurs on interior Alaskan floodplains (Yarie et al. 1998). A distribution map for the Old-growth *Picea glauca* Floodplain Forest biophysical setting was developed from sampling locations targeting floodplain old growth *Picea glauca* stands collected by Juday and others (2015), *Picea glauca*-dominated landcover classes from the Alaska Vegetation Map (Boggs et al. 2015) and floodplains delineated within the State Surficial Geology Map of Alaska (USGS 1999). The final distribution map represents closed to open canopy spruce forests occurring on floodplains (Figure 78).

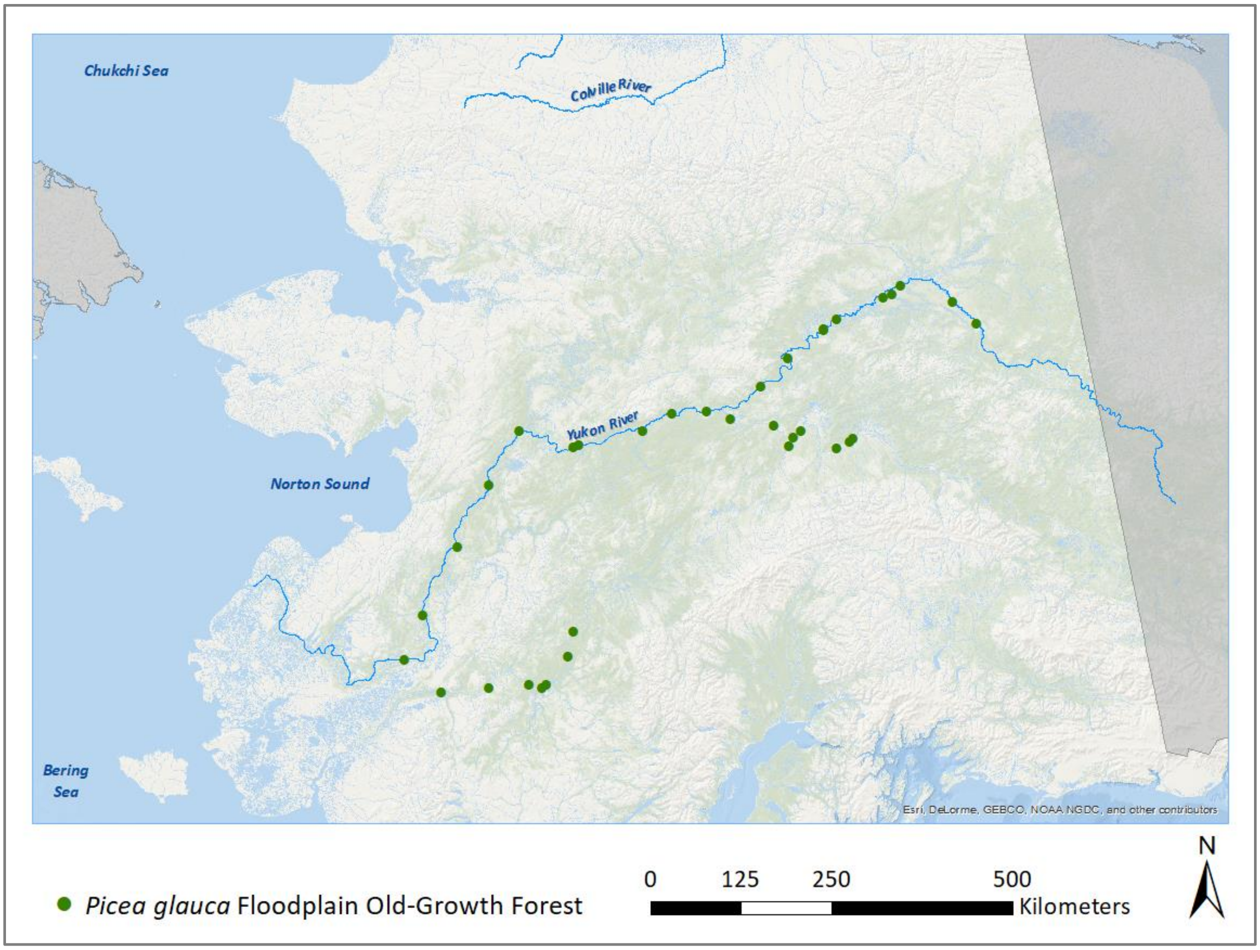

Figure 78. Distribution of the *Picea glauca* Floodplain Old-growth Forests Biophysical Setting. Note point occurrences in this map are buffered for better visibility.

Climate

Short, warm summers and long, very cold winters characterize the subarctic continental climate of the area (NRCS 2006). The average annual precipitation ranges from 25 to 38 cm in the east and north and 38 to 51 cm in the south and west. Maximum precipitation occurs in the late summer, mainly as a result of thunderstorms. The average annual snowfall ranges from 76 to 203 cm. The average annual temperature ranges from -5.5 ºC in the east to -4 ºC in the west. The average frost-free period ranges from 70 to 120 days. The temperature usually remains above freezing from June through mid-September.

Environmental Characteristics

In interior Alaska, mature *Picea glauca* occur on both floodplains and south facing uplands. Upland stands are thought to burn more frequently, and as a result, individual upland trees older than 200 years are rare (Van Cleve and Viereck 1981). Trees over 200 years, however, are known from floodplain sites, which are thought to contain the oldest stands of *Picea glauca* in Alaska. Here, *Picea glauca* trees have ranged from over 300 years on the Tanana River floodplain (Farr 1967, Juday and Zasada 1984), to 250 on the Chena River floodplain (Viereck 1970, Viereck 1989, Juday and Zasada 1984, Boggs and Sturdy 2005, Yarie 1983).

The formation of new land and the initiation of primary successional processes in floodplain ecosystems is well documented (Leopold et al. 1964). Along a meandering river, alluvium typically is deposited on the inner, point bank the river channel. The opposing bank is cut, providing sediment for downstream deposition and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain. Vegetation growing on new deposits near the river may be contrasted with that on older deposits inland to recognize and measure successional processes. Alluvium also is deposited on the soil surface during flooding, further raising the soil surface height.

Soils are mostly comprised of well-drained alluvial sand and gravel deposited during flooding events. Due to frequent alluvial disturbance, soils in the active floodplain show little development and are often classified as inceptisols or entisols (Martin et al. 1995); older sites elevated above the active floodplain may support spodisols.

Water availability plays a major role in plant community structure and composition on floodplain terraces. Water is input from overbank flow (flooding), groundwater and precipitation, with terraces becoming progressively drier with increasing vertical and horizontal distance from the active channels. Within the stands, soil and air moisture are high, and as a result, fires are rare. When they do occur, fires burn out in the humid understory and rarely reach the spruce canopy.

Figure 79. The *Picea glauca/Alnus viridis* ssp. *crispa/Rosa acicularis/Arctostaphylos rubra* Plant Association on the Yukon River, Alaska (Boggs and Sturdy 2005).

Vegetation and Succession

In boreal Alaska, old-growth floodplain forests are dominated by uneven-aged stands of *Picea glauca*, which ranges in age from 130 to 350 years, in height from 30 to 34 m, and in canopy cover from 30 to 50%. The tall shrub, *Alnus viridis* ssp. *crispa* dominates or codominates with *Alnus incana* ssp. *tenuifolia* in the tall shrub layer with 25 to 90% cover (Figure 79). These alder species are commonly over 3 m tall. Low shrubs include, *Ledum groenlandicum*, *Rosa acicularis*, *Vaccinium vitis-idaea* and *Viburnum edule*. *Arctostaphylos rubra* and *Linnaea borealis* are common dwarf shrubs. Common herbaceous species include *Cornus canadensis*, *Equisetum arvense*, *E. pratense*, and *Geocaulon lividum*. The feather mosses, *Hylocomium splendens* and *Rhytidiadelphus triquetrus* are the dominant species and often blanket the ground. Lichen cover is low.

In some old-growth *Picea glauca* stands, alder cover is less than 25% cover and the understory is instead dominated by the shrub *Rosa acicularis* with *Ledum palustre* ssp. *decumbens, Vaccinium vitis-idaea* and *Viburnum edule* occurring at lower cover (Boggs and Sturdy 2005). Common herbaceous species are the grass *Calamagrostis canadensis* and the forb *Mertensia paniculata*. Similar to the alder-dominated understories, the feather moss, *Hylocomium splendens* often blankets the ground and lichen cover is low.

Floodplain succession in interior Alaska has been well documented. Across these chronosequences, newly-formed gravel bars are colonized by light-seeded herbs and shrubs in the *Salix* genus (Viereck 1970). Within five years, willow saplings and *Populus balsamifera* (balsam poplar) seedlings and are abundant (Walker et al. 1986, Boggs and Sturdy 2005). During this stage, *Alnus incana* ssp. *tenuifolia* and *Picea glauca* seedlings are often present but less abundant. Under conditions of low sedimentation, and good soil aeration, *Alnus incana* ssp. *tenuifolia* may be an important pioneer shrub. Within 10 to 15 years, the *Populus balsamifera* saplings are able to overtop the *Salix* species, which are gradually replaced by *Rosa acicularis* and *Viburnum edule* shrubs in the understory (Figure 80). *Equisetum* species become nearly continuous on the forest floor.

In mid-seral stages *Picea glauca* trees codominate with *Populus balsamifera.* Because *Populus balsamifera* are short-lived (100 to 150 years), poorly-recruited, and subject to felling by beaver, *Picea glauca* eventually dominate the forest canopy (Viereck et al. 1983, Walker et al. 1986, Oechel and Van Cleve 1986). Initially, stands of *Picea glauca* are relatively evenly aged due to similar time of establishment; however, variable recruitment eventually produces multi-aged stands with the oldest individuals more than 300 years old (Chapin et al. 2006). The dominance of alder species (*Alnus incana* ssp. *tenuifolia* and *Alnus viridis* ssp. *sinuata*) in the understory, and feather mosses (*Hylocomium* spp. and *Pleurozioum schreberi*) on the forest floor may persist.

Figure 80. The *Picea glauca/Rosa acicularis* Plant Association on the Yukon River in Yukon-Charley Rivers National Preserve, Alaska (Boggs and Sturdy 2005).

In late-seral stages, the closed *Picea glauca* canopy reduces light infiltration to the forest floor, slowing soil thaw in the spring and summer. A combination of low soil temperature, acidification, and other factors reduces the rate of decomposition and thus nutrient cycling (Flanagan and Van Cleve 1983, Van Cleve et al. 1983, Van Cleve et al. 1993), leading to the accumulation of organic material on the forest floor, which further reduces soil temperatures. While permafrost may underlie *Picea glauca* stands, it is more common *Picea mariana*-dominated plant associations due to their higher soil moisture contents (Boggs and Sturdy 2005).

Common disturbances to stands of *Picea glauca* include flooding, browsing by snowshoe hares, and winter ice storms (Viereck et al. 1993). *Picea glauca* is attacked by a number of bark beetles in the genera *Dendroctonus, Ips, Trypodendron, Dryocoetes, Scolytus, Polygraphus* and others (USDA, FSRD 2014). Although most of these species attack trees of low vigor, the spruce bark beetle (*Dendroctonus rufipennis*) attacks trees of normal vigor and has killed large areas of mature and old-growth *Picea glauca*.

Conservation Status

Rarity: In interior Alaska, stands of old-growth *Picea glauca* growing on well-drained alluvial and riparian soils are relatively rare; 35 locations have been documented (Juday et al. 2015).

Threats: Old-growth *Picea glauca* forests on floodplains are susceptible to damage from timber harvest, forest fire, spruce bark beetle *(Dendroctonus rufipennis)* infestation, and climate change. A westward shift of the *Picea glauca* range appears to be driven by increasing summer temperatures in interior Alaska, which can exceed the physiological tolerances of *Picea glauca* (Juday et al. 2015).

Trend: Floodplain forests were exploited during the gold rush and settlement period of the early 1900s but current logging is small scale and localized near remote villages (Zasada et al. 1987). However, short-term declines are predicted due to an intensified disturbance regime (insects and fire). Long-term declines are predicted to account for *Picea glauca* mortality in lowland interior sites where future warming is expected to be most intense (Juday et al. 2015).

Species of Conservation Concern

The bird and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 38, Table 39). While just a few species of conservation concern have been documented for this biophysical setting, old-growth canopy structure may be vital to cavity-nesting species such as the boreal owl (*Aegolius funereus*), hawk owl (*Surnia ulula*), northern flying squirrel (*Glaucomys sabrinus*), and hairy woodpecker (*Picoides villosus*). In Alaska, American marten (*Martes americana*) utilize large tree cavities for denning and resting and thus reach each peak abundance in mature conifer forests and are generally absent from extensive tracts of secondary successional vegetation (Bailey 1981). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 38. Bird species of conservation concern within the *Picea glauca* Floodplain Old-growth Forest Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Birds				
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	Could use river habitat during nonbreeding seasons.
Osprey	*Pandion haliaetus*	G5	S3S4B	Known to use mature spruce tree habitat along major river systems in Interior Alaska (Hughes 1990).

Table 39. Plant species of conservation concern within the *Picea glauca* Floodplain Old-Growth Forest Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Carex eburnea	G5	S3	Moist *Picea glauca* woods on river terrace
Festuca occidentalis	G5	S1	Upper terrace of Takhin River floodplain

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 40).

Table 40. Plant associations of conservation concern within the *Picea glauca* Old-Growth Forest Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Open *Picea glauca/Alnus crispa*-Alnus tenuifolia*/Vaccinium vitis-idaea/Hylocomium splendens*	G3	S3	Viereck 1989
Picea glauca/Alnus crispa/Rosa acicularis/Arctostaphylos rubra*	G3	S3	Yarie 1983

*2016 taxonomy is *Alnus viridis* ssp. *crispa* and *Alnus incana* ssp. *tenuifolia*

Classification Concept Source

The classification concept for this Biophysical Setting is based on Viereck (1970) and Juday and Zasada (1984).

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Steppe Bluff Biophysical Setting

Boreal Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

Steppe bluffs are open, graminoid and sagebrush (*Artemisia frigida*) dominated sites occurring on steep, south-facing slopes in the interior of Alaska (Figure 81). The warm and dry microclimates of the steppe bluffs are thought to exclude trees and foster a distinctive flora characterized by a high diversity of Beringian and endemic plant species (Edwards and Armbruster 1989, Murray et al. 1983, Roland 1996). Steppe associations are considered analogues of vegetation that was widespread across Beringia during the colder and drier conditions of the late Pleistocene (Kassler 1979, Lipkin and Tande 1991, Murray 1981, Murray et al. 1983, Walker et al. 1991).

Figure 81. Steppe bluff habitat near Delta Junction, Alaska.

Distribution

Steppe associations occur primarily on bluffs overlooking interior rivers, including the Tanana, Porcupine, Copper and a section of the Yukon east of Galena (Edwards and Armbruster 1989, Hanson 1951, Juday and Dyrness 1985, Kassler 1979, Lipkin and Tande 1991, Murray et al. 1983, Osgood 1909, Tande 1996, Roland 1990). Beyond interior river systems, steppe associations occur on bluffs in Denali National Park and valley sides along Arrigetch Creek (Cooper 1986) and the Matanuska River. The northernmost occurrence of steppe-like associations in North America has been reported from the south-facing slopes and summits of pingos within the central Arctic Coastal Plain of Alaska (Walker et al. 1991). The Anderson River steppe in Canada's Northwest Territory is the easternmost known occurrence of steppe in North America (Kesting 1993). Additional steppe locations in Canada include esker slopes above Kluane Lake (Marsh et al. 2006) and south-facing slopes in the Aishihil-Sekulmun Lakes area, both in the Yukon Territory (Vetter 2000).

The Steppe Bluff biophysical setting distribution was modeled from locations documented in literature or represented by collections of *Artemisia frigida* and *Calamagrostis purpurascens* (purple reedgrass). Herbaria records were only accepted into the model if location notes explicitly described the site as steppe habitat and/or inspection of the underlying remotely-sensed imagery indicated steppe habitat. Modeling was performed using MaxEnt (Phillips and Dudík 2008), a predictive technique that expresses the suitability of the landscape for a given species or system as a function of the environmental variables that are most highly correlated with its documented occurrences. The final model incorporated the following environmental variables (listed in order of decreasing importance): mean annual precipitation, elevation, mean summer temperature, heat load index, mean spring temperature and mean winter temperature (SNAP 2016). Modeled distribution of Steppe Bluff is shown in Figure 82. Statistical analysis showed correlation between the environmental variables and the likelihood of steppe bluff habitat, the area under the curve value was 0.863, indicating that modeled steppe bluffs were effectively modeled based on the environmental inputs and not likely to be coincidentally mapped.

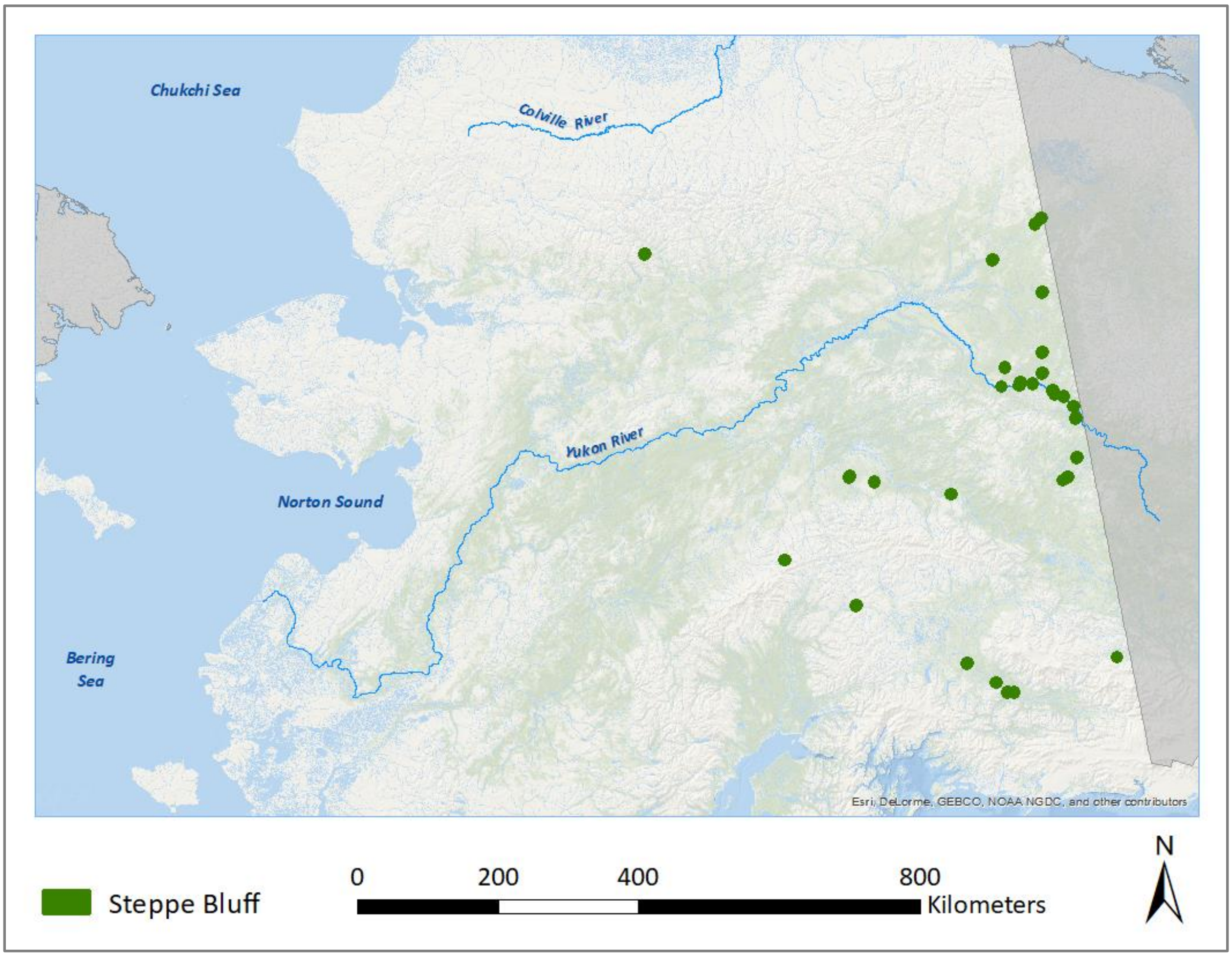

Figure 82. Distribution of the Steppe Bluff Biophysical Setting. Note that areas of occurrence in this map are buffered for greater visibility.

Climate

Short, warm summers and long, cold winters characterize the subarctic continental interior of Alaska. Average annual precipitation ranges from less than 25.4 cm in valley bottoms and lowlands to between 51 and 102 cm at higher elevations. Greatest rainfall occurs in late summer, primarily as a result of thunderstorms. Average annual snowfall ranges from 114 to 254 cm. Average annual temperature is between -8.8 to 12.2 °C in the north and ranges from highs of 20 to 25 °C to lows of -6.7 to -3.9 °C in the south. The average frost-free period is 60 to 100 days with the temperature remaining above freezing from June through mid-September (NRCS 2004).

Figure 83. Steppe bluff habitat near Copper River, Alaska.

Environmental Characteristics

Steppe bluffs typically occupy steep slopes (inclination 30-46°) that are oriented to the south (aspect 121-225°) and range in elevation from 244 to 914 m (Figure 83; Roland 1990). Associated landforms are commonly river bluffs, but can also include terraces, (Howenstein et al. 1985) low hills (Vetter 2000) or pingos (Walker et al. 1991). The topography of steppe bluffs has implications for microclimate in so far that surfaces undergo great daily and annual fluctuations in temperature and moisture (Edwards and Armbruster 1989, Lewis 1998, Roland 1996, Walker et al. 1991). Moisture of steppe soils is strongly limited by exposure to wind, low accumulation and residence of snow, drainage across steep slopes, and high soil evaporation and transpiration caused by the slopes' direct orientation to the low-angled sun (Bliss et al. 1973, Lewis 1998, Lloyd et al. 1994, Kassler 1979, Roland 1990, Wesser 1989).

Steppe soils are well-drained, silty loams to loams with low organic matter content (Roland 1996). Permafrost is typically absent due to warm soil temperatures in the summer and poor insulation in the winter (Boggs and Sturdy 2005). Soil pH ranges from 6.2 to 8.0 with a mean of 7.0 and is often elevated by input of calcium carbonate-rich loess (Kassler 1979, Marsh et al. 2006, Roland 1996, Walker et al. 1991). Bare soil is characteristic of developing steppe (Howenstein et al. 1985, Lewis 1998, Murray et al. 1983, Shacklette 1966).

Vegetation

Steppe bluffs are generally vegetated with dry, open low shrub and dry, graminoid-herbaceous associations characterized by the low shrubs *Artemisia frigida*, *Amelanchier alnifolia*, *Elaeagnus commutata*, *Shepherdia canadensis*, and *Juniperus communis*, the dwarf shrub *Arctostaphylos uva-ursi*, the grasses *Bromus pumpellianus*, *Festuca altaica*, *Calamagrostis purpurascens*, and *Poa glauca*, and the forbs *Artemisia arctica*, *A. alaskana*, *Bupleurum americanum*, and *Saxifraga tricuspidata* (Lipkin and Tande 1991). *Populus tremuloides* (quaking aspen) and *Picea glauca* (white spruce) associations occur peripheral to bluffs. Vascular plant cover is often sparse (Lipkin and Tande 1991, Roland 1996) with bare soil or lichen occupying the interstices (Batten et al. 1979, Lewis 1998, Roland 1996). A variety of shrub and herbaceous plant associations of conservation concern are provided in Table 43 (Batten et al. 1979, Boggs and Sturdy 2005, Chapin et al. 2006, Hanson 1951, Juday and Dyrness 1985, Kassler 1979, Lewis 1998, Lipkin and Tande 1991, Roland 1990, 1996; Tande 1996, Vetter 2000, Wesser and Armbruster 1991).

The presence of biological soil crusts have been noted in several mature steppe bluffs (e.g. Dickson 2000, Marsh et al. 2006, Walker et al. 1991, Zazula et al. 2002). Predominance of cyanobacteria in the *Collema* genus suggests that crusts make important contributions to the nitrogen budget of steppe ecosystems (Marsh et al. 2006). Foliose lichens and bryophytes are also sometimes common, and can include *Dermatocarpon*, *Diploschistes*, *Endocarpon*, *Fulgensia*, *Psora*, *Toninia*, *Xanthoparmelia*, *Rhytidium rugosum* and *Tortula ruralis* (Roland 1996). Steppe bluffs support a disproportionately high diversity and abundance of rare plant taxa (Murray et al. 1983, Shacklette 1966). The rare plants are often associated with rock outcrops and scree (C. Roland pers. comm. 2014).

Succession

Large scale disturbances affecting steppe bluffs include fire and mass wasting (Lewis 1998); smaller scale disturbances include burrowing and/or grazing by rodents and ungulates (Vetter 2000). Fire is thought to favor steppe development by removing competitive forest taxa that would otherwise exclude steppe taxa (Lewis 1998, Roland 1990). Similarly, landslides are thought to favor steppe development by removing forest taxa, exposing mineral soil for colonization by seedlings, and altering the competitive balance in favor of faster growing, more readily dispersed plants (Roland 1990 and 1996).

The herbaceous and shrub steppe associations depend on disturbance to persist (Lewis 1998) and are thought to be seral to *Populus tremuloides* (quaking aspen) woodlands with dry understory species such as *Arctostaphylos uva-ursi*, *Rosa acicularis* and *Sheperdia canadensis* (Vetter 2000, Boggs and Sturdy 2005). Where there is sufficient moisture, *Betula neoalaskana* (paper birch) and *Picea glauca* (white spruce) are able to colonize the *Populus tremuloides* woodland; a xeric *Picea glauca* forest may eventually establish (Chapin et al. 2006, Lewis 1998). Following fire, *Populus tremuloides* woodlands may revert to steppe associations (Lewis 1998).

Conservation Status

Rarity: Although limited in spatial extent (31 km^2) and occurrence (31 sites documented from literature), steppe bluffs contribute significantly to regional biodiversity and provide an analogue of late Pleistocene vegetation and the climatic conditions responsible for its formation (Murray et al. 1983, Roland 1990, Kassler 1979). Modern day steppe bluff habitats support high insect diversity (Guinn and Armbruster 1985), as well as a distinctive flora comprised of a disproportionately high number of rare, endemic and disjunct taxa (Roland 1996, Shacklette 1966). Consequently, this biophysical setting provides an opportunity to conserve a diversity of rare taxa by focusing management on a single habitat (Parker and Batten 1995).

Threat: Threats to steppe habitats in Alaska include invasion by nonnative plant species and increased use and development. As one of the warmest and driest microclimates in Alaska, steppe bluffs may be susceptible to invasion by nonnative ruderal species introduced from more temperate climates (Flagstad et al. 2012). The open and rocky substrates of steppe bluffs offer natural hiking routes, yet are unstable enough to be greatly disturbed by foot traffic (Parker and Batten 1995). Development of roads and pipelines, or material sourcing to support such development are additional threats (Batten et al. 1979, Parker and Batten 1995); however, the remote locations and steep topography of most steppe habitats would likely preclude the economic feasibility of such projects.

Trend: Climate envelopes modeled for steppe bluffs predict increases in the suitability of existing habitat and shift in the extent of suitable habitat toward the continent center in response to higher continental rates of evapotranspiration (Boucher et al. 2016, Flagstad et al. 2012). In a warming and drying climate, graminoid-dominated systems such as steppe bluffs could expand into areas currently occupied by xeric forests (Blinnikov et al. 2011, Chapin et al. 2006). Moreover, it is possible that the distinctive flora of steppe associations could source the initial colonization of habitat (Kesting 1993, Roland 1996) or provide destination habitats for taxa purposefully migrated from more temperate regions.

Species of Conservation Concern

The mammal, bird, insect, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 41, Table 42). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 41. Bird, mammal and insect species of conservation concern within the Steppe Bluff Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alaska tiny shrew	*Sorex yukonicus*	GNR	S3	A habitat generalist that is suspected to use steppe bluff habitat when present.
Woodchuck	*Marmota monax*	G5	S2	Prefers dry, open grassy areas – and are suspected to occur in steppe bluff habitat.
Birds				
American Peregrine Falcon	*Falco peregrinus anatum*	G4T2	S3B	Thought to utilize steppe bluff habitats for nesting and hunting.
Fox Sparrow	*Passerella iliaca*	G5	S3	Occur within edge habitat of steppe bluffs, primarily in wooded understory.
Mountain Bluebird	*Sialia currucoides*	G5	S3B	Thought to use steppe bluff habitats for feeding, nearby open woodlands provide nesting habitat.
Osprey	*Pandion haliaetus*	G5	S3	Known to use bluff habitat near Northway-Tetlin and other riverine bluffs in Interior Alaska.
Sharp-shinned Hawk	*Accipiter striatus*	G5	S3	Inhabits the boreal forest, steppe bluff habitat would be for opportunistic feeding.
Smith’s Longspur	*Calcarius pictus*	G5	S3	Breed in dry tundra and is known to occur near steppe bluff habitat in southern Central AK (Wrangell Mountains).
Swainson’s Hawk	*Buteo swainsoni*	G5	S2	Could use steppe bluff habitat within its known range for opportunistic feeding on mammals and insects.
Insects	various species	-	-	Steppe bluff systems are hot spots for insect diversity. Many species of solitary bees includes members of the *Andrena, Andrenidae, Lasioglossum, Halictus, Megachile, Osmia, Coelioxys, Anthophora*, *Nomada* and *Epeolis* genera appear to be restricted to the hottest and driest sites in the interior.

Table 42. Plant species of conservation concern within the Steppe Bluff Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Alyssum obovatum	G5	S2S3	Occurs on south facing steppe bluffs near the Porcupine River.
Apocynum androsaemifolium	G5	S3	Reaches its northern distribution limit in steppe communities of interior Alaska.
Artemisia tanacetifolia	GNR	S3	Grass shrub steppes, grass forb steppes, aspen woodland, dwarf shrub tundra.
Botrychium campestre var. *lineare*	G2?	S1	Grows on open soil in dry graminoid-forb steppe vegetation on steep, treeless S-facing slopes of the Nutzotin Mountains.
Carex eburnea	G5	S3	Occurs on south facing steppe bluffs near Porcupine River.
Chamaerhodos erecta	G5	S2S3	Reaches its northernmost distribution in steppe communities of Interior Alaska.
Cryptantha shackletteana	G1Q	S1	Recruitment is high on steppe bluffs. Four populations in Alaska.
Douglasia arctica	G3	S3	Sparsely vegetated, aspen and spruce woodland, low birch scrub, graminoid steppe, and Dryas heath.
Draba murrayi	G2	S2S3	Small populations occur on open slopes or in graminoid steppes along the upper Yukon River.
Elymus lanceolatus ssp. *psammophilus*	G3G4	S1S2	Populations on steppe bluffs near the confluence of the Copper and Chitina Rivers represent the most western distribution for this species of grass.
Erigeron ochroleucus	G5	S1S2	Occurs on sparsely vegetated graminoid steppes.
Eriogonum flavum var. *aquilinum*	G5	S2	Sparsely vegetated river bluffs and rock outcrops. Seedlings appear to be uncommon, suggesting that this species reproduces slowly.
Erysimum angustatum	G5T2	S2	Found on sparsely vegetated, open graminoid steppe, open sites in aspen or birch forest.
Maianthemum stellatum	G5	S3	Occurs on steppe slopes along the Yukon River.
Orobanche fasciculata	G4	S1	A parasitic plant, known from a few locations in eastern Interior Alaska.
Phacelia mollis	G2G3	S3	Occurs in steppe communities in eastern Interior Alaska.
Rosa woodsii ssp. *woodsii*	G5T5	S2S3	Steppe and hill prairie communities, open Aspen-mixed forest woodlands.
Townsendia hookeri	G5	S1	In Alaska known only from a few locations at south-facing steppe bluffs along the Porcupine River.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 43).

Table 43. Plant associations of conservation concern within the Steppe Bluff Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Tree			
Populus tremuloides/Elaeagnus commutata-Shepherdia canadensis/Arctostaphylos spp./*lichens*	G3	S3	Neiland and Viereck 1977
Shrub			
Amelanchier alnifolia	G3	S3	Wesser and Devoe 1987
Artemisia frigida-Bromus pumpellianus	G3	S3	Hanson 1951
Artemisia frigida	G3	S3	Young and Racine 1976
Festuca altaica-Calamagrostis spp.	G3	S3	Batten et al. 1979
Juniperus communis	G3	S3	Young and Racine 1976
Herbaceous			
Agropyron spicatum-Artemisia frigida	G3	S3	Hanson 1951
Calamagrostis purpurascens	G3	S3	Hanson 1951
Calamagrostis purpurascens-Artemisia frigida	G3	S3	Boggs 2000

Classification Concept Source

The classification concept for this biophysical setting is based on Osgood (1909).

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Southern Alaska and Aleutian Islands Biophysical Settings and Plant Associations

Anthelia juratzkana–Gymnomitrion corallioides Biological Crust Plant Association

Liverwort Biological Crust Plant Association

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The most recent pyroclastic flow from Aniakchak Volcano is thought to have occurred approximately 3,400 years before the present; a major eruption created the approximately 10 km wide caldera, pyroclastic flow filled many of the pre-existing valleys blanketing the peninsula from coast to coast (Neal et al. 2001). Pyroclastic flows typically lack nutrients necessary for plant growth and the volcanic fines are freely moved by wind and water. The Aeolian effect commonly strips the fines from the surface of volcanic deposits, leaving larger material that does not hold enough water for plant growth (del Moral and Bliss 1993). Biological soil crusts, also called 'microbiotic' or cyano-bacterial-lichen' crusts, are sets of early colonizers

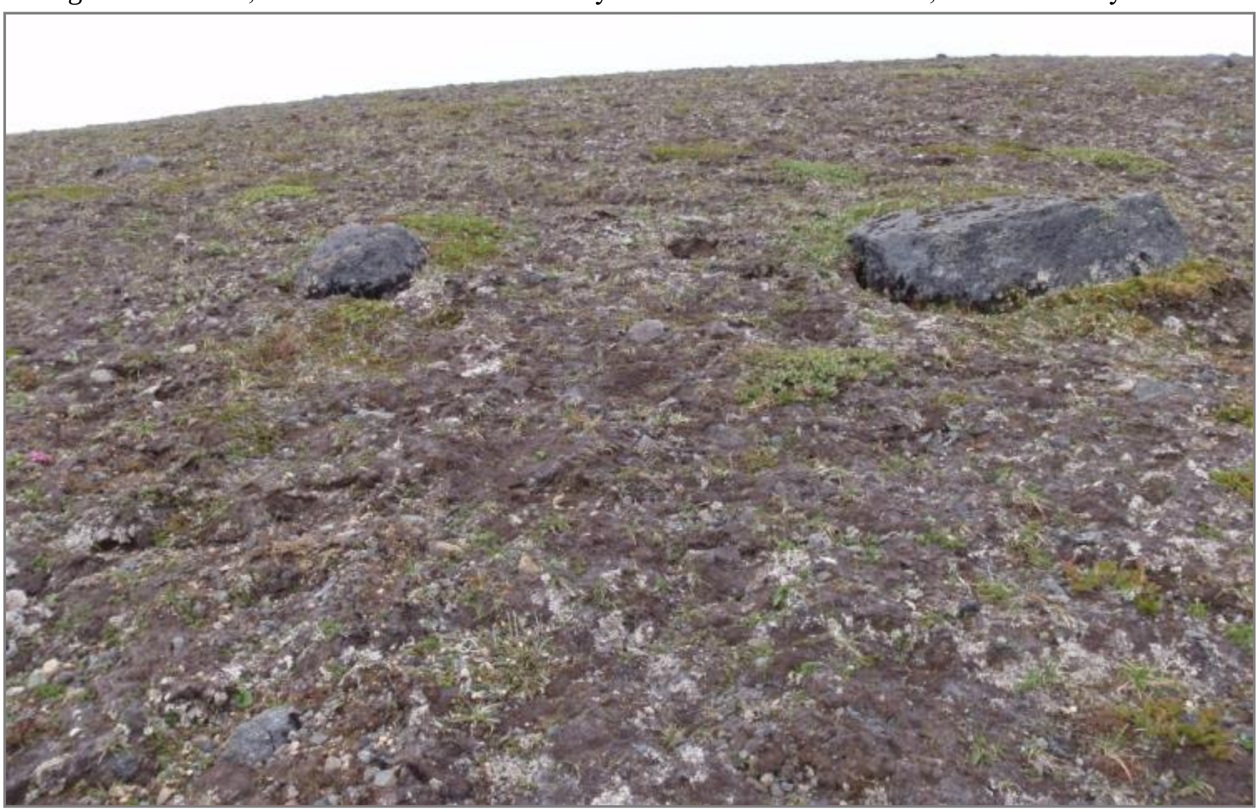

Figure 84. The *Anthelia juratzkana–Gymnomitrion corallioides* Plant Association on a sideslope of the Aniakchak Volcano, Alaska.

of unvegetated landscapes throughout the world (Belknap and Gillette 1997). These crusts hold the soil together while larger plants move in to revegetate the area.

The *Anthelia juratzkana–Gymnomitrion corallioides* (liverwort) Biological Crust Plant Association is an early-seral type dominated by liverwort species occurring on open, exposed sites. The association has only been described on pyroclastic flow deposits in southwest Alaska (Bosworth 1987, Hasselbach 1995, Boucher et al. 2012; Figure 84). This association typically occupies a small total area when present and represents a unique habitat. Impacts are not well documented, but thought to be low.

Distribution

This association has a small total area and few documented occurrences but is suspected to be widespread on pyroclastic flows in Southwest Alaska and the Aleutian Islands. The only known occurrence of this association occurs on pyroclastic flow and deposits from the Aniakchak Volcano (Figure 85). The *Anthelia juratzkana–Gymnomitrion corallioides* distribution map was developed from the extent of pyroclastic flow discharged from the Aniakchak Volcano (VanderHoek and Myron 2004) and the cryptobiotic soil landcover class mapped by Boucher and others (2012).

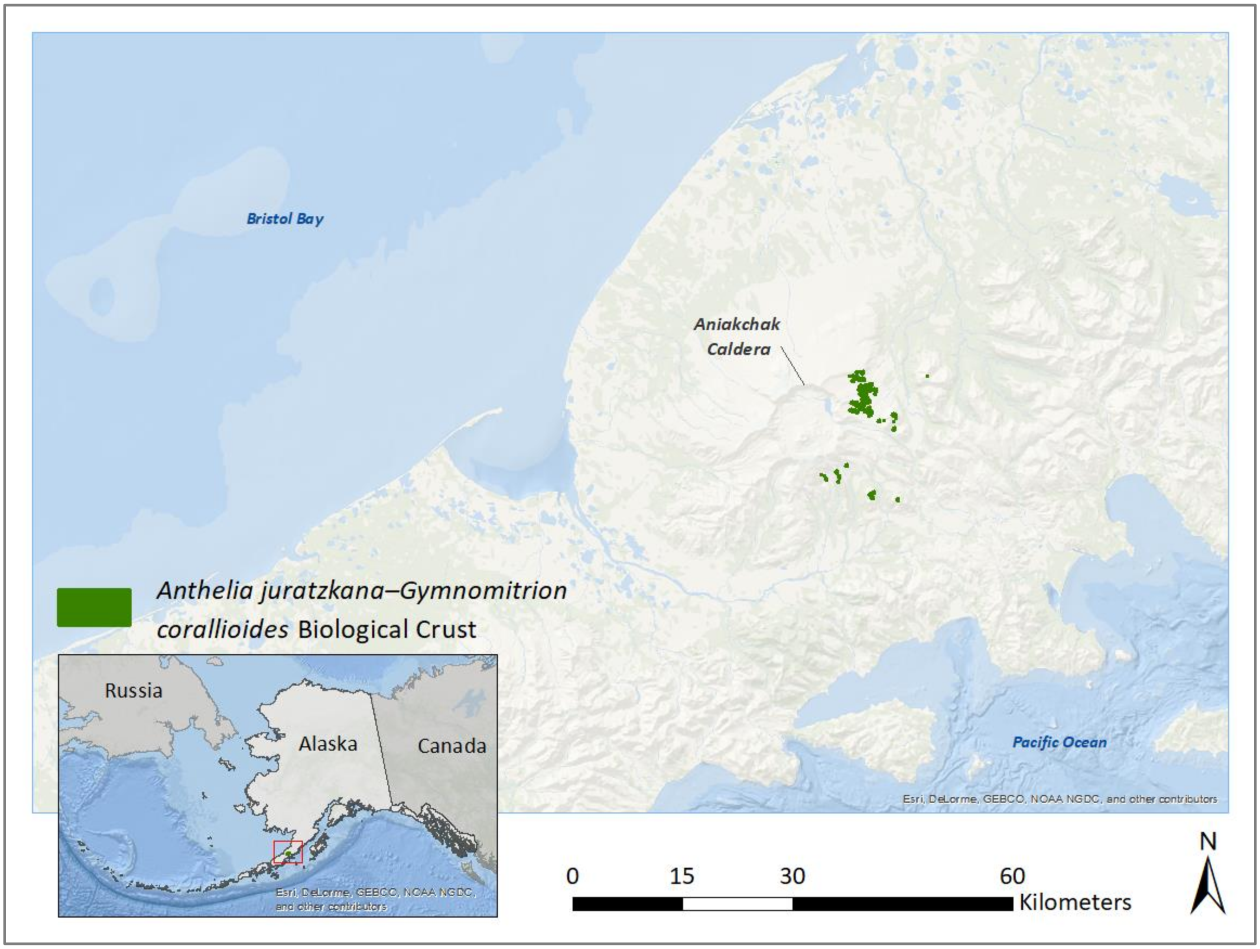

Figure 85. Distribution of the *Anthelia juratzkana–Gymnomitrion corallioides* Plant Association on the Alaska Peninsula. Note that the occurrences in this map is buffered for greater visibility.

Climate

The southwest Alaska Peninsula area has a cool maritime climate characterized by cloudy and foggy conditions, moderate temperatures, and abundant rainfall. Gale force winds, occasionally approaching 161 km/h, are common during storms. The average annual precipitation ranges from 53 to 198 cm. Annual snowfall is 75 to 215 cm and is generally limited to higher elevations. The average annual temperature is 2 to 4 ^{o}C the average frost-free period is about 115 to 140 days (NRCS 2004).

Environmental Characteristics

The *Anthelia juratzkana–Gymnomitrion corallioides* Plant Association occurs on pyroclastic material and overdeposits of eolian ash. In Aniakchak, the association occurs as small to large patches across gentle slopes of the caldera. Sites are often alpine, with elevation ranging from 361 to 773 m and mesic with water primarily delivered by moisture-laden winds. Characteristic soil profiles include a shallow organic horizon with pH ranging from 4.8 to 7.5 and/or an A horizon with pH ranging from 4.9 to 6.1 over unaltered parent material composed of volcanic pumice and tephra with pH ranging from 6.2 to 6.9 (Boucher et al. 2012).

Vegetation and Succession

This association is characterized by a well-developed cryptogamic crust dominated by the liverwort species *Anthelia juratzkana* and *Gymnomitrion corallioides* (Boucher et al. 2012; Figure 86). In addition to the nominal species, liverworts in the *Calypogeia* and *Cephaloziella* genera, *Nardia breidleri*, *Scapania undulata*, and cyanobacteria in the *Scytonema* genus occupy at least 30% of the ground surface. Moss, lichen, and vascular plant species cooccur at low canopy cover. Common moss species include members of the *Synthrichia*, *Grimmia*, *Dicranum,* and *Racomitrium* genera. Common lichens are *Cetraria ericetorum*, *Stereocaulon vesuvianum*, and *Peltigera* species. Common vascular associates include the dwarf shrubs *Empetrum nigrum*, *Salix ovalifolia*, *Loiseleuria procumbens*, *S. rotundifolia*, *Vaccinium uliginosum*, and the graminoids *Deschampsia cespitosa* and *Carex microchaeta* (Boucher et al. 2012).

Figure 86. Liverwort mat formed by *Anthelia juratzkana* and *Gymnomitrion corallioides* species, Aniakchak Volcano, Alaska.

Biological soil crusts develop as a complex mosaic of cyanobacteria, liverwort, lichen, and moss species. During the initial colonization of bare mineral soil, cyanobacteria and microfungi weave filaments through the top few millimeters of soil, forming a surface crust that is resistant to wind erosion (Cameron 1966, Harper and Marble 1988, West 1990). In the Aniachak caldera, the importance of this biological crust has been emphasized with respect to Nitrogen fixation, substrate amendment, and subsequent colonization of vascular plant species (Hasselbach 1995). In the absence of disturbance, sites develop towards an alpine dwarf shrub community dominated by *Salix ovalifolia*, *Empetrum nigrum* and/or *Vaccinium uliginosum* (Boucher et al. 2012).

Conservation Status

Rarity: While multiple (12) occurrences of the *Anthelia juratzkana–Gymnomitrion corallioides* plant association have been documented in Alaska, their range is restricted to the flanks of the Aniakchak Volcano. However, it is likely that this association occurs in additional early-successional volcanic habitats in southwest Alaska.

Threats: Renewed volcanic activity threatens this association in so far that the entire system could be buried by lava, pumice or ash. Trampling by hikers has been noted as a concern (Bosworth 1987, Hasselbach 1995).

Trend: Short-term declines are not expected but long-term impacts are inevitable. The Aniakchak caldera erupted catastrophically 3,500 years ago with at least 12 lesser eruptions since with the most recent occurring in 1931. While the volcano shows no sign of current unrest, eruptions are fully expected to occur in the future (Neal et al. 2001). In the absence of disturbance, vegetation succession on these sites may develop towards alpine dwarf shrub communities.

Species of Conservation Concern

The plant species listed below are designated critically imperiled or vulnerable globally (G1-G3) and are known or suspected to occur in this plant association, they are not currently ranked at a statewide level (SNR) (Table 44). Please visit the NatureServe Explorer website for species descriptions (NatureServe 2015). Additional study is required to evaluate whether this plant association supports animal species of conservation concern.

Table 44. Plant species of conservation concern within the *Anthelia juratzkana-Gymnomitrion corallioides* Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Anthelia julacea	G3G4	SNR	Widely distributed but rare arctic-alpine liverwort. Associated with areas of late-lying snow.
Gymnomitrion mucrophorum	G1	SNR	Newly described species from Alaska (Schuster 1995). It is known only from its type locality in the Talkeetna Mountains of Alaska where it was growing with other hepactics on thin soil over boulders in a moist boulder field (Schuster 1995).
Gymnomitrion apiculatum	G3G4	SNR	Arctic-alpine species found in North America only in Alaska and Greenland, where it is local and often rare.

Classification Concept Source

Initial descriptions of this community are by Bosworth (1987) and Hasselbach (1995). Formal placement into a plant association is by Boucher and others (2012).

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Artemisia arctica-Trisetum spicatum Nunatak Plant Association

Boreal Sagebrush-Spike Trisetum Nunatak Plant Association

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Artemisia arctica-Trisetum spicatum* (boreal sagebrush-spike trisetum) Nunatak Plant Association is a late-seral, herbaceous type occupying high-alpine sites in a periglacial environment (Figure 87). Impacts are generally low. Nunataks are isolated rocky areas projecting above inland areas of ice and/or snow.

Figure 87. The *Artemisia arctica-Trisetum spicatum* Nunatak Plant Association in Kenai Fjords, Alaska.

Distribution

This plant association occurs as small patches in high alpine sites of southern Alaska. It has been sampled on the Kenai Peninsula and Lake Clark National Park and Preserve (Miller et. al. 2006), and occurs on the Juneau Ice Field (Heusser 1954), the southeastern Wrangell Mountains (Scott 1974) and likely in other coastal mountain ranges. The distribution of this plant association was developed from mapping alpine (over 1,000 m) habitats that are completely surrounded by glacial ice (GLIMS 2005). Four occurrence records represent herbaria collections of either *Artemisia arctica* or *Trisetum spicatum* within this range of distribution (CPNWH 2016, Figure 88).

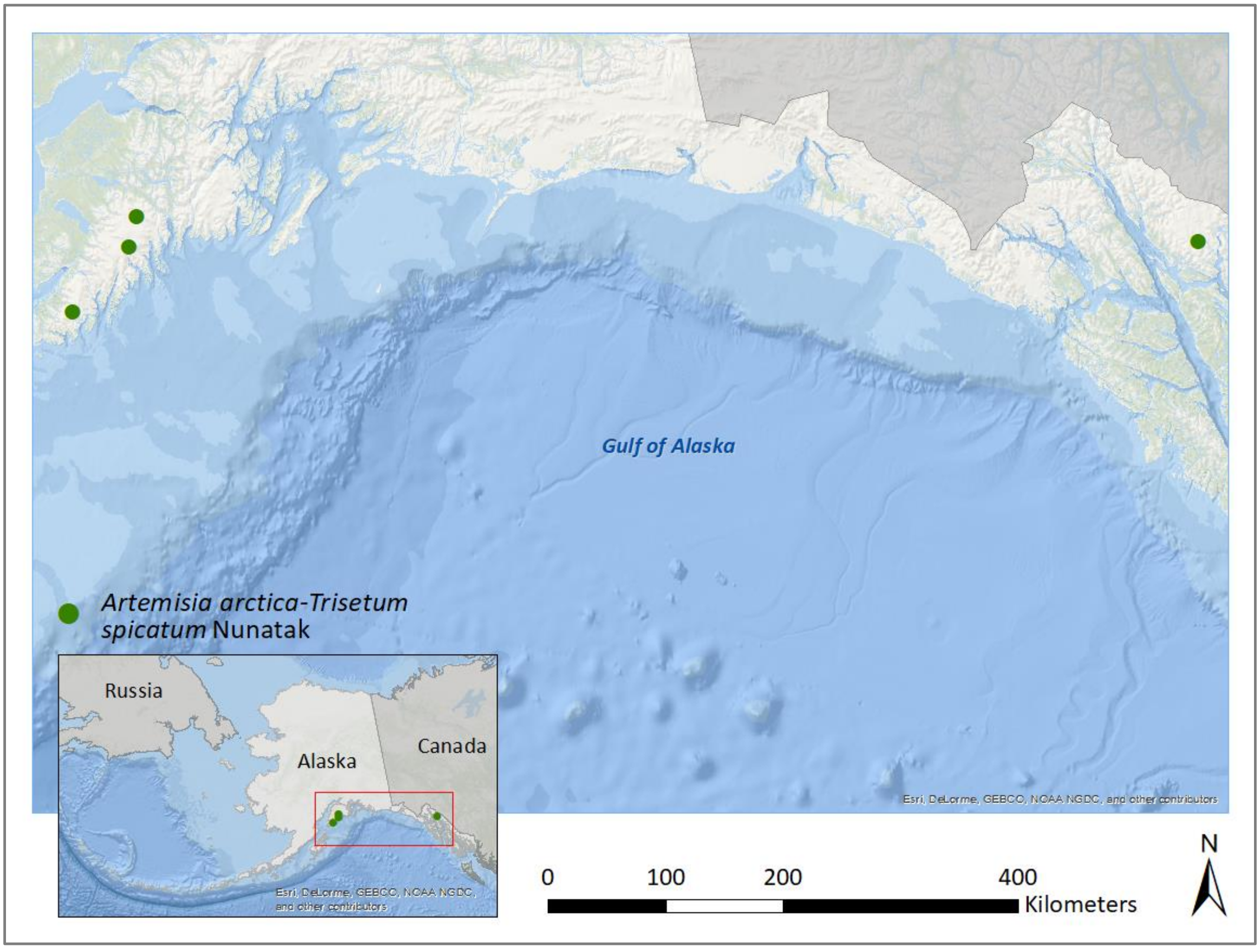

Figure 88. Distribution of the *Artemisia arctica-Trisetum spicatum* Nunatak Plant Association. Note that point occurrences in this map are buffered for greater visibility.

Climate

Southern Alaska has a cool, wet maritime climate and is generally free of permafrost (Gallant et al. 1995, Nowacki et al. 2001). Mean annual precipitation ranges from 135 to 390 cm with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C.

Environmental Characteristics

This association occurs on alpine ridges, nunataks and sideslopes at elevations that are typically greater than 1,000 m (Figure 89). Depending on landform, slopes range from 2 to 40 degrees. These sites experience high winds and deep snows; soils may freeze in winter but permafrost does not occur. Exposed bedrock and surface rock are common. Sites are dry to mesic with a soil pH of 5.2. The soils are typically silt, sand, and angular gravel over bedrock.

Vegetation

Due to the high cover of exposed rock, total vascular plant cover may be less than 25%. Species composition is variable but often includes *Artemisia arctica*, *Salix rotundifolia*, *Carex microchaeta*, *Trisetum spicatum*, *Astragalus alpinus*, *Minuartia arctica*, *Saxifraga bracteata*, *S. bronchialis*, *Sibbaldia procumbens* and *Silene acaulis*. Common nonvascular genera include moss and lichen species in the *Racomitrium* and

Stereocaulon genera, respectively. This association cooccurs with other high alpine associations in the region, including *Salix rotundifolia/Carex microchaeta*, *Carex microchaeta* and *Luzula wahlenbergii* (DeVelice et al. 1999). Based on soil development, this association likely represents a late-seral stage.

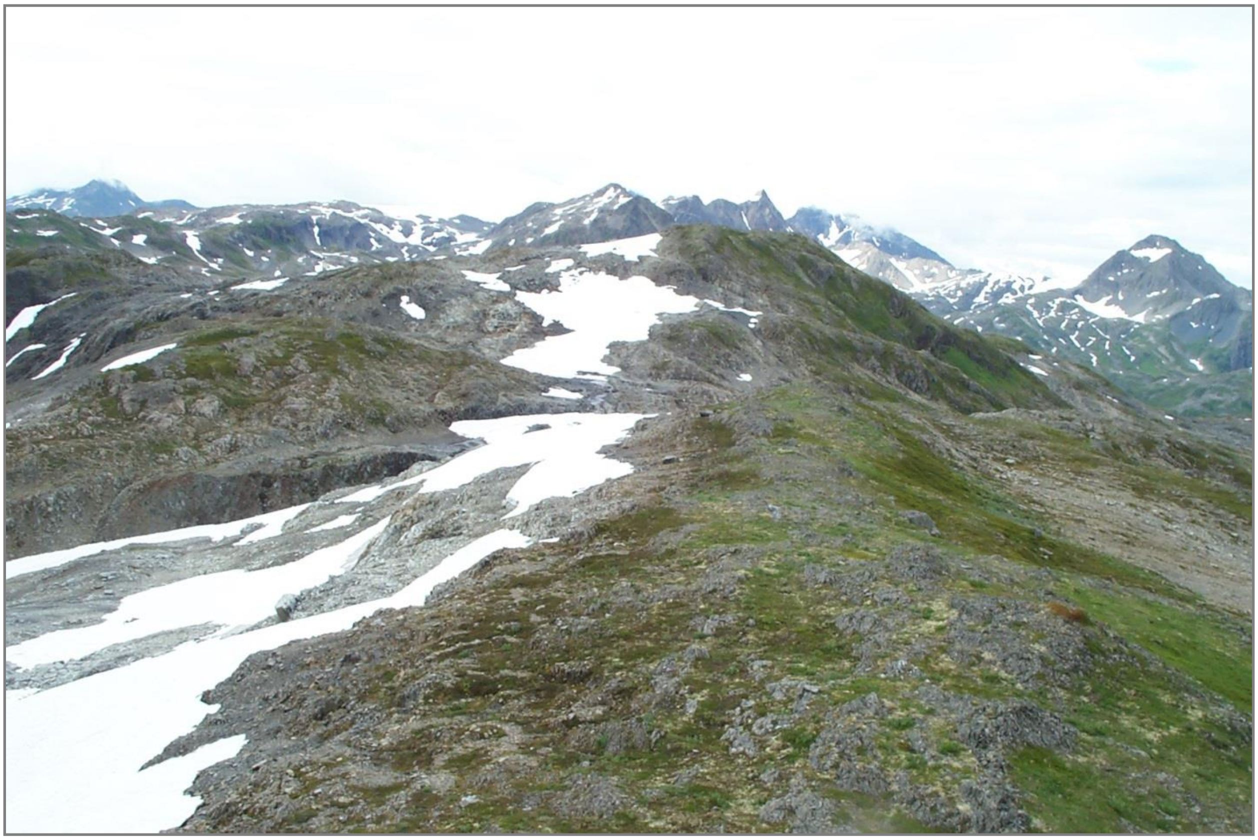

Figure 89. The *Artemisia arctica-Trisetum spicatum* Nunatak Plant Association in Kenai Fjords, Alaska.

Conservation Status

Rarity: Within Southeast Alaska, nunataks are estimated to occupy 2,900 km^2. Within this potential range, four occurrences of the *Artemisia arctica – Trisetum spicatum* association have been documented. This association is known only from Alaska.

Threats: Owing to its remote, alpine location, impacts are assumed to be low; however climate warming may promote the colonization of species from more temperate, lower elevation sites.

Trend: Short- and long-term increases in extent are predicted due to ice melt and expansion of nunatak habitat.

Species of Conservation Concern

The plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this plant association (Table 45). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016). Additional study is required to evaluate whether this plant association supports animal species of conservation concern.

Table 45. Plant species of conservation concern within the *Artemisia arctica-Trisetum spicatum* Nunatak Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Douglasia laevigata	G3	S2S3	Grows in rock crevices on vertical faces of basalt cliffs, rock outcrops and talus slopes, from mountain ridges to coastal bluffs.
Draba incerta	G5	S3	Rock outcrops, talus, gravelly areas, tundra.
Micranthes porsildiana	G4	S2	Mineral soil, scree, rock; known to occur on both ultramafic and acidic substrates.
Carex phaeocephala	G4	S3	High-montane to alpine areas, usually rocky soils.

Classification Concept Source

This association was defined by (Boggs et al. 2008) and is similar to other alpine associations defined by DeVelice et al. (1999).

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Callitropsis nootkatensis Wetland Biophysical Setting

Yellow Cedar Wetland Biophysical Setting

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Callitropsis nootkatensis* (yellow cedar) Wetland Biophysical Setting is a forested type dominated by *Callitropsis nootkatensis* occurring on poorly-drained, coastal sites in a temperate rainforest environment (Figure 90). Drainage is considered intermediate between forested peatlands and well-drained hemlock forests. *Callitropsis nootkatensis* is an ecologically, culturally and economically important tree species in the Pacific Northwest. This slow-growing, long-lived tree has few natural insect and disease agents and can achieve ages of more than 1,000 years (Harris 1990). In the climatically milder parts of it range, *Callitropsis nootkatensis* is a species of conservation concern due to drastic population reductions related to root injury under conditions of decreased snowpack (Hennon et al. 2006). Low snow cover may also impact *Callitropsis nootkatensis* populations by increasing the availability of first and second year growth to grazing deer (White et al. 2009).

Figure 90. Mixed conifer association including Callitropsis nootkatensis and with Lysichiton americanus in the understory in Glacier Bay National Park and Preserve.

Distribution

Callitropsis nootkatensis occurs in coastal mountain ranges from southern Alaska to the Siskiyou mountains in northern California (Figure 91). In the northern portion of its range, *Callitropsis nootkatensis* grows from sea level to near timberline but is limited to high elevations in its southern range (Harris 1990). The *Callitropsis nootkatensis* Wetland Biophysical Setting distribution map (Figure 91) was developed from the intersection of the U.S. Forest Service yellow cedar range draft map (Hennon et al. 2016) with forested wetland classes delineated by the National Wetlands Inventory (USFWS 2015).

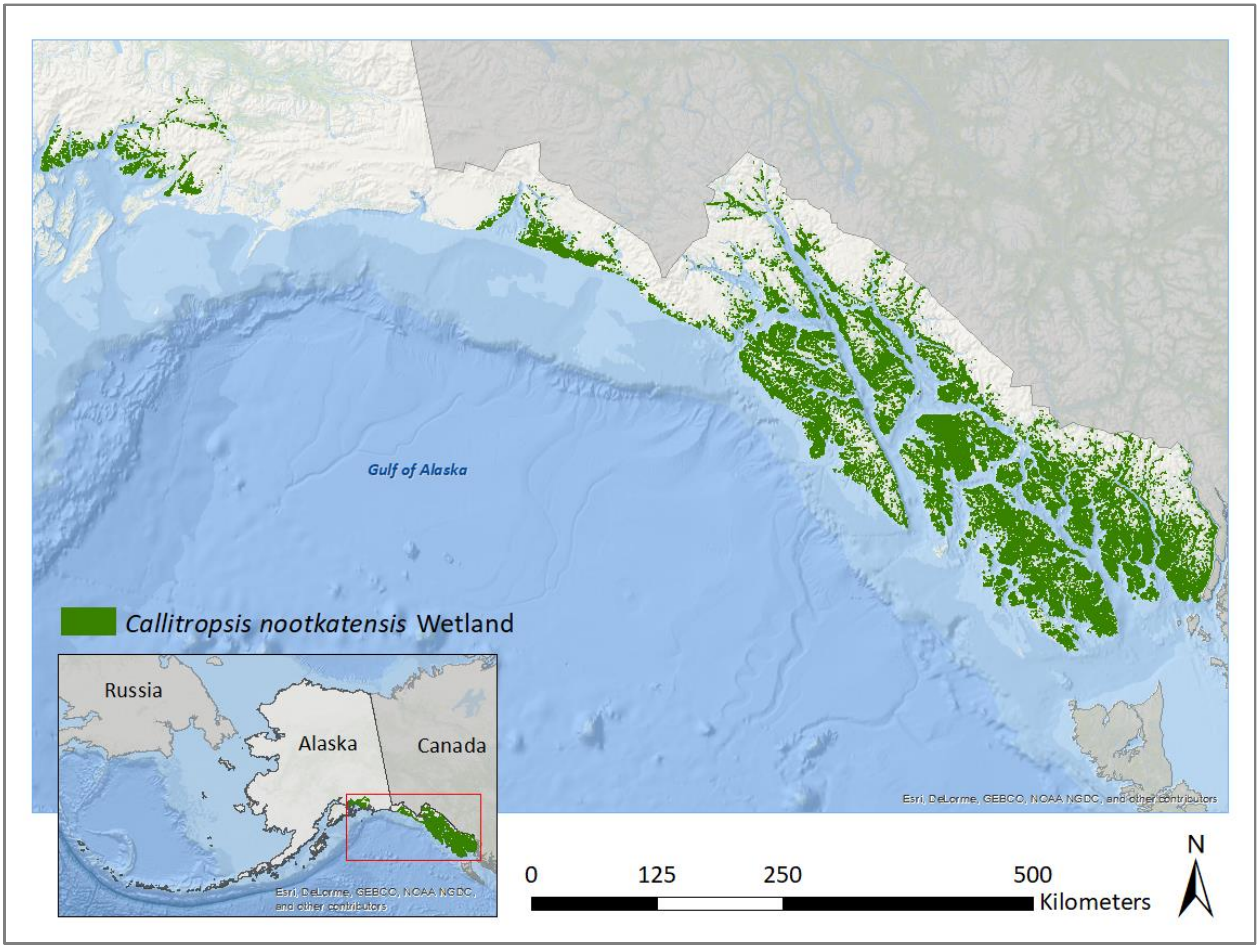

Figure 91. Distribution of the *Callitropsis nootkatensis* Wetland Biophysical Setting in southeast Alaska (Hennon et al. 2016). Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Southern Alaska has a cool, wet maritime climate and is generally free of permafrost (Gallant et al. 1995, Nowacki et al. 2001). Mean annual precipitation ranges from 135 to 390 cm with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C.

Environmental Characteristics

This biophysical setting generally occupies poorly-drained and low-elevation sites. The setting occurs on gently sloping and flat lowlands, and glacial kames, kettles, drumlins and outburst floodplains (Leighty et al. 2006). Soil supporting *Callitropsis nootkatensis* wetlands are either classified as histosols or have a histic epipedon. On sites with high water tables, *Callitropsis nootkatensis* is adapted to root shallowly and concentrate fine root growth near the soil surface; this strategy allows roots to respire and avoid hypoxia under saturated conditions (Hennon et al. 2016). Most commonly, drainage is retarded by compacted till or volcanic ash, which forms an impermeable layer. However, high water inputs may also contribute to wet soil conditions. On deep soils formed in colluviums or alluvium, excessive water received from neighboring slopes saturates the soil. Soils are usually stable. Sites with hummocky topography tend to accumulate deep, poorly-drained, organic-rich soils in the topographic lows leaving better drained soils on the topographic highs.

Vegetation

Poorly drained sites in coastal temperate rainforests typically support *Callitropsis nootkatensis* in association with other conifers. Tree species include *Callitropsis nootkatensis* and sometimes *Tsuga mertensiana* (mountain hemlock), *Tsuga heterophylla* (western hemlock), *Pinus contorta* (lodgepole pine) and occasionally *Picea sitchensis* (Sitka spruce). In the southern portion of its range, *Thuja plicata* (redcedar) may also be present. The overstory is open with less than 45% cover. Snags are common and often represent 25% or more of the basal area. Poor soil drainage and low nutrient availability usually limit tree heights to 10 to 21 m, yet cedars in these associations often exceed 1,000 years in age. The understory is usually comprised of a dense shrub layer combined with dwarf conifers. Shrubs include *Menziesia ferruginea*, *Oplopanax horridus* and *Vaccinium* species. Understory wetland indicator species include *Gaultheria shallon*, *Lysichiton americanus* or both. These open forests have higher species richness compared to more productive sites with greater canopy closure, as greater sunlight penetration to the understory results in more niches for herbaceous plants and shrubs (Caouette et al. 2016).

Climate Change, Succession and Disturbance

Mortality of *Callitropsis nootkatensis* is widespread, totaling approximately 2,000 km^2 in the forests of Southeast Alaska (Figure 92). Affected stands are typically composed of long dead, recently dead, dying and some surviving trees, which suggests that the decline is long term and continuing. Tree death is expressed in a narrow, low-elevation band from sea level to 152 m (Hennon et al. 2012). *Callitropsis nootkatensis* roots are shallower and less cold tolerant than those of other associated conifers and are therefore more vulnerable to injury from superficial soil freezing. It is suspected that the persistence of snow beyond the last hard spring freeze protects *Callitropsis nootkatensis* from root injury. Thus, lower snowpack explains the broad spatial distribution of *Callitropsis nootkatensis* decline and heightened mortality in the warmer areas of its range (Hennon et al. 2008). The successional trajectory in these areas of decline is not well understood. Other conifer species already present as understory trees appear to be favored where the *Callitropsis nootkatensis* overstory has died. This secondary growth may remain even-aged for up to 300 years before gradually changing to an uneven-aged condition. Research of forest inventory plots in relationship to landscape factors in southeast Alaska suggests that *Callitropsis nootkatensis* is moving upslope with warming climatic conditions (Caouette et al. 2016).

Stand-scale disturbances include blowdowns, floods, tidal waves and clearing. Blowdown is less common in relatively open *Callitropsis nootkatensis* stands than in other forest types with higher canopy closure. The response of vegetation relates to the scale and severity of the disturbance. In general, disturbances that impact the forest canopy but spare the understory and soil initiate secondary successional processes that are characterized by a short period of shrub dominance characterized by *Vaccinium* species, *Gaultheria shallon* and/or *Menziesia ferruginea*, followed by reestablishment by conifers that are either present in the understory prior to the disturbance or germinated after the disturbance.

Figure 92. *Callitropsis nootkatensis* decline on a hillslope just above sea level on Chichagof Island, Southeast Alaska. Photo by P. Hennon.

Conservation Status

Rarity: Just under 500 occurrences of *Callitropsis nootkatensis* wetlands occupying 7,785 km^2 are estimated to occur in Southeast Alaska.

Threats: Climate change, particularly that effecting the duration of snowpack relative to late-season cold events is suspected to drive *Callitropsis nootkatensis* population declines in Alaska (Hennon et al. 2008). Timber harvest, especially activity targeting low and accessible locations, represents an additional threat.

Trend: Widespread mortality of *Callitropsis nootkatensis* totaling more than 2,000 km^2 of its approximate 10,000 km^2 range in Alaska has been documented by Hennon and others (2016). In the short-term, 29% of the range is projected to decline, with declines reaching 38% in the long-term (Hennon et al. 2016).

Species of Conservation Concern

The animal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 46, Table 47). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 46. Amphibian, mammal and bird species within the *Callitropsis nootkatensis* Wetland Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Amphibians				
Columbia spotted frog	*Rana luteiventris*	G4	S2	Known from isolated ponds in the Taku, Stikine and Unuk River corridors, could occur in ponds associated with Callitropsis nootkatensis wetlands.
Northwestern salamander	*Ambystoma gracile*	G5	S3	Known to occur in south of Ketchikan on Mary Island and northwest Chichagof Island near Pelican, likely found in Callitropsis nootkatensis wetlands in these areas.
Western toad	*Anaxyrus boreas*	G4	S3S4	Known to occur in southeast Alaska's island and mainland coastal rainforest habitat; and likely found in Callitropsis nootkatensis wetlands.
Mammals				
Alexander Archipelago wolf	*Canis lupis* ssp. *ligoni*	G4T3	S3	Found in coastal spruce-hemlock forests with preference for areas where prey are most abundant. This coastal wolf subspecies likely uses Callitropsis nootkatensis forested wetlands in search of prey.
California myotis	*Myotis californicus*	G5	S2	Suspected to occur in limited areas of Callitropsis nootkatensis forested wetlands.
Keen's myotis	*Myotis keenii*	G2G3	S1S2	In Southeast Alaska this species occurs primarily in coniferous forests with females preferring old-growth forests and cedar trees in riparian areas for day roosts.
Long-tailed vole	*Microtus longicaudus*	G5	S3	Prefers various habitats and likely occurs in Callitropsis nootkatensis forested wetlands.
Prince of Wales flying squirrel	*Glaucomys sabrinus* ssp. *griseifrons*	G5T2	S2	This Prince of Wales island endemic is dependent on old-growth Sitka spruce-western hemlock forest and is likely present in Callitropsis nootkatensis forested wetlands.
Wrangell Island red-backed vole	*Myodes gapperi* ssp. *wrangeli*	G5T3	S3	Endemic known from three islands in southeast Alaska, prefers mesic forested habitats and likely occurs in Callitropsis nootkatensis wetlands.
Birds				
Cedar Waxwing	*Bombycilla cedrorum*	G5	S3B	Prefers coniferous wetland edge with peatland habitat.
Great Blue Heron	*Ardea herodias*	G5	S2S3	Suspected to nest in tall trees of wetlands near tidal and freshwater.
Marbled Murrelet	*Brachyramphus marmoratus*	G3G4	S2S3	Nest in old-growth hemlock and Sitka spruce on moss-covered trunks, or on

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
				ground near sea-facing talus slopes or cliffs.
Northern Pygmy Owl	*Glaucidium gnoma*	G5	S3	Habitat consist of forests or open woodlands in foothills and mountains, including adjacent meadows while foraging (AOU 1983).
Queen Charlotte Goshawk	*Accipiter gentilis laingi*	G5T2	S2	Nest in either Sitka-spruce or western hemlock. Typically hunt in continuous forests.

Table 47. Plant species of conservation concern within the *Callitropsis nootkatensis* Wetland Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Cardamine angulata	G5T3	S3	Wetland plant likely found in association with *Callitropsis nootkatensis.*
Cardamine pensylvanica	G5T3	S3	Wetland plant likely found in association with *Callitropsis nootkatensis.*
Luzula comosa	G4G5	S1	Meadows, open woods and coniferous forests.
Lycopodiella inundata	G5	S3	Wet meadows and bogs.
Platanthera orbiculata	G5	S3S4	Occurs in wet coniferous and deciduous forest and forested fens.
Polystichum setigerum	G3	S3	Mixed conifer forests.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 48).

Table 48. Plant associations of conservation concern within the *Callitropsis nootkatensis* Wetland Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Mixed conifer/*Gaultheria shallon*	G3	S3	DeMeo et al. 1992
Mixed conifer/*Gaultheria shallon/Lysichiton americanum*	G3	S3	DeMeo et al. 1992
Mixed conifer/*Lysichiton americanus-Athyrium filix-femina*	G3	S3	Martin et al. 1995
Mixed conifer/*Vaccinium* spp.-*Gaultheria shallon*	G3	S3	DeMeo et al. 1992
Mixed conifer/*Vaccinium* spp.-*Gaultheria shallon/Fauria crista-galli*	G3	S3	DeMeo et al. 1992

Classification Concept Source

The classification concept for this biophysical setting is derived from DeMeo and others (1992), Martin (1989), and Pawuk and Kissinger (1989).

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Karst Alpine Herbaceous Meadow and Heath Biophysical Setting

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The Karst Alpine Herbaceous Meadow and Heath Biophysical Setting is represented by herbaceous or heath vegetation growing near or above treeline on calcareous soils (Figure 93). This setting is uncommon in Alaska's coastal rainforest zone. The calcareous substrate, high elevation and geographic proximity to glacial refugia (e.g. Queen Charlotte Islands) provides unique habitat for rare taxa, regional endemics and disjunct species (Jaques 1973). Owing largely to their remote alpine location, impacts are thought to be low.

Figure 93. Karst herbaceous meadow on Chichagof Island, Alaska.

Distribution

The karst alpine herbaceous meadow and heath biophysical setting is uncommon in Southeast Alaska. Occurrences are characteristically on the upper sections of moderate to steep slopes over karst in the Boundary Ranges and the Alexander Archipelago, including Admiralty, Chichagof, Kosciusko, Kuiu, Hecata, and Prince of Wales Islands (Figure 94). The karst alpine herbaceous meadow and heath distribution map was developed from the intersection of the mesic herbaceous and dwarf shrub landcover classes of the Alaska Landcover Map (Boggs et al. 2015) and of the karst topography mapped by Albert and Schoen (2006).

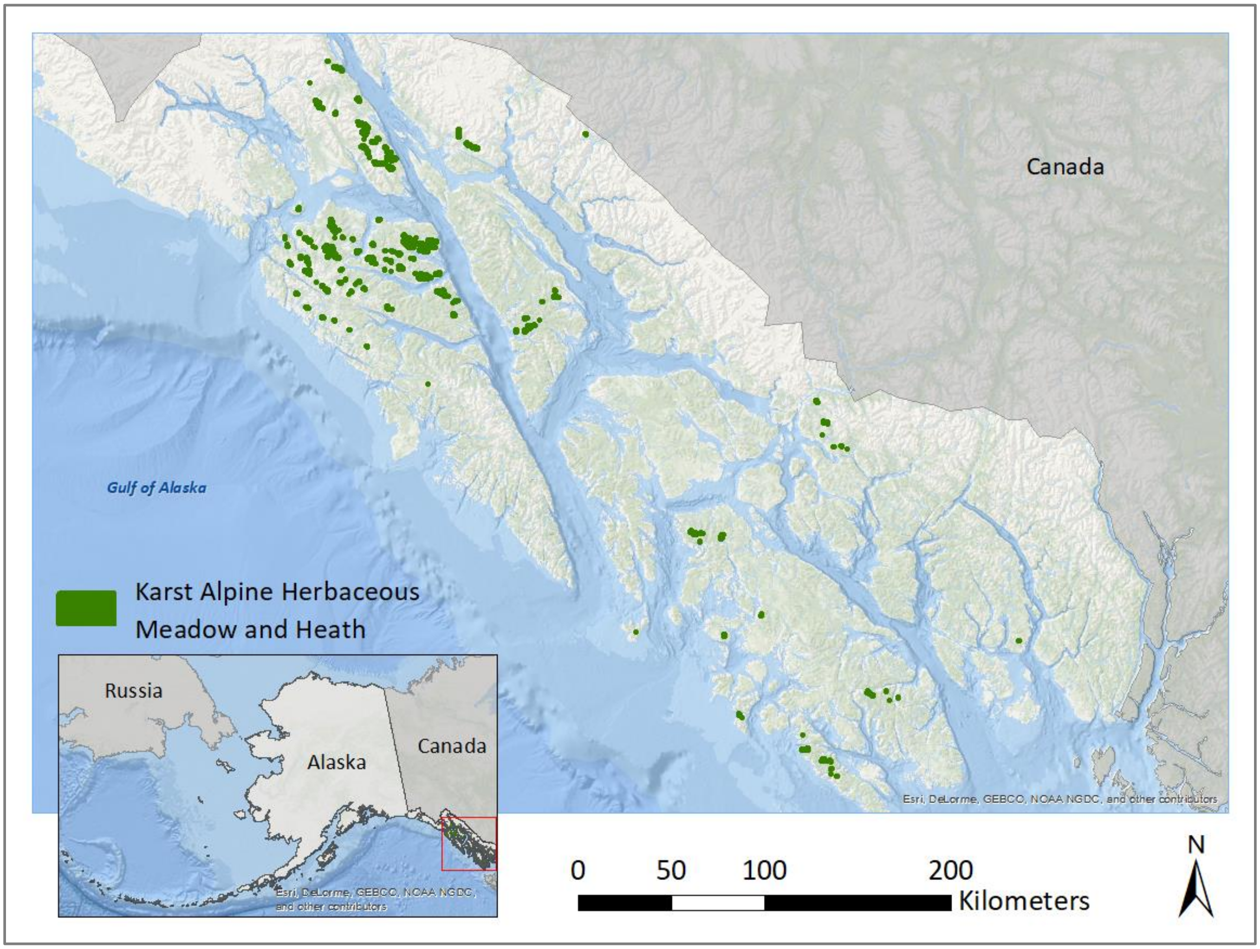

Figure 94. Distribution of the Karst Alpine Herbaceous Meadow and Heath Biophysical Setting in Southeast Alaska. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). The mean annual precipitation in coastal rainforests ranges from 135 to 390 cm (including snowmelt) with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures range from -3 to 3°C.

Environmental Characteristics

Karst topography is formed by the differential dissolution of sedimentary rock such as limestone by the infiltration of weakly-acidic surface water. The resulting landscape may be characterized by sinkholes, springs, and depressions. Southern Alaska is underlain by extensive carbonate bedrock (ca. 2,100 km^2) in the areas of Chichagof, Kuiu, Hecata and Prince of Wales Islands in the Alexander Archipelago, which supports the karst communities described herein. The carbonate rocks of the Alexander Archipelago originated on tropical Pacific Islands and were transported northeastward by plate tectonics; their current location represents the greatest displacement of tropical limestone to high latitudes in an archipelago setting in the world (Aley et al. 1993).

Due to subsurface dissolution chambers, snowmelt drains rapidly from karst topography and produces few meltwater channels at the ground surface. Channels that do develop extend only a few meters along the surface before traveling underground (Jaques 1973). This rapid drainage makes alpine calcareous soils in Southeast Alaska seasonally xeric habitats with soil moisture characteristics resembling the drier tundra habitats of more continental areas (Jaques 1973, Duffy 1993).

Rock outcrops, cliffs and ledges are common features of karst in alpine and subalpine areas. Frost commonly splits large boulders from bedrock, forming cliffs, talus slopes and blockfields. Soil disturbances, including avalanches, soil sloughing and rock movement occur frequently and inhibit the development of meadow and heath vegetation.

Vegetation and Succession

Karst alpine meadows occupy small patches on the landscape and support calciphytic plant species. Vegetative cover, usually ranging from 50 to 75%, is not as continuous as it is in noncalcareous meadows (Figure 95; Jaques 1973). Most karst in Southeast Alaska have moderate to steep surface slopes and subsurface hydraulic gradients, as well as very high rainfall. These characteristics enable more rapid karst development and vegetation change.

Figure 95. Karst alpine herbaceous meadow in Glacier Bay National Park and Preserve, Alaska.

Heath is the primary vegetation in the alpine zone of Southeast Alaska where species composition varies with snow cover and summer moisture conditions (Figure 96; Jacques 1973). Despite its abundance on other substrates in the alpine, true alpine heath vegetation is extremely limited on calcareous parent materials, especially on dry limestone ridgetops. Heath vegetation found on limestone ridgetops may include the following species: the dwarf shrubs *Empetrum nigrum* and *Harrimanella stelleriana*, the low shrubs *Vaccinium caespitosum* and *V. uliginosum,* and the herbs *Achillea millefolium*, *Cornus canadensis*, *Geum calthifolium*, *Huperzia selago* and *Lupinus nootkatensis*. In areas of limestone, heath vegetation is more commonly found on protected gentle slopes or cirque basins, where sufficient soil development occurs. The ericaceous heath species that dominate on acidic substrates are not present on calcareous substrates in any abundance (Jacques 1973).

Succession on calcareous sites can proceed from herbaceous meadow to dwarf shrub to forest. In a British Columbia study, bare limestone was colonized by the dwarf shrub *Dryas drummondii*, the grasses *Festuca brachyphylla* and *Trisetum spicatum*, and the forbs *Arenaria rubella*, *Cerastium beeringianum*, *Polygonum viviparum* and *Saxifraga oppositifolia*. With increasing organic accumulation and acidification, the dwarf shrubs *Cassiope mertensiana*, *C. stelleriana*, and *Phyllodoce glanduliflora*, and the forbs *Luetkea pectinata* and *Saxifraga nelsoniana* ssp. *pacifica* colonized. After further soil development, several tree species, including *Abies lasiocarpa* (subalpine fir), *Picea sitchensis* (Sitka spruce), and *Callitropsis nootkatensis* (yellow cedar) established (Archer 1964).

The movement of trees into treeless areas above timberline appears to be taking place in many areas of the Pacific Northwest (Brink 1959, Franklin 1971). In the alpine, consistent reduction of snowpack encourages colonization of *Phyllodoce-Cassiope* heath vegetation by *Abies lasiocarpa* and *Tsuga mertensiana* (Archer 1964). Additional evidence of treeline expansion is evident on Prince of Wales Island where isolated copses of *Tsuga mertensiana* are found on south-facing slopes above the elevation of the continuous subalpine forest. On calcareous sites these trees are associated with *Abies lasiocarpa* (Jacques 1973).

Figure 96. Karst alpine heath in Glacier Bay National Park and Preserve, Alaska.

Conservation Status

Rarity: The occurrence of high-latitude, alpine-subalpine karst meadows (total area 70 km^2) in an archipelago may be limited to the Alexander Archipelago (Aley et al. 1993).

Threats: Threats to the karst alpine herbaceous meadow and heath biophysical setting include recreation, and any activities that influence the balance between surface and ground water inflow and discharge.

Trend: Owing largely to their remote alpine location, the extent and condition of these meadows is not expected to change in the short or long term.

Species of Conservation Concern

The mammal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 49, Table 50). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 49. Mammal species of conservation concern within the Karst Alpine Herbaceous Meadow and Heath Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Alexander Archipelago wolf	*Canis lupus ligoni*	G4T2T3	S3	Primarily found in rugged coastal spruce-hemlock forests supporting prey such as deer, small mammals, and spawning salmon.
California myotis	*Myotis californicus*	G3G4	S2	Suspected to occur in karst caves associated with this biophysical setting.

Table 50. Plant species of conservation concern within the Karst Alpine Herbaceous Meadow and Heath Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Botrychium spathulatum	G3	S1	Found in alpine and subalpine meadows. Some sources describe soil preferences as calcareous or alkaline.
Botrychium tunux	G3?	S2	Found in alpine and subalpine meadows. Some sources describe soil preferences as calcareous or alkaline.
Cypripedium montanum	G4	S2	Found at the northern edge of its range in St. Elias Mountain and the northern Alexander Archipelago, where it is disjunct from southern British Columbia populations.
Draba incerta	G4	S3	Often found on calcareous scree slopes of Prince of Wales Island. More common in the Rocky Mountains.
Ligusticum calderi	G3G4	S2	Known principally from the Queen Charlotte Islands and northern Vancouver Island in British Columbia. In Alaska occurs on moist, rocky, limestone at high elevations on Kodiak Island, Dall Island and southern Prince of Wales Island.
Lonicera involucrata	G4G5	S3	Occurs on karst alpine landscape on Dall Island.
Packera subnuda var. *moresbiensis*	GNRT3T4	S3	Known only from the extreme southeastern coast of Alaska, the Queen Charlotte Islands, and northern Vancouver Island, it frequently occurs on limestone talus in the alpine.
Polystichum setigerum	G3	S3	Endemic to the Pacific Northwest. Grows on karst and other substrates in lowland coastal forests in British Columbia and Alaska.
Romanzoffia unalaschcensis	G3	S3S4	Occurs from Kodiak Island west through the Aleutians. A disjunct population also found on Heceta Island in Southeast Alaska on a blocky talus slope under a limestone cliff.
Acroscyphus sphaeophoroides	GNR	S1	This lichen occurs on base-enriched rock and conifer wood in exposed coastal hypermaritime and subalpine localities (Goward 1999). It is rare in North America, where the only known populations occur on rock outcrops along alpine ridges in southern Alaska and British Columbia.
Seligeria acutifolia	G3G5	S1	This moss of calcareous substrates is rare but widespread. In North America, it is known from only a few localities in British Columbia and Alaska.

Plant Associations of Conservation Concern

No plant associations of conservation concern are known or suspected to occur within this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports plant associations of conservation concern.

Classification Concept Source

The classification concept for this biophysical setting is based on Jacques (1973).

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Karst Fen Biophysical Setting

Pacific Alaska

Conservation Status Rank: S2 (imperiled)

Introduction

The Karst Fen Biophysical Setting is a wetland type with high, slow-moving water tables fed by calcium-enriched groundwater (Figure 97). The unique hydrogeochemistry of these fens fosters high species diversity and unique plant associations that are distinct from the peatland associations, which dominate the surrounding area (Johnson 2006, McClellan et al. 2003). Considered to be one of the rarest wetland types in North America (Almendinger and Leete 1998), karst fens occur in association with limestone terrain in the coastal rainforests of southern Alaska (McClellan et al. 2003) and adjacent north-coastal British Columbia (Banner et al. 1987 and 1998). Owing largely to their remote location, impacts are thought to be low.

Figure 97. Karst fen on Chichagof Island, Alaska.

Distribution

Small-scale surveys targeting the cooccurrence of wetlands and carbonate terrain have identified and described several karst fens, occupying a total of 0.4 km^2 in the Alexander Archipelago (Figure 98) (McClellan et al. 2003, Johnson 2006, Walton et al. 2014). These uncommon peatlands are found in low- to mid-elevation hydrologic discharge zones below limestone outcrops and ridges and likely other settings where the wetland groundwater sources are in contact with carbonate terrain. Karst fen occurrences in Southern Alaska were derived from surveys conducted by McClellan and others (2003) and Walton and others (2014). The occupancy of karst fens was hand delineated on satellite imagery surrounding the four occurrences documented in literature and targeted signatures showing open, low-growing vegetation.

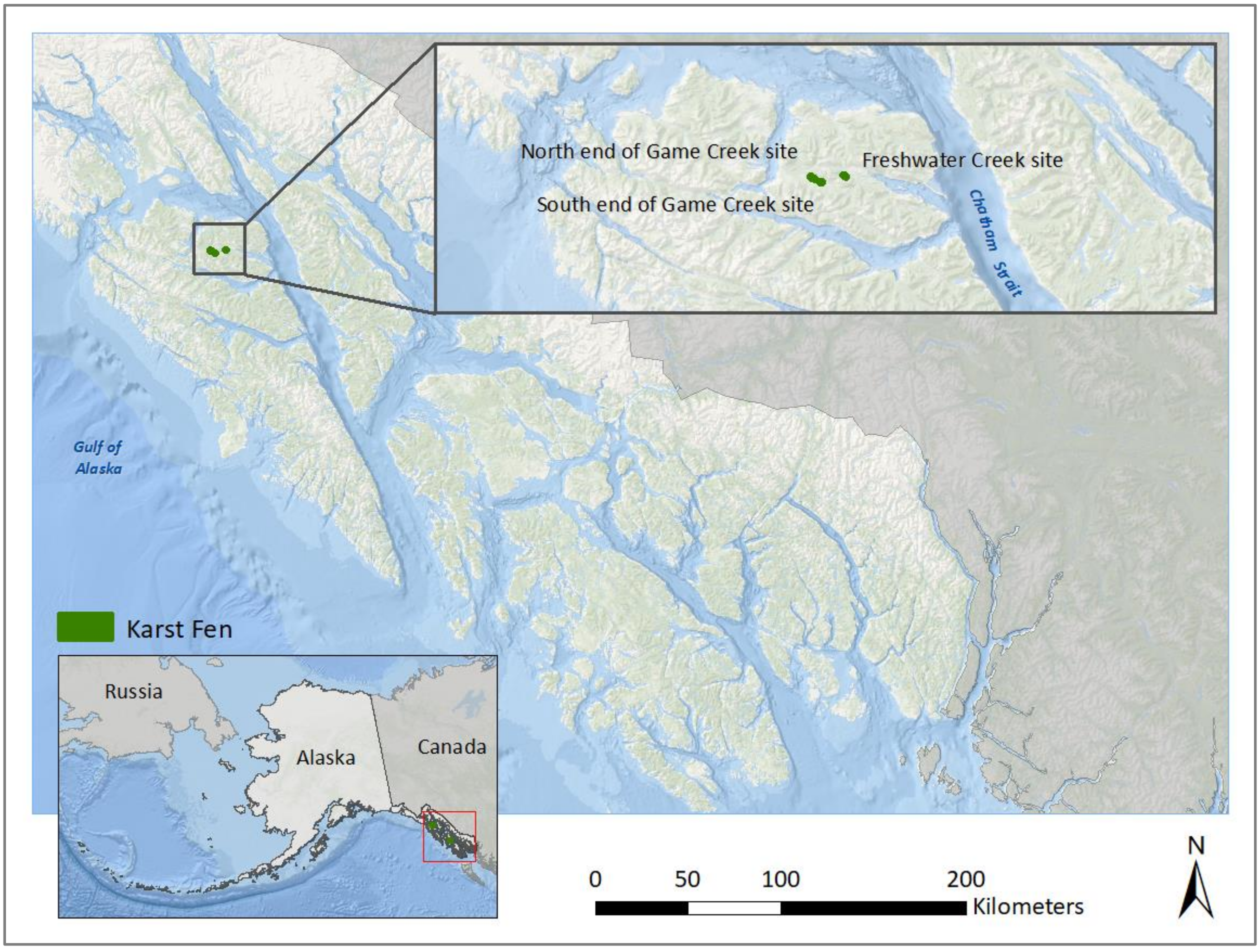

Figure 98. Distribution of the Karst Fen Biophysical Setting in southeast Alaska. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). The mean annual precipitation in coastal rainforests ranges from 135 to 390 cm (including snowmelt) with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures range from -3 to 3°C.

Environmental Characteristics

Karst topography is formed by the differential dissolution of sedimentary rock such as limestone by the infiltration of weakly acidic surface water. The resulting landscape may be characterized by sinkholes, springs, and depressions. Southern Alaska is underlain by extensive carbonate bedrock (ca. 2,100 km^2) in the areas of Chichagof, Kuiu, Hecata and Prince of Wales Islands in the Alexander Archipelago, which supports the karst communities described herein.

The few karst fens sampled in Southeast Alaska are found in low to mid elevation hydrologic discharge zones along bases of slopes below carbonate (limestone, dolomite or marble) outcrops and ridges

(McClellan et al. 2003, Johnson 2006). Calcium-rich water is sourced from streams flowing over the carbonate deposits, or seeps and springs from groundwater flowing through the carbonate deposits. The fens contain small channels, and it is apparent that water flows through and from the fens both as surface stream flow and groundwater discharge. Water tables fluctuate seasonally and are strongly influenced by the surrounding surface and ground waters (Zoltai and Vitt 1995), as well as by precipitation events.

Soils supporting this biophysical setting are typically organic matter underlain by marine silt and glacial till. Moisture and pH levels are affected by ground water volume and flow patterns. In southern Alaska, pH levels are between 6.7 and 7.4 and calcium concentrations ranges between 41.8 to 51.4 mg/L (Figure 99). Specific conductivity values are between 315 and 380 µS/cm. While pH, conductivity and calcium concentrations have been related to different associations within calcareous fens (Motkzin 1994, Komor 1994, Chee and Vitt 1989, Slack et al. 1980), species compositions in and among karst fens in southern Alaska are most strongly influenced by water table and less so by soil and water chemistry (Slack et al. 1980, Johnson 2006).

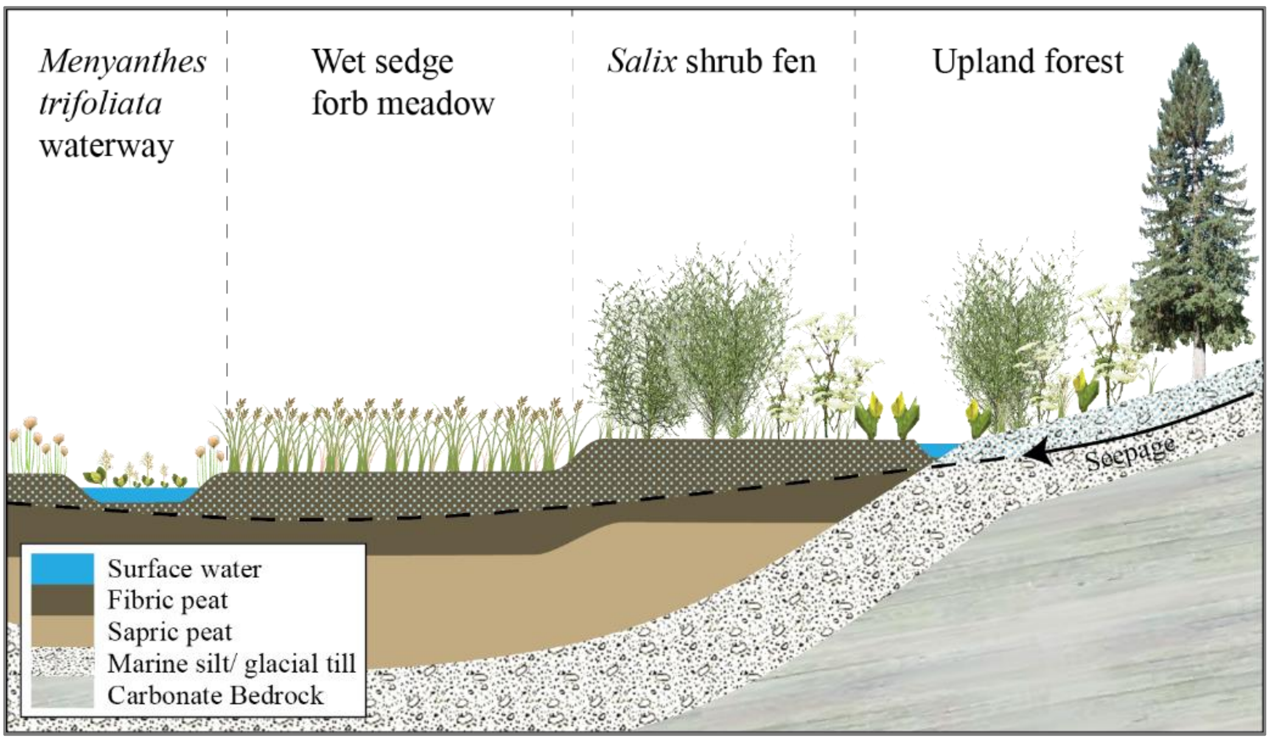

Figure 99. Schematic physiography and vegetation profile of a karst fen in southeast Alaska.

Vegetation

Karst fens in Alaska's coastal rainforests are typically herbaceous, but may also include shrub and forest associations (Figure 100). These fens usually lack *Pinus contorta* var. *contorta* (shore pine), *Sphagnum*, ericaceous shrubs and hummocky microrelief that are common in most other wetlands of the region. The plant associations found within karst fens vary in relation to moisture gradients between elevational terraces. Lower terraces with high water tables support obligate wetland species (Reed 1988) such as the sedges *Carex flava*, *C. echinata*, and *Eriophorum viridicarinatum* and the forbs *Lysichiton americanum* and *Menyanthes trifoliata.* Higher terraces support associations that may include patches of trees such as *Malus fusca* and the shrubs *Salix barclayi* and *Viburnum edule*, the forb *Cornus sericea* ssp. *sericea*, and calciphytic herbaceous plants including *Carex flava*, *Deschampsia cespitosa*, *Cystopteris montana*, *Dodecatheon pulchellum,* and *Parnassia fimbriata* (McClellan et al. 2003, Johnson 2006, Klinka et al. 1989).

Karst fens are also known to support disjunct and peripheral species including the shrub *Betula glandulosa* (Johnson 2006) and forbs *Caltha leptosepala* and *Castilleja unalaschcensis* (Jacques 1973). Additional boreal species present in karst fens that are uncommon on mainland and throughout the northern islands include *Pyrola asarifolia* var. *purpurea, Carex saxatilis*, *Botrychium virginianum*, *Cystopteris fragilis*, *Galium kamtschaticum, Malaxis brachypoda* and *Polemonium acutiflorum* (Johnson 2006).

Figure 100. Surface water channel flowing through a karst fen on Chichagof Island, Alaska.

Succession

Succession in fens has been described as a slow, unidirectional, autogenic process in which a minerotrophic fen association gradually develops into an ombrotrophic bog with surface vegetation raised above the influence of the groundwater (Zobel 1988). These fens may persist without change for thousands of years, with fen peat depth being equally deep as bogs (Zoltai et al. 2000). In general, the fen to bog transition occurs in two steps: (1) the acidification of the fen by *Sphagnum* species and (2) peat accumulation and isolation from the influence of water inflow from the surrounding mineral soil. *Sphagnum* species adapted to ombrotrophy initiate feedback processes (acidification and peat accumulation) favoring *Sphagnum* over vascular plants and other mosses. *Sphagnum* does this by producing an acid and decay-resistant litter and forming a drier, ombrotrophic habitat (van Breemen 1995, Granath et al. 2010). Changes in drainage or inflow water volume also alter the influence of the groundwater influx at the peat surface (Wassen and Joosten 1996).

Some studies report the transition from calcareous fen to bog is relatively rapid. Stratigraphic data show that the transition from fen to bog may occur within 100 to 200 years (Vitt and Kuhry 1992), whereas others report the transition can occur within decades (Janssens et al. 1992).

Allogenic processes, including those affecting hydrology and the water table, are also likely to be integral in inducing the fen-bog transition, and there are indications that such processes can also reverse peatland succession (Magyari et al. 2001, Hughes and Dumayne-Peaty 2002). Flooding apparently prevents the establishment of bog *Sphagnum* (Granath et al. 2010) and therefore acidification.

Conservation Status

Rarity: Karst fens are considered to be the rarest wetland type in North America, (Almendinger and Leete 1998, Boyer and Wheeler 1989). In Southeast Alaska karst fens have been documented from three locations, which occupy 0.4 km^2 (McClellan et al. 2003, Johnson 2006, Klinka et al. 1989). While karst fens are likely undersampled, their potential range of occurrence is limited to karst, which occupies less than 500 km^2 within the region (Albert and Schoen 2006).

Threats: Karst fens frequently occur in watersheds that are heavily managed for timber harvest, thus fens may be adversely impacted by the increased runoff after timber harvest on upgradient karst. Additional threats include any activities that influence the balance between surface and ground water inflow and discharge.

Trend: Many calcareous fens in Europe have been historically altered by land use practices including conversion to pastures for grazing (Tyler 1984). However, In Southeast Alaska their extent and condition is not expected to change in the short- or long-term.

Species of Conservation Concern

Throughout the world calcareous fens are associated with rare and sensitive plant species as well as high biodiversity (Almendinger and Leete 1998, Boyer and Wheeler 1989). Karst fens in Southeast Alaska contribute to the region’s biological diversity and have ecological functions different from the ubiquitous forested wetlands, bogs and poor fens that are more common to the region (McClellan et al. 2003). Evidence of extensive use by large mammals (brown bear, wolves and Sitka blacktail deer), including well-worn trails, crushed and matted vegetation, and scat, has been observed in karst fens (McClellan et al. 2003). The tall, dense vegetation may serve both as forage and cover. Karst fens likely support unique communities of aquatic invertebrates and mollusks adapted to calcareous habitats (D. Bogan, pers. comm.). New species of aquatic invertebrates have been reported from karst streams in the Alexander Archipelago (Carlson 1994 and 1996).

The mammal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 51, Table 52). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 51. Mammal species of conservation concern within the Karst Fens Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Admiralty beaver	*Castor canadensis phaeus*	G5T3	S3	Prefers low gradient streams, ponds, and small mud-bottomed lakes with dammable outlets. Could occur on islands nearby.
Sitka root vole	*Microtus oeconomus sitkensis*	G5T3	S2	Occurs in wet sedge and grass-forb meadows, bogs or fens, and other herbaceous habitats.
Admiralty meadow vole	*Microtus pennsylvanicus admiraltiae*	G5T3	S3	Inhabits herbaceous meadows, and marshes; often in wet riparian areas. Could occur on islands nearby.

Table 52. Plant species of conservation concern within the Karst Fens Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Botrychium virginianum	G5	S3	The most widespread Botrychium in North America, in southern Alaska grows in shaded forests and shrub fens.
Cypripedium parviflorum var. *pubescens*	G5	S1	Often associated with calcareous soils and is found in peatlands habitats in southern Alaska.
Eriophorum viridicarinatum	G5	S2S3	Widespread patchy distribution in western Canada and Alaska, where it grows in marshes, meadows, bogs, fens, and wet woods.

Plant Associations of Conservation Concern

The plant association listed below is designated vulnerable within Alaska (S1-S3) and is known or suspected to occur in this biophysical setting (Table 53). Karst fens support additional associations that are not listed because they are common (G4-G5) in other biophysical settings.

Table 53. Plant associations of conservation concern within the Karst Fens Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Carex sitchensis /Equisetum fluviatile	G3	S3	Shephard 1995

Classification Concept Source

The classification concept for this biophysical setting is partially derived from McClellan and others (2003), Banner and others (1987, 1998) and Johnson (2006).

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Karst *Tsuga heterophylla-Picea sitchensis* Plant Association

Karst Western Hemlock-Sitka Spruce Plant Association

Pacific Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

The Karst *Tsuga heterophylla-Picea sitchensis* (western hemlock-Sitka spruce) Plant Association is a forested type dominated by the coniferous tree species *Tsuga heterophylla* and *Picea sitchensis* and occurring on karst topography (Figure 101) While *Tsuga heterophylla-Picea sitchensis* forests are a dominant component of coastal rainforests in Southeast Alaska, their occurrence on karst represents a unique plant association characterized by the presence of old, large diameter trees and large dead standing trees. The underlying bedrock is characterized by chemically-weathered limestone, dolomite or marble bedrock and dissolution chambers, that when connected, allow subsurface drainage. Cave and rock shelter deposits found within the karst are often associated with significant paleontological and archeological sites. As important winter refugia, breeding grounds for birds and mammals, and the terrestrial backdrop to anadromous fish habitat, *Tsuga heterophylla-Picea sitchensis* karst forests support high biological diversity.

Figure 101. Karst forest, Chichagof Island, Alaska.

Distribution

Tsuga heterophylla-Picea sitchensis forests underlain by karst occur on rounded ridges, steep slopes and valley floors in the Alexander Archipelago of Southeast Alaska, including Admiralty, Chichagof, Kuiu, Heceta and Prince of Wales Islands and sporadically in the boundary range between Alaska and Canada (Figure 102). These forests occupy about 48,000 ha and represent less than 5% of the total remaining old-growth forest found within Southeast Alaska (Albert and Schoen 2006). Rainforests on karst are rare to unknown in the remainder of southern Alaska. The karst *Tsuga heterophylla-Picea sitchensis* forest distribution map was developed from the large productive old growth (POG), V67 (karst), Med POG, V4 (karst) and Med POG, V5 (karst) landcover classes mapped by Albert and Schoen (2006).

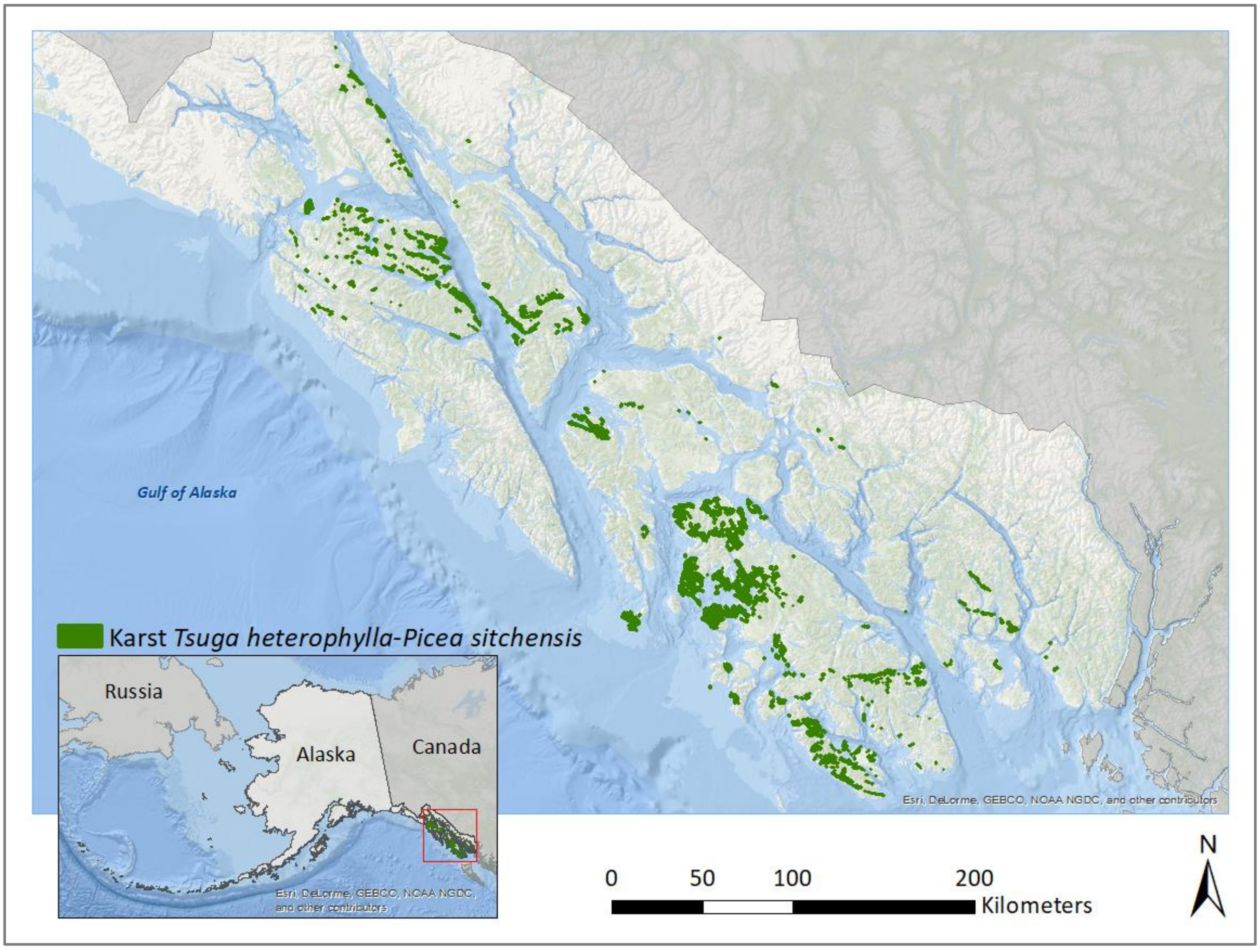

Figure 102. Distribution of the Karst *Tsuga heterophylla-Picea sitchensis* Plant Association in southeast Alaska. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Southern Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). Mean annual precipitation in coastal rain forests ranges from 135 to 390 cm (including snowmelt) with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3 °C.

Environmental Characteristics

Karst topography is formed by the differential dissolution of sedimentary rock such as limestone by the infiltration of weakly acidic groundwater originating from organic-rich peatlands and forest soils. Southern Alaska is underlain by extensive carbonate bedrock (ca. 2,100 km^2) in the areas of Chichagof, Kuiu, Hecata and Prince of Wales Islands in the Alexander Archipelago, which supports the karst communities described herein. The susceptibility of carbonate-rich rocks to weathering, along with the texture of the weathered stone, results in loose, well-drained soils that facilitate extensive root growth. Soils derived from these rock types appear to be especially productive.

In Southeast Alaska, forests occur upon and within nearly pure carbonate bedrock that have exceptionally well-defined surface features (epikarst) due to chemical weathering. Thicknesses of the epikarst zone ranges from more than 30 meters to less than 2 meters (Aley et al. 1993) and can include fissures, pits, channels, tube shafts and caves. Fissures funnel groundwater and sediments into complex subsurface drainage systems through which they are transported to one or more divergent points of resurgence (e.g. springs). Both sediment and water transported through these subsurface systems may reemerge distant from their entrance and frequently beyond their surface watershed boundary (Aley et al. 1993). Drainage networks of subsurface fissures and channels share little relation to, and function independently from, the typically less complex overlying surface drainage systems (Aley and Aley 1993, Huntoon 1992b).

Vegetation

Rainforests on karst terrain have not been formally studied in Alaska. Based on anecdotal observations, they have a closed canopy of very large diameter *Tsuga heterophylla* and *Picea sitchensis* trees. Snags, decadent trees, downed logs and other coarse woody debris are common (Figure 103). Shrubs, including *Oplopanax horridus* and *Vaccinium* species are usually present in low cover. Herbaceous plant cover is also low and may include species such as *Coptis asplenifolia*, *Corallorhiza mertensiana*, *Listera caurina* and *Moneses uniflora*. Bedrock outcrops within the forest provide habitat for calciphillic ferns such as *Asplenium trichomanes-ramosum, Cystopteris fragilis* and *Polypodium glycyrrhiza*.

Nonvascular plants add significantly to the biomass and biodiversity in this association. With high water-holding capacities, bryophytes and lichens act as hydrologic buffers, while cyanolichens are a major source of fixed nitrogen in old-growth forests (Pike 1972 and 1978, Denison 1973). Moss covers the abundant woody debris and forest floor. Forage lichens, such as the long hair-like species of *Bryoria* and *Alectoria*, are a primary component of the diet of flying squirrels, which are primary prey species for raptors such as owls and goshawks. Epiphytic mosses, especially *Antitrichia curtipendula,* are preferred nesting material for Marbled Murrelets.

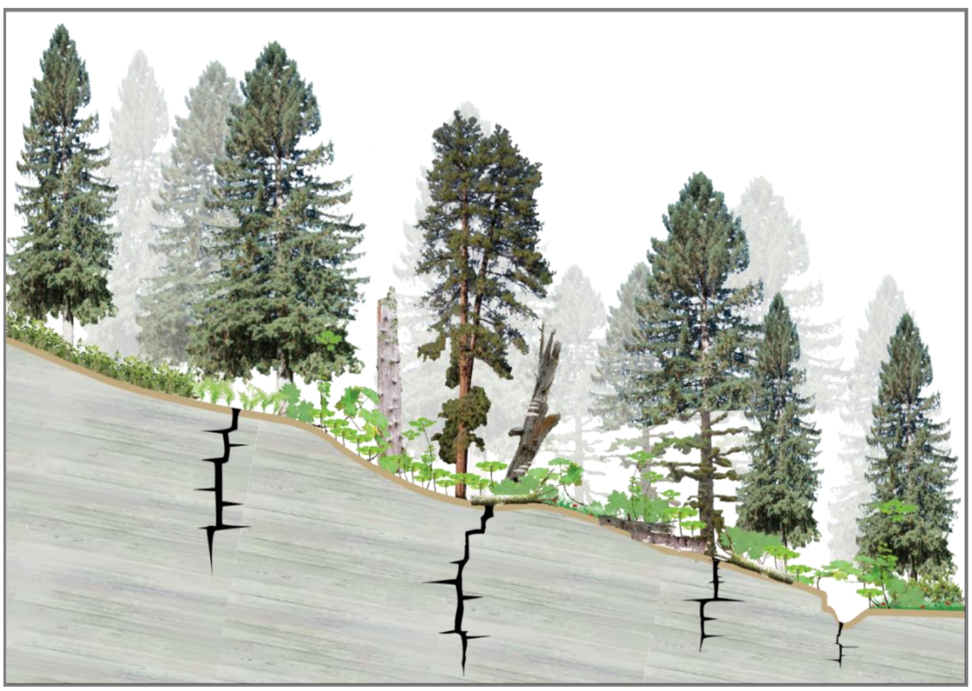

Figure 103. Schematic physiography and vegetation profile of the *Karst Tsuga heterophylla-Picea sitchensis* Plant Association.

The well-drained soils and plant nutrient availability associated with karst makes their forests more productive than nonkarst forests

(Baichtal and Swanson 1996, Albert and Schoen 2006, Aley et al. 1993, KMHBC 2003). Plants rooted deep into enlarged subsurface karst features may also better withstand high winds accompanying frequent fall and winter storms.

Succession

Succession within karst forests is poorly understood. The temperate, maritime climate, high annual precipitation and low frequency of fire throughout the region has resulted in few forests of intermediate ages (i.e. 50-150 years old; DeMeo et al. 1992, Dellasala et al. 1994 and 1996) and more old-growth stands. Wind is the major cause of natural catastrophic change in the vegetation mosaic, although avalanches and floods also occur. While individual treefall is common throughout the forest, stand-level disturbances are less common (Martin 1989). Following stand-level disturbances, *Picea sitchensis* may maintain dominance for hundreds of years (Martin et al. 1995). Old-growth karst forests codominated by *Tsuga heterophylla* and *Picea sitchensis* represent late-seral associations.

Conservation Status

Rarity: Outside of Southeast Alaska, the only karst landscapes known from temperate rainforest are located in British Columbia, Chile and Tasmania. In Southeast Alaska, forested karst is known from the Alexander Archipelago and the Coastal Range between the Alaska and Canada. Their 500 km^2 area of occupancy represents less than 5% of the total remaining old-growth forest found within Southeast Alaska. It is highly probable that the largest old-growth karst forest stands have already been eliminated from Alaska (Albert and Schoen 2006).

Threats: These forests are susceptible to damage from timber harvest. On karst landscapes worldwide, timber harvesting often results in nutrient and sediment loss and leads to long-term declines in soil depth and fertility, which occasionally results in permanent deforestation (Harding and Ford 1993, Huntoon 1992a and 1992b, Kieman 1993). Additional threats include any activities that influence the balance between surface and ground water inflow and discharge.

Trend: Most karst in Southeast Alaska is characterized by moderate to steep surface slopes and subsurface hydraulic gradients, as well as very high rainfall. These characteristics enable more rapid karst development and vegetation change. Consistent with the historic trend of logging productive landscapes, timber harvest in Southeast Alaska occurs disproportionately on karst. While low-elevation karst represents only 2.7% of all productive forests in Southeast Alaska, 15.1% of all timber harvest has occurred in these areas at a harvest rate 560% above proportional abundance. Consequently, 44% of all productive old-growth forests on karst lands in Southeast Alaska have been logged since 1954 (Albert and Schoen 2006).

Species of Conservation Concern

The occurrence of temperate karst rainforest within pristine watersheds, which support productive salmon runs and top predators, may be globally limited to the archipelago of Southeast Alaska. The animal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this plant association (Table 54, Table 55). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 54. Bird, mammal, amphibian, and invertebrate species of conservation concern within the Karst *Tsuga heterophylla-Picea sitchensis* Plant Association.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Birds				
Great Blue Heron	*Ardea herodias*	G5	S2S3	Nest in tall trees near tidal and freshwater.
Queen Charlotte Goshawk	*Accipiter gentilis laingi*	G5T2	S2	Nest in either Sitka-spruce or western hemlock. Typically hunt in continuous forests.
Marbled Murrelet	*Brachyramphus marmoratus*	G3G4	S2S3	Nest in old-growth hemlock and Sitka spruce on moss-covered trunks, or on ground near sea-facing talus slopes or cliffs.
Mammals				
Alexander Archipelago wolf	*Canis lupus ligoni*	G4T2T3	S3	Primarily found in rugged coastal spruce-hemlock forests supporting prey such as deer, small mammals, and spawning salmon.
California myotis	*Myotis californicus*	G3G4	S2	In SE Alaska, occur primarily in closed forests with snags and fallen logs. Karst also provides caves that bats use for hibernation in winter.
Keen's myotis	*Myotis keenii*	G2G3	S1S2	In SE Alaska, occur primarily in coniferous forests with females preferring old-growth forests and cedar trees in riparian areas for day roosts.
Long-legged myotis	*Myotis volans*	G5	S2	In Alaska, likely prefers old-growth forests and riparian habitats. Roost and maternity colonies in cliff, ground and tree crevices and in buildings.
Prince of Wales flying squirrel	*Glaucomys sabrinus griseifrons*	G5T2?	S2	Old growth western hemlock-Sitka spruce forests, and peatland scrub-mixed-conifer forests. Dens in tree cavities and woodpecker holes
Admiralty Island ermine	*Mustela erminea salva*	G5T3T4	S2S3	Occurs in forests, shrublands and alpine. May favor forest-wetland ecotones.
Prince of Wales Island ermine	*Mustela erminea celenda*	G5T3	S3	See Admiralty Island Ermine description.
Baranof Island ermine	*Mustela erminea initis*	G5T3T4	S3	See Admiralty Island Ermine description.
Suemez Island ermine	*Mustela erminea seclusa*	G5T2T3	S3	See Admiralty Island Ermine description.
Kupreanof red squirrel	*Tamiasciurus hudsonicus picatus*	G5T3?	S3	Variety of coniferous and mixed habitats. Nests in holes in tree trunks or in a mass of twigs, leaves, mosses, and lichens in densest foliage of a tree.
Amphibians and amphipods				
Western toad	*Anaxyrus boreas*	G4	S3S4	Found in rainforest and riverine habitats in southeast Alaska.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Cave scud	*Stygobromus quatsinens*	G2G3		This Amphipod (Crustacea) occurs in karst groundwater habitats in the Alexander Archipelago, including Nautilus cave, Heceta Island, and in numerous springs and caves on Dall, Baker, Sumez and Coronation Islands adjacent to Prince of Wales Island (Carlson 1994, 1996, 1997a, Holsinger et al. 1997). This species was previously known only from caves on Vancouver Island. This discovery is a high-latitude Western Hemisphere record for a cave-adapted species.
Amphipod	*Cratigonyx obliquus-richmondensis*	GNR		Found in a karst cave in the Alexander Archipelago, this amphipod is not known to occur elsewhere in northwestern North America (Carlson 1993a, from Baichtal).

Table 55. Plant species of conservation concern within the Karst *Tsuga heterophylla-Picea sitchensis* Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Abies amabilis	G5	S3	Occasional species in southern southeast Alaska's Sitka spruce and hemlock forests.
Asplenium trichomanes ssp. *quadrivalens*	G5T5?	S2S3	Grows on limestone cliffs associated with hemlock spruce forests.
Ligusticum calderi	G3G4	S2	Known principally from the Queen Charlotte Islands and northern Vancouver Island in British Columbia. In Alaska occurs on moist, rocky, limestone at high elevations on Kodiak Island, Dall Island and southern Prince of Wales Island.
Polystichum setigerum	G3	S3	Endemic to coastal northwest British Columbia and southeastern Alaska. Grows on forest floors in lowland coastal forests, forest edges, and along run-off channels up to 250 m elevation.
Romanzoffia unalaschcensis	G3	S3S4	Occurs from Kodiak Island west through the Aleutians. A disjunct population also found on Heceta Island in Southeast Alaska on a blocky talus slope under a limestone cliff.
Lobaria amplissima	GNR	S1S3	This foliose lichen is found on the trunks and branches of old-growth Sitka spruce and western hemlock.

Classification Concept Source

The classification concept for this plant association is derived from Albert and Schoen (2006), Baichtal and Swanson (1996) and Aley and others (1993).

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Pacific Barrier Island and Spit Biophysical Setting

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Barrier islands and spits are elongate, broadly-arcuate features that may be separated from each other by inlets and from the mainland by lagoons, estuaries or bays (Figure 104). Unlike barrier islands, spits maintain connection to the mainland and are thought to represent continuations of coastal dunes into the ocean (Ritter 1986). Due to similarities in landform, geomorphic process, and parent material, barrier islands and spits are treated here as a single biophysical setting. Within the Gulf of Alaska, barrier islands and spits are typically associated with large river deltas. While barrier islands are created by processes similar to those that create spits, they are unique in that their separation from the mainland reduces access by predators such as brown bears and wolves. As a result, these islands provide protected haulouts for harbor seals (*Phoca vitulina*), stopover feeding grounds for migrating shorebirds, and they support a variety of bird species, including some of conservation concern, such as the sanderling (*Calidris alba*) and Dusky Canada Goose (*Branta Canadensis occidentalis*; Sowls et al. 1978).

Figure 104. Coastal dunes on Egg Island, Copper River Delta, Alaska (photo by M. Bishop).

Distribution

Barrier islands are uncommon in southern Alaska (Hayes and Ruby 1994, Boggs 2000, DeVelice et al. 2007), occupying less than 1% of the coastline. Occurrences cluster on the exposed, northern shoreline of the Alaska Peninsula in the vicinity of Izembek Lagoon, along the coastlines of the Tugidak, Sitkinak and Southern Kodiak Islands, at the mouth of sediment-laden rivers such as the Katmai and Copper Rivers (Figure 105, inset map), as well as the Homer Spit. Barrier islands and spits become more common along the western and northern coasts of Alaska, and occupy 13% of the coastline worldwide (King 1972). The distribution of barrier islands and spits in southern Alaska and the Aleutian Islands was extracted from the

Alaska Department of Natural Resources coastline map for Alaska (2015); additional barrier islands and spits were hand-digitized from remotely-sensed imagery.

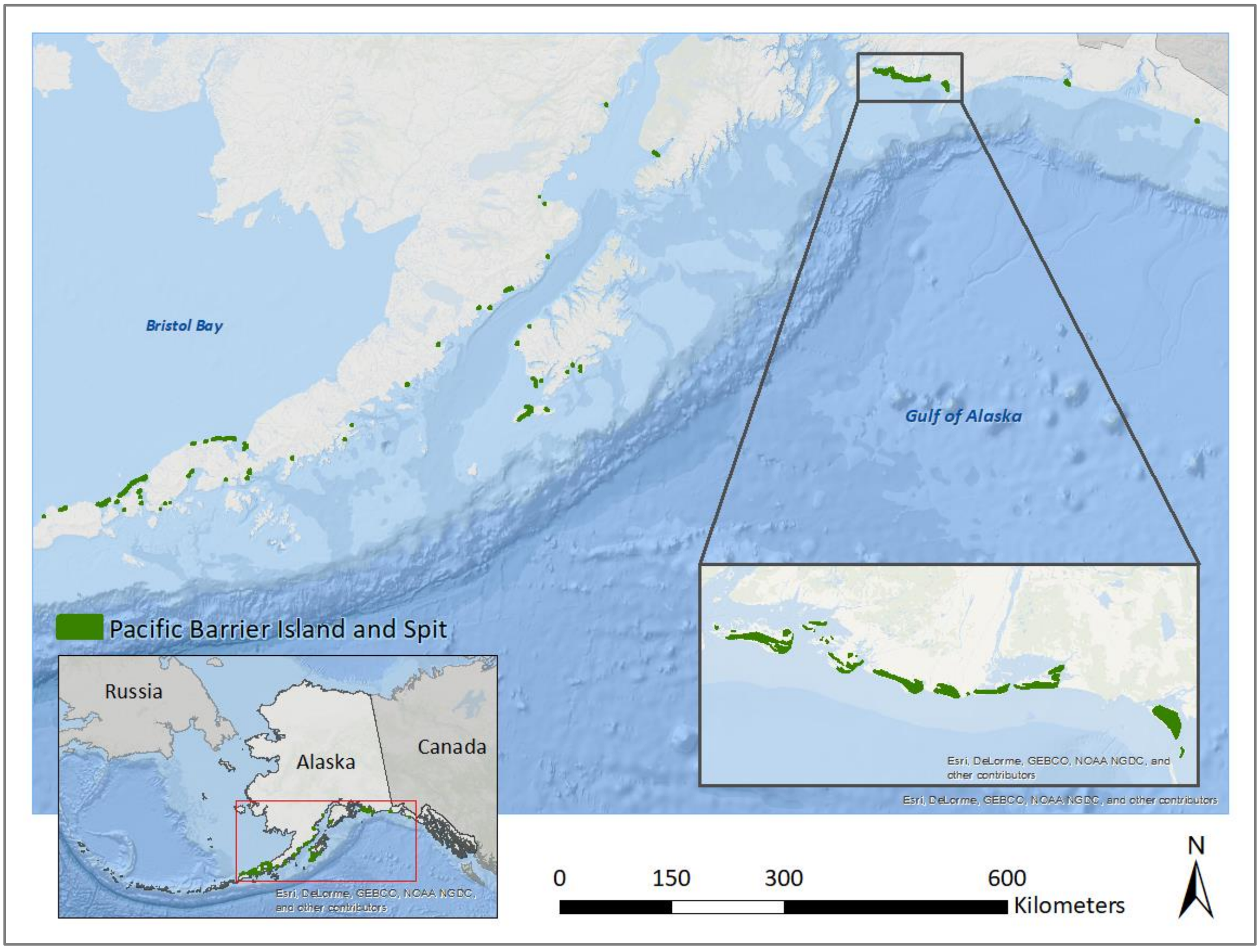

Figure 105. Distribution of the Pacific Barrier Island and Spit Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Southern Alaska has a cool, wet maritime climate and is generally free of permafrost (Gallant et al. 1995, Nowacki et al. 2001). Mean annual precipitation ranges from 135 to 390 cm with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18°C; average winter temperatures are between -3 and 3°C.

Environmental Characteristics

Barrier islands and spits are temporary in location and shape with their geomorphology controlled by the amount and type of sediment, the magnitude of natural processes and the stability of sea level (Dolan 1980). While several major river systems deliver sediment to the Gulf of Alaska, there are few areas of the outer coast that are characterized by low offshore gradients, tidal range and wave energy, which contributes to the regional rarity of barrier islands in southern Alaska. This suite of conditions is met at the Copper River Delta, where the riverine sediment load is transferred to the marine environment across the delta. Minor amounts of sediment are delivered by wind from various sources or by onshore transport of sediment sourced from sea cliffs or the ocean shelf (Ritter 1986). Here barrier islands range up to13 km in length, 2 km in width and typically rise less than 10 m above sea level (Thilenius 1990).

Longshore currents, which generate waves that strike beaches obliquely, tend to move sediment along the shoreline for considerable distances. Islands, spits and inlets thus migrate parallel to these currents. Storm surges may breach low-relief barrier islands and spits. During such overwash events, material is transported from the island or spits' high-energy; erosive environment on the windward side to the low-energy, depositional environment on the leeward side and in this way form gravel beaches backed by sandy dunes that grade to fine sand beaches and washover fans (Ritter 1986).

Vegetation

Distinct landform and vegetation patterns are common among barrier islands (Figure 106). Low-gradient beaches emerge from the ocean and transition to sparsely-vegetated dunes, taller back dunes dominated by herbaceous plants, and shrub associations interspersed with slacks dominated by low herbaceous vegetation and wetlands. Landward from the tall back dunes, elevation tapers towards the estuary where vegetation grades to uplifted tidal marshes, tidal marshes and tide flats.

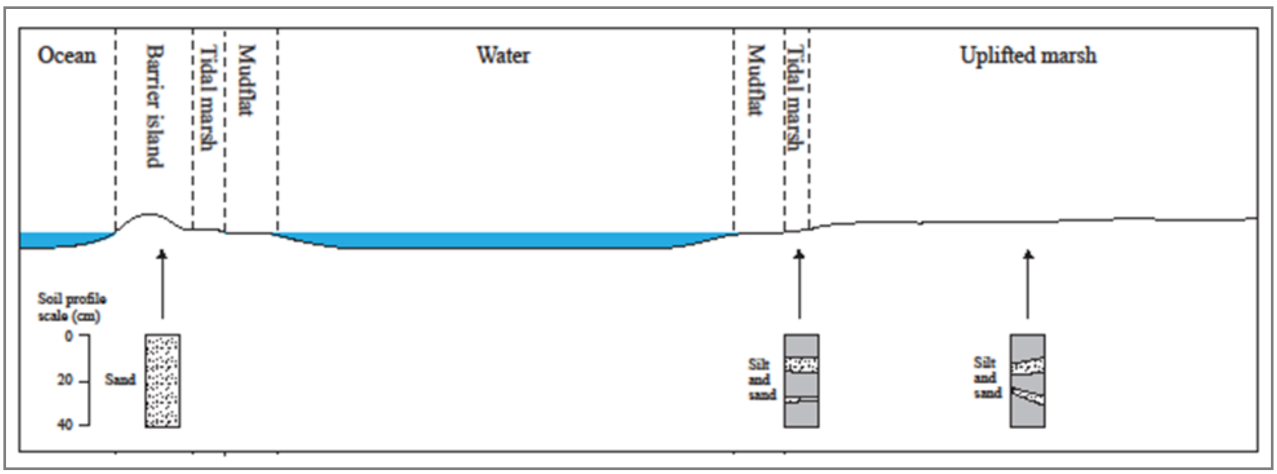

Figure 106. Schematic physiography and vegetation profile of a barrier island on the Copper River Delta, Alaska.

The barren or sparsely-vegetated dunes located toward the ocean receive significant windblown sand. Pioneer species such as *Leymus mollis* stabilize the sand with roots that penetrate 1 m and deeper to water (Boggs 2000, DeVelice et al. 2007). Species and plant association diversity increases with dune stability. Herbaceous associations include *Chamerion angustifolium*, *Fragaria chiloensis*, *Leymus mollis/Achillea borealis* and *Lupinus nootkatensis*. Low to tall shrub associations may include *Alnus viridis* ssp. *sinuata*, *Salix barclayi,* and *Salix alaxensis.* Dune slacks are often wet and are colonized by *Equisetum variegatum* and other wet-site herbaceous species. Progressive deposition of tidal and wind-blown sand and in some areas, isostatic uplift, elevates sites tidal and storm surge influence and allows shrubs such as *Myrica gale* to establish. Increased vegetation and decreased disturbance allows organic material to accumulate and mats to develop. The tidal marshes support typical plant associations of the region, such as *Carex lyngbyei* and *Puccinellia nutkaensis*.

Conservation Status

Rarity: Barrier islands and spits are uncommon in southern Alaska, occupying a total area of 178 km^2 and representing less than 1% of the coastline.

Threats: Due to their landscape position, barrier islands and spits are highly susceptible to damage from oil spills human use. Degree of damage from an oil spill to nearshore waters will likely vary with factors such as tidal range and level, and location, season, extent and duration of the spill. All-terrain vehicle traffic also impacts some spits.

Trend: In general, barrier islands and spits represent dynamic habitats capable of repositioning, growing and shrinking in response to changing conditions. Change in extent and condition is not expected in the short- or long-term.

Figure 107. Semipalmated plover (*Charadrius semipalmatus*) (photo by T. Bowman).

Species of Conservation Concern

Barrier islands, spits and their associated dunes, swales, lagoons, estuaries and bays provide a wide variety of habitats that, where separated from the mainland, reduces access by predators (Boggs 2000). The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 56, Table 57). Numerous species that are not considered species of conservation concern use barrier islands in the Copper River Delta area as a stopover during migration (Figure 107). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 56. Mammal and bird species of conservation concern within the Pacific Barrier Island and Spit Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Steller's sea lion	*Eumetopias jubatus*	G3	S3	Sea lions use beaches of remote islands and uninhabited areas of southeast Alaska for haulouts and rookeries.
Birds				
Aleutian Tern	*Sterna aleutica*	G4	S3B	Nests usually on sand spits, sandbar islands, sand dunes, and flat vegetated summits of more rugged islands; on low wet coastal marsh and tundra in some areas.
Black Oystercatcher	*Haematopus bachmani*	G5	S2S3B	Breeding habitat is exclusively associated with the high tide margin of the inter-tidal zone. In Alaska, the highest breeding densities occur on nonforested islands dominated by sloping beaches of shell or gravel (Andres 1998).
Black Scoter	*Melanitta americana*	G5	S3S4BS3N	Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
Black Turnstone	*Arenaria melanocephala*	G5	S3NS4B	Nonbreeding: rocky seacoasts and offshore islets, less frequently in seaweed on sandy beaches and tidal mudflats (AOU 1983). Nests mainly in salt-grass tundra; breeds along the coast or on offshore islands.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Double-crested Cormorant	*Phalacrocorax auritus*	G5	S3	Habitat includes: lakes, ponds, rivers, lagoons, swamps, coastal bays, marine islands, and seacoasts; usually within sight of land. Nests on the ground or in trees in freshwater, and on coastal cliffs (usually high sloping areas with good visibility).
Dusky Canada Goose	*Branta canadensis occidentalis*	G3G4	S3S4	Breeding range restricted to the Cooper River Delta. Common on tidal marshes, uplifted tidal marshes and barrier islands.
Eurasian Wigeon	*Anas penelope*	G5	S3N	Winters primarily in freshwater (marshes, lakes) and brackish situations in coastal areas but migrates through inland regions. Rare in Southcoastal Alaska.
Gray-crowned Rosy-finch	*Leucosticte tephrocotis*	G5	S3NS5B	Barren, rocky or grassy areas and cliffs among glaciers or beyond timberline; in migration and winter also in open fields, cultivated lands, brushy areas, and around human habitation (AOU 1983).
Hudsonian Godwit	*Limosa haemastica*	G4	S2S3B	Nests on grassy tundra, near water – bogs, marshes, coastal or riverine areas. Nonbreeding habitat includes marshes, beaches, flooded fields, and tidal mudflats (AOU 1983); lake and pond shores, inlets.
Killdeer	*Charadrius vociferus*	G5	S3S4B	Habitat includes various open areas such as fields, meadows, lawns, pastures, mudflats, and shores of lakes, ponds, rivers, and seacoasts (AOU 1983).
King Eider	*Somateria spectabilis*	G5	S3B, S3N	Known to nest in arctic coastal tundra. Nearshore marine waters provides wintering and migration habitat.
Kittlitz's Murrelet	*Brachyramphus brevirostris*	G2	S2B, S2N	Wintering areas largely unknown for most birds. Populations in the Bering and Chukchi Seas probably move south away from pack ice (Day et al. 1999). Nests on coastal cliffs, rock ledges.
Marbled Murrelet	*Brachyramphus marmoratus*	G3G4	S2S3	Nest in old-growth hemlock and Sitka spruce on moss-covered trunks, or on ground near sea-facing talus slopes or cliffs. Likely forages in nearshore waters of barrier islands and spits.
Red-faced Cormorant	*Phalacrocorax urile*	G5	S3	Closely associated with rock-bottom coastlines of North Pacific marine islands and isolated areas of mainland Alaska, Kamchatka and Japan; often close to shore in water less than 200 m deep. Nests on steep, relatively inaccessible slopes.
Red Knot	*Calidris canutus*	G5	S2S3B	Nests on ground of barren tundra and well vegetated moist tundra in Northwest Alaska including the Seward Peninsula and less commonly near Point Barrow. Likely uses barrier island and spits for migration and staging.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Rock Sandpiper	*Calidris ptilocnemis*	G5	S3NS4B	Winters on rocky seacoasts, breakwaters, and mudflats. Nests in the open on the ground, prefers grassy or mossy tundra in coastal or montane areas (AOU 1983).
Sanderling	*Calidris alba*	G5	S2B	Breeds in small area of high arctic tundra on the Arctic Coastal Plain near Barrow. Likely uses barrier island and spits for migration and staging.
Snowy Owl	*Bubo scandiacus*	G5	S3S4	Suspected to winter in open areas near shorelines. Breeds in tundra from near treeline to the edge of polar seas.
Steller's Eider	*Polysticta stelleri*	G3	S2BS3N	During molting, utilize tidal flats and deeper bays. Winter habitat includes eelgrass, intertidal sand flats, and mudflats possibly foraging on invertebrates.
Surfbird	*Aphriza virgata*	G5	S2NS3B	Congregates on barrier islands and spits of Southcoastal Alaska during migration. Nests on dry alpine tundra.
Whimbrel	*Numenius phaeopus*	G5	S3S4B	Feeds on sandy beaches and spits during breeding season. Nests in nearby dwarf shrub tundra. Uses nearshore marine waters in Southcoastal Alaska during migration.
Yellow-billed Loon	*Gavia adamsii*	G4	S2B, S2S3N	Arctic tundra areas near open water are used as summer breeding grounds. Likely uses nearshore marine habitat provided by barrier islands and spits during migration and as winter habitat along Southern coastal Alaska.

Table 57. Plant species of conservation concern known or suspected to occur in the Pacific Barrier Island and Spit Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Cochlearia sessilifolia	G1G2Q	S2Q	Grows in intertidal gravel and fines that typically are submersed at high tide (Nawrocki et al. 2013).
Glehnia littoralis ssp. *leiocarpa*	G5T5	S2S3	Copper Sands barrier island, Copper River Delta.
Poa macrantha	G5T5	S1S2	The northern most range of this species is the barrier islands of the Copper River Delta.
Polygonum fowleri	G5TNR	S3S4	Copper Sands barrier island, Copper River Delta.

Plant Associations of Conservation Concern

No plant associations of conservation concern are known or suspected to occur within this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports plant associations of conservation concern.

Classification Concept Source

The classification concept for this biophysical setting is based on Thilenius (1990).

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Pacific Forested Glacial Ablation Plain Biophysical Setting

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Forested glacial ablation plains are represented by mature trees and associated understory species growing in a periglacial environment on ice-cored deposits. Through various geomorphic processes, glaciers may accumulate rock, gravel and sand on their upper surfaces. Where this debris reaches a depth sufficient to insulate roots, plants may colonize and a vegetated glacial ablation plain may develop (Figure 108). In Southeast Alaska, seres occurring in this unique environment transition from pioneer *Alnus viridis* ssp. *sinuata* associations to mid-seral *Picea sitchensis* forests to mature *Picea sitchensis-Tsuga heterophylla* forests (Figure 108 and Figure 109; Russell 1891, Molnia 2006, Stephens 1969, Post and Streveler 1976, Benn and Evans 1998). Additional study is required to evaluate whether these plant associations support unique vegetation, rare plants, and/or wildlife habitat. Many of these forests are 300 years and older, and many of the ice-cored ablation plains are estimated to last 600 years, ample time to allow forests to mature and even for secondary succession to occur (Post and Streveler 1976). However, in a rapidly warming climate, the melt processes that have produced these stable ablation plains become a liability to their existence (Tarr and Martin 1914).

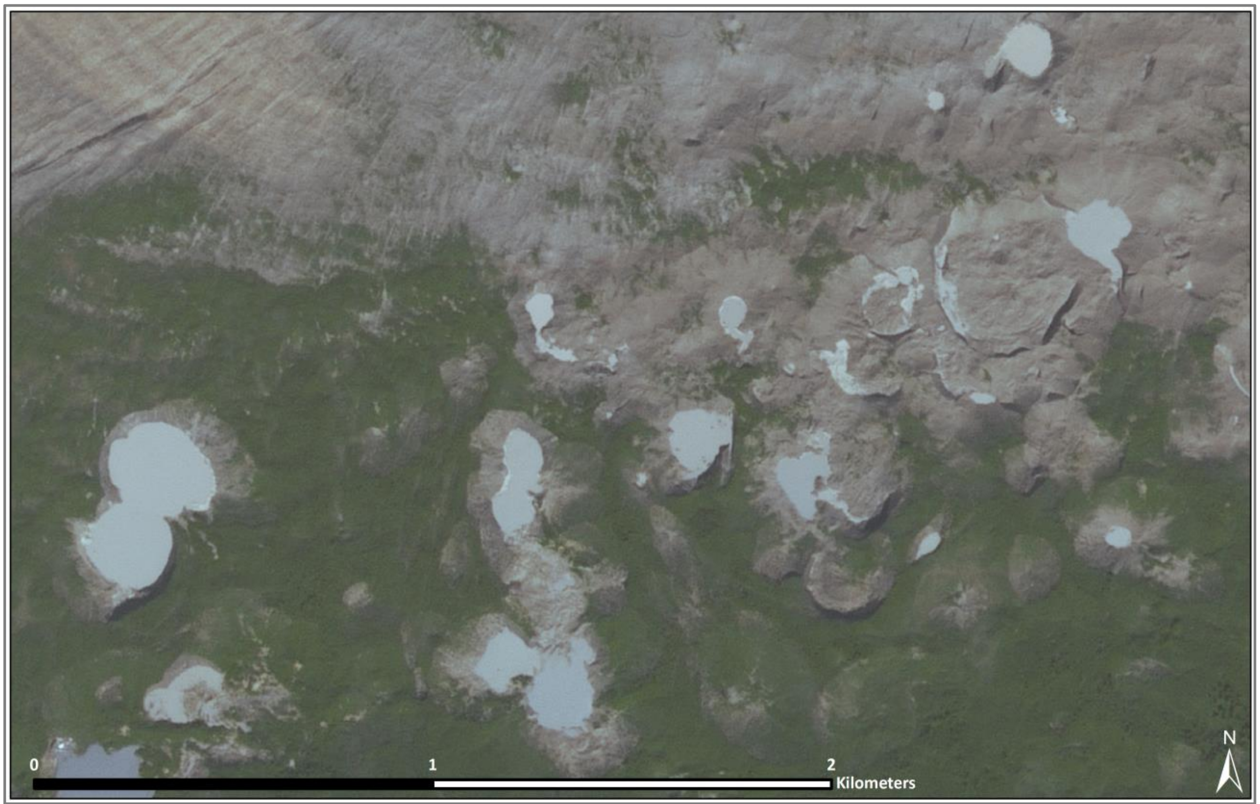

Figure 108. The Martin River glacier ablation plain showing the transition from barren debris to scattered spruce mixed with Alnus viridis ssp. sinuata to mature Picea sitchensis forest. Note the occurrence of craters and small lakes across the ablation plain.

Figure 109. Early seral communities on the supraglacial debris of the Martin River Glacier with pond in the foreground (photo by T. Boucher).

Distribution

Mature forests dominated or codominated by *Picea sitchensis* and/or *Tsuga heterophylla* on glacial ablation plains are rare and occur as isolated stands on the lower elevations of the Bering, Fairweather, Grand Plateau, Malaspina, Martin River, and Sherman Glaciers and on remnant ice on the north side of Lituya Bay (Russell 1891, Molnia 2006, Stephens 1969, Post and Streveler 1976, Benn and Evans 1998). Earlier seral-stages occur on additional ablation plains, and are more common than the mature forests. The distribution of forested glacial ablation plains (Figure 110) was developed from the intersection of glacial ice (GLIMS 2005) with *Picea sitchensis*-dominated landcover classes of the Alaska Vegetation Map (Boggs et al. 2015).

Climate

Southern Alaska has a cool, wet maritime climate and is generally free of permafrost (Gallant et al. 1995, Nowacki et al. 2001). Mean annual precipitation ranges from 135 to 390 cm with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C.

Environmental Characteristics

Supraglacial debris is largely derived from medial and lateral moraines or landslides to the glacier surface (Fickert et al. 2007); lesser sources may include alluvial or aeolian sediment transport and solifluction, as well as thrusting of bed-derived sediment from the bottom of a glacier to its surface (Alley et al. 1997). Depending on the energy of the depositional process, debris may include boulders 2 to 3 m in diameter and may reach thicknesses exceeding 0.5 m (Rampton 1970, Birks 1980). Of these varied sources, medial and lateral moraines are thought to be the dominant sources of supraglacial debris (Figure 111). Medial and lateral moraines form as narrow strips of debris, but increase in width and relief as they move downgradient past the equilibrium line to the ablation zone. In the ablation zone, where ice melt exceeds accumulation, debris is most commonly reworked by meltwater into outwash plains and ice may be degraded by above-freezing temperatures, stream erosion, or the exposure of ice by removal of sediment. Melt across steep ice faces can initiate small soil-vegetation slides, forming a chaotic accumulation of debris and vegetation

(Figure 112; Russell 1891). Slides across slopes of craters may form bluffs 8 m high littered with standing, leaning and fallen dead trees.

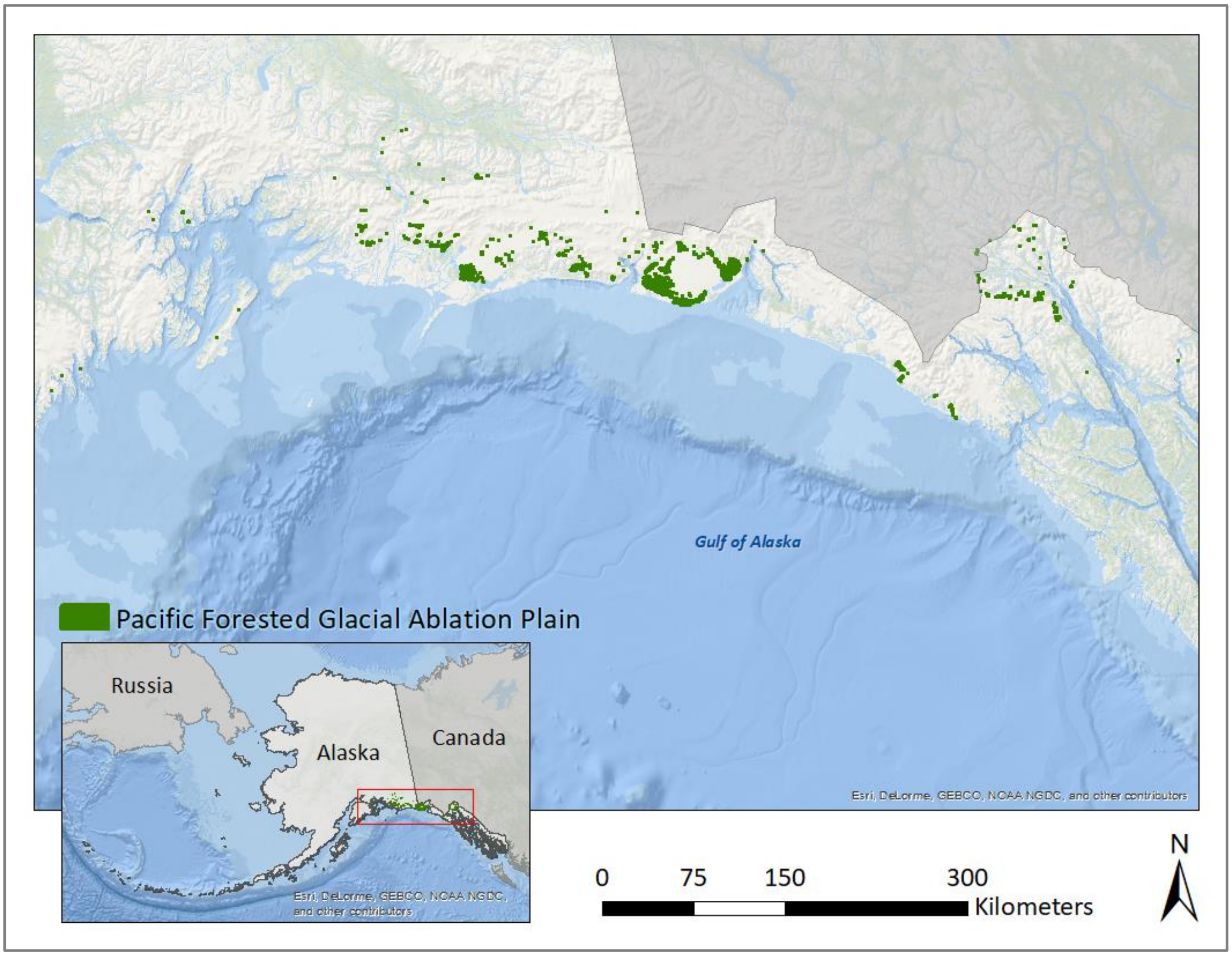

Figure 110. Distribution of the Pacific Forested Glacial Ablation Plain Biophysical Setting. Note that the areas of occupancy shown on the map are buffered for greater visibility.

Under less rapid melt conditions debris may build over ice allowing vegetation to establish (Figure 113). Due to the insulation provided to the underlying ice by supraglacial debris, the thermodynamics of 'dirty' glaciers differ from those of 'clean' glaciers. Supraglacial debris can reduce glacial ablation rates, allowing the glacier to extend further down valley than meteorology alone would suggest (Anderson 2000). Research on the vegetation communities on glacier ablation plains have shown that the lifespan of supraglacial trees is mainly controlled by glacier surface displacements and by the occurrence of backwasting and downwasting processes, whereas tree germination was associated with fine debris presence (Pelfini et al. 2007) Debris-covered glaciers have been estimated to last over 350 years in Alaska with another 300 years of ice remaining (Post and Streveler 1976). Trees more than 300 years in age have been documented on the supraglacial debris of the Martin River Glacier (Post and Streveler 1976) while trees more than 50 cm in diameter have been observed on the debris-covered termini of more than a dozen glaciers in southern Alaska, including the Bering, Malaspina, Fairweather, Grand Plateau, and Martin-River Glacier (Russell 1891, Molnia 2006, Stephens 1969, Post and Streveler 1976, Benn and Evans 1998).

Vegetation and Soil Succession

Figure 111. The Martin River Glacier showing the formation and widening of its medial moraine from the confluence of the glacial arms at upper right.

Newly stabilized supraglacial debris is invaded by a variety of pioneer plant associations. These include associations dominated by the shrub *Alnus viridis* ssp. *sinuata* (Sitka alder) such as *Alnus viridis* ssp. *sinuata-Oplopanax horridus/Aruncus dioicus*, *Alnus viridis* ssp. *sinuata/Rhytidiadelphus* species or early seral *Picea sitchensis/Alnus viridis* ssp. *sinuata* (Barrett and Christansen 2011, Stephens 1969, Russell 1891). Scattered *Populus trichocarpa* saplings are also common. Soil development is minimal, with multiple surface cracks exposing glacial ice and initiating soil and vegetation slumping.

On mid-seral sites, *Picea sitchensis* gradually overtops the *Alnus viridis* ssp. *sinuata*, and within 100 years a dense forest dominated by *Picea sitchensis* or in combination with *Tsuga heterophylla* develops (Figure 113; Post and Streveler 1976, Stephens 1969). The forest floor is dominated by mosses in the *Rhytidiadelphus* and *Hylocomium* genera (Stephens 1969). Other species include shrubs in the *Ribes* genus, *Oplopanax horridus*, *Pyrola secunda*, and *Dryopteris expansa*. The height, diameter and age of *Picea sitchensis* ranges from 18 m tall, 15-30 cm dbh, and 65 years old on the Kushtaka Glacier (Stephens 1969) to much larger and over 300 years old on the Martin River Glacier (Post and Streveler 1976, Russell 1891). Soil in these spruce forests are spodosols, with A, B and C horizons developed. The gravelly sandy loam comprising the C layer has 70% coarse fragments. Soil thickness ranges from 0.5 to 3 m (Post and Streveler 1976, Stephens 1969). Following the eventual melt of the underlying ice, it is expected that the organic matter, nitrogen and other soil nutrients accumulated will make significant contributions to young post-glacial ecosystems (Crocker and Dickson 1957, Stephens 1969).

Figure 112. Melt across steep ice faces can initiate small landslides, which expose glacial ice; Matanuska Glacier ablation plain.

Conservation Status

Rarity: Mature *Picea sitchensis* or *Tsuga heterophylla-Picea sitchensis* forests rarely develop on glacial ablation plains and are only documented from seven periglacial environments in Southern Alaska (Russell 1891, Molnia 2006, Stephens 1969, Post and Streveler 1976, Benn and Evans 1998). Their estimated potential range is less than 1,000 km^2.

Threats: Change in glacier movement threatens this system. In a rapidly warming climate, the melt processes that have produced these stable ablation plains become a liability to their further existence (Tarr and Martin 1914, Stephens 1969). In contrast, it is unclear as to whether advancing glaciers would support an ablation plain stable enough to allow the development of forests.

Trend: Ice-cored ablation plains are estimated to last well beyond the time required for forests to mature and even for secondary forest succession to occur (600 years; Rampton 1970, Birks 1980). Thus in the absence of significant glacier recession or advance, change in the extent and condition of this system in not expected. It is not known how increased ablation rates due to a warming climate will affect the maintenance of this system.

Species of Conservation Concern

No animal or plants species of conservation concern are known or suspected to occur in this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports animal and plants of conservation concern.

Classification Concept Source

The classification concept for this biophysical setting is based on Russell (1891).

Figure 113. Supraglacial debris on the Martin River Glacier supporting *Picea sitchensis* forest on left side of the image, a crater with a lake, and scattered spruce mixed with *Alnus viridis* ssp. *sinuata* on the right (source: Google Earth, accessed September 2, 2015).

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Pacific Tidal Marsh Biophysical Setting

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

Tidal marshes develop where relatively flat land receives periodic input of tidal waters (Frohne 1953). As an interface between the ocean and land, tidal marshes combine aquatic and terrestrial habitats, anoxic and oxic conditions, as well as saline and fresh waters (Stone 1984). This dynamic environment supports life highly-adapted to saturation and saline conditions. Along the Gulf of Alaska coastline, tidal marshes are uncommon, developing as marshes in protected topographic pockets, or larger complexes on the major river deltas (Figure 114; Viereck et al. 1992). In this region they are one of Alaska's most critical habitats. As staging areas for millions of migrating shorebirds, geese, and swans, this biophysical setting supports nine animal taxa of conservation concern and provides important rearing habitat for salmon. Tidal marshes are also one of Southeast Alaska's most impacted biophysical settings due to the location of villages, towns and cities adjacent to and sometimes on these flat, yet fragile habitats. Pacific tidal marshes are considered unique from those found in Cook Inlet and western Alaska due to their wet, mild maritime climate, a lack of permafrost and the general dominance of *Carex lyngbyei*. The dominant sedge in Beringian tidal marshes is generally *Carex ramenskii* (Batten et al. 1978).

Figure 114. Tidal marsh in Kenai Fjords, Alaska.

Distribution

Tidal marshes are widely distributed along the coastline of Southern Alaska and the Aleutian Islands (**Error! Reference source not found.**). Here, numerous small tidal marshes are maintained in protected ockets along the fjordlands' rocky shores, typically at the heads of bays or lagoons (circa one acre; Crow 1977). More extensive systems are less common; long (up to 50 km), narrow tidal marshes are found at the Copper River Delta, Yakutat Forelands (from the Dangerous River) and the Stikine River Delta. The Pacific Tidal Marsh distribution was developed from the estuarine and marine intertidal subsystems of the National Wetland Inventory (USFWS 2015). Because National Wetlands Inventory coverage is not available for the Aleutian Islands, the distribution of Pacific tidal marshes west of Kodiak Island were not mapped.

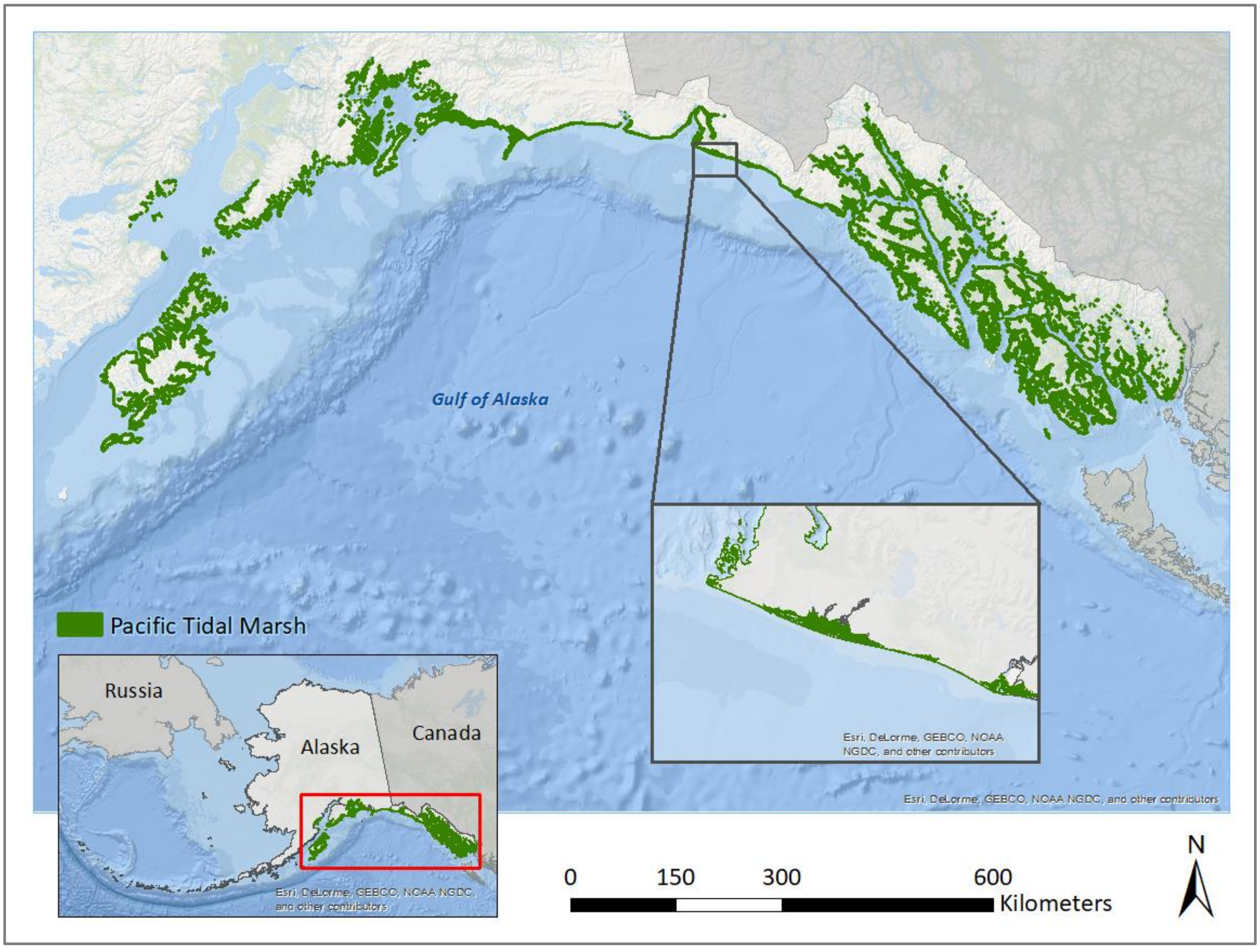


Figure 115. Distribution of the Pacific Tidal Marsh Biophysical Setting. Tidal marshes have not been mapped in the Aleutian Islands. Note that the areas of occupancy in this map are buffered for greater visibility.

Climate

Southeast Alaska and the Aleutian Islands have a cool, wet maritime climate and are generally free of permafrost (Gallant et al. 1995, Nowacki et al. 2001). The mean annual precipitation in coastal rainforests ranges from 135 to 390 cm with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18°C; average winter temperatures are between -3 and 3°C. The Aleutian Islands have a mean annual precipitation ranging from 60 to 330 cm with snowfall from 55 to 150 cm. Average summer temperatures range from 6 to 15°C; average winter temperatures are between -11 and -6°C.

Environmental Characteristics

Tidal marshes occur wherever there is flat land at sea level (Frohne 1953). Three elements are typically required for their formation: 1) Input of tidal waters that range from twice daily inundation of mudflats to occasional exposure of upper marsh habitats to storm surges. 2) Sediment deposition from rivers depositing their sediment load on deltas, or sediment imported from adjacent coastlines via long-shore drift; there is commonly a concurrent buildup of organic matter. 3) Protection from ocean waves and ocean current erosion provided by topography (e.g. barrier islands, spits, peninsulas, shallow bays) and, at a smaller scale, by established vegetation which effectively slows the water current and/or wave energy (Chapman 1960, Boggs et al. 2008).

Tidal marshes may receive fresh water from streams and rivers, as well as overland and subsurface flow. Water salinity is inversely related to freshwater inputs and is subsequently lower in the spring when freshwater contributions from melting snow and river ice are higher (Jefferies 1977).

Figure 116. Tidal marsh in Kenai Fjords, Alaska.

The coastline along Southeast Alaska and the Aleutian Islands is extremely dynamic in relation to sea-level. Some land is currently rising due to isostatic rebound and tectonic uplift, while other coastlines are falling due to tectonic down-warping and rising sea level, as a result of climate change. Changes in relative sea level have a dramatic effect on tidal marshes and other coastal ecosystems. Along a rising coastline the upper marsh will pass out of tidal influence and transition to vegetation characteristic of the surrounding nontidal habitats. At the same time, tidal associations along the outer marsh may invade newly exposed mudflats. Along a falling coastline, tidal marshes migrate inland with tidewater inundating previously nontidal sites, such as forests or peatlands while tidal associations along the outer marsh may erode or drown. As a result of this dynamic rising and falling coastline, most tidal marshes of southern Alaska and the Aleutian Islands are relatively young (Figure 116). For example, newly uplifted inter-tidal surfaces support pioneer species (principally *Puccinellia* species and *Carex lyngbyei*), mudflats, tide channels, and distributary channels (Batten et al. 1978, Boggs and Shephard 1999, Thilenius 1990). If given enough time these tidal marshes will develop deep tide channels, levees, and basins dominated by *Carex lyngbyei* with thick root mats.

Wind also plays a strong role in retarding marsh development in the Aleutian Islands and Alaska Peninsula. Frequent strong winds leads to erosive waves even in protected lagoons. Consequently, tidal marshes are more infrequent than one would expect based on topography.

Vegetation and Succession

The zonation of vegetation within tidal marshes can be conspicuous both globally and in Alaska but is not always expressed (Hanson 1951, Vince and Snow 1984, Streveler et al. 2003). The following describes vegetation zones from mudflats, to low marsh, towards uplands along an idealized gradient of decreasing inundation and salinity (**Error! Reference source not found.**). Relationships between tidal levels and egetation are outlined but may vary depending on environmental conditions such as exposure, orientation, and adjoining topography and vegetation type.

At the lowest elevation exposed at low tide, barren mudflats may be interspersed with the green algae *Fucus distichus*. These mudflats support benthic invertebrates (bivalves, polychaetes, amphipods, and chironomids; Powers et al. 2002) that contribute heavily to the diet of the migrating shorebirds (Senner 1979).

Above these sparsely vegetated mudflats, the low marsh generally occurs below or at mean high tide level (Taylor 1981). The low marsh supports halophytic graminoids of the *Puccinellia* genus. Other forbs include

Cochlearia groenlandica, *Fucus distichus*, *Eleocharis palustris*, *Glaux maritima*, *Plantago maritima*, *Potentilla anserina* ssp. *egedii*, *Ranunculus cymbalaria* and *Triglochin maritima*, (Batten et al. 1978, Hanson 1951, Crow 1968, Fleming and Spencer 2007, del Moral and Watson 1978, Turner 2010, Vince and Snow 1984, DeVelice et al. 1999, Boggs 2000, Shephard 1995).

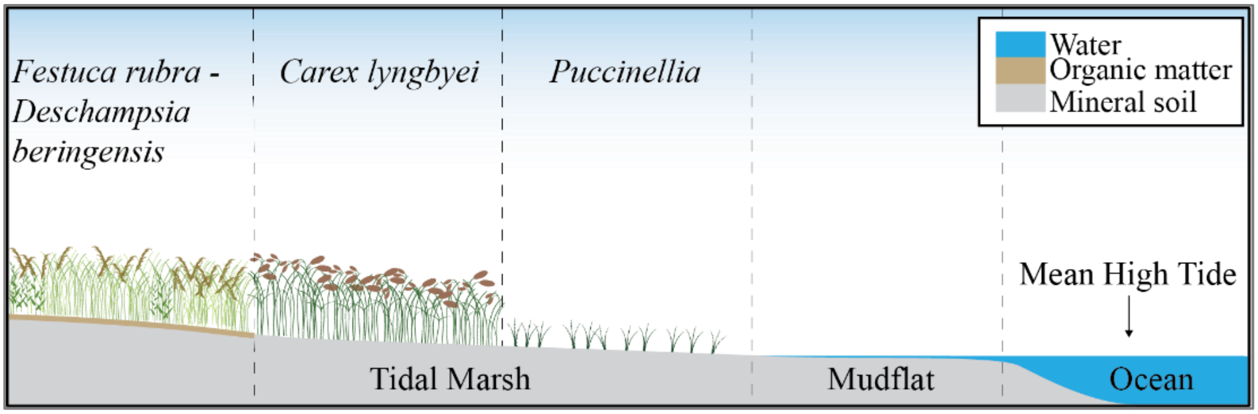


Figure 117. Schematic physiography and vegetation profile of a tidal marsh on a young tidal surface, Copper River Delta, Alaska.

The mid marsh occupies the reach of land that is inundated only at the highest tides during the growing season (Crow 1977, Batten et al. 1978). It typically supports dense swards of *Carex lyngbyei* (del Moral and Watson 1978, Stephens and Billings 1967, Turner 2010, DeVelice et al. 1999, Boggs 2000, Shephard 1995). Less common mid marsh sedges include *Carex pluriflora, C. cryptocarpa* and *C. glaerosa* (Crow 1968, Hanson 1951). With increased elevation, dominance transitions from *Carex lyngbyei* to associations dominated or codominated by *Deschampsia cespitosa* and *Vahlodea atropurpurea* (Stephens and Billings 1967, Crow 1968, Turner 2010).

The high marsh ranges from the highest tide line to the maximum level reached by storm surges during the growing season (Batten et al. 1978). It supports a diversity of salt-tolerant graminoid and forb associations including the sedges *Carex mackenziei*, and *C. pluriflora*, and the grasses *Calamagrostis canadensis, C. nutkaensis*, *Deschampsia beringensis*, *Festuca rubra*, *Leymus mollis* and *Poa eminens* (McCormick and Pichon 1978, Neiland 1971, Quimby 1972, Turner and Barker 1999, Batten et al. 1978, del Moral and Watson 1978, Turner 2010, Vince and Snow 1984). The forbs *Potentilla anserina* ssp. *egedii, Ligusticum scoticum* and *Lathyrus palustris* typically increase in dominance with elevation across the high marsh (Stephens and Billings 1967, Vince and Snow 1984). The low shrub *Myrica gale/Carex lyngbyei* and *Salix hookeriana* associations also occur (Hanson 1951, Boggs 2000).

Conservation Status

Rarity: Tidal marshes are widely distributed along the coastlines of Southeast Alaska and the Aleutian Islands, but their small total area (450 km^2), and the fidelity of its component species makes this biophysical setting of one conservation concern.

Threats: Due to their landscape position, tidal marshes are highly susceptible to damage from development, oil spills, sea level rise, and earthquake-induced slides and tsunamis. Because tidal marshes in Southeast Alaska provide flat land along an otherwise rocky coastline, cities, towns and villages are often located adjacent to these habitats (e.g. Seward, Juneau, Cordova).

Figure 118. Tidal marshes and mudflats at Hartney Bay near Cordova, Alaska.

Trend: Short-term decline due to development and human activity is expected; long-term trend is more difficult to predict. Degree of damage from an oil spill to nearshore waters is expected to vary with factors such as degree of tidal influx, tide level, location, season and extent and duration of the spill. Sites with high freshwater outflow will be less susceptible (Crow 1977). The long-term loss of coastal habitat due to climate-induced, global sea level rise is difficult to predict as projections must account for local trends of tectonic uplift and subsidence, the potential for seismic repositioning of the shoreline and glacial rebound in relation to global sea level rise. The average global sea level rose about 18 cm over the 20th century, 10 times faster than the average rate of sea-level rise during the previous 3,000 years (Haufler 2010). Since 1990, sea level has been rising 0.4 cm/year, twice as fast as the average over the 20th century and projections show the rate will continue to accelerate (Haufler 2010, Garrett 2014). Sea level, however, has rarely been constant in southern Alaska and the Aleutian Islands. Some land is currently rising due to isostatic rebound and tectonic uplift, while other coastlines are falling due to tectonic down-warping. The occurrence of deep subduction zone earthquakes and their attendant disturbances are notoriously difficult to predict. For southern Alaska the reoccurrence time for these large-magnitude earthquakes is estimated to be on the order of 500 to 1,350 years (Plafker and Rubin 1978). Considering the relative recentness of the 1964 Good Friday Earthquake, impacts from this threat are only expected in the extreme long-term.

Species of Conservation Concern

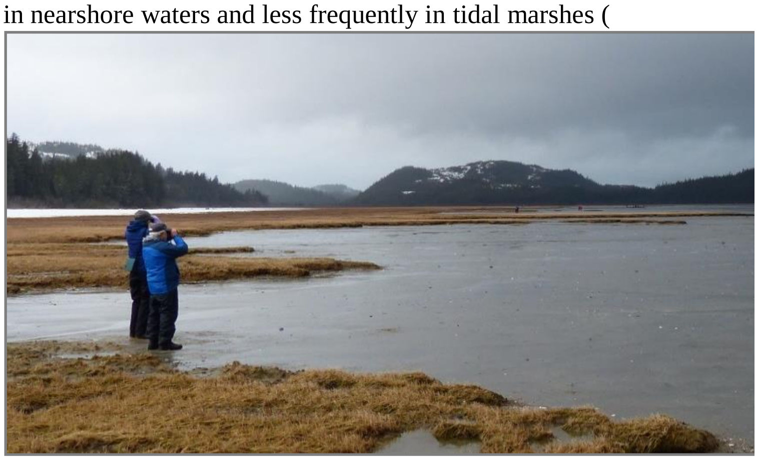
Tidal marshes provide a staging area for millions of migrating shorebirds and waterfowl (Figure 119), is an important rearing habitat for salmon, and supports numerous taxa of concern.

The animal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 58, Table 59). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Figure 119. Marbled Godwit (photo by T. Bowman).

Table 58. Bird and amphibian species of conservation concern within the Pacific Tidal Marsh Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Amphibians				
Western toad	*Anaxyrus boreas*	G4	S3S4	Known to occur in southeast Alaska's island and mainland coastal rainforest habitat; could occur on upper tidal marsh.
Birds				
Aleutian Tern	*Sterna aleutica*	G4	S3B	Nests usually on sand spits, sandbar islands, sand dunes, and flat vegetated summits of more rugged islands; on low wet coastal marsh and tundra in some areas.
Bar-tailed Godwit	*Limosa lapponica*	G5	S3B	Nests in sedge meadows and coastal tundra. Staging in nearshore estuarine areas and beaches.
Beringian Marbled Godwit	*Limosa fedoa beringiae*	G5T2T3	S2B	The entire breeding population is thought to move to intertidal and estuarine habitats of the Alaska Peninsula after breeding.
Black Guillemot	*Cepphus grylle*	G5	S2	Nest along beaches and in coastal cliff crevices in Northern Alaska.
Black Oystercatcher	*Haematopus bachmani*	G5	S2S3B	Breeding habitat is exclusively associated with the high tide margin of the inter-tidal zone. In Alaska, the highest breeding densities occur on nonforested islands dominated by sloping beaches of shell or gravel (Andres 1998).
Black Scoter	*Melanitta americana*	G5	S3S4B, S3N	May use inshore marine habitat during nonbreeding seasons. Nests near lakes and pools on grassy or bushy tundra (AOU 1983).
Black Turnstone	*Arenaria melanocephala*	G5	S3N, S4B	Nonbreeding found on rocky seacoasts and offshore islets (AOU 1983). Nests mainly in salt-grass tundra; breeds along the coast or on offshore islands.
Bristle-thighed Curlew	*Numenius tahitiensis*	G2	S2B	Known to nest in the low mountainous regions of the Yukon-Kuskokwim delta and the Seward Peninsula. Tidal flats and beaches near Prince William Sound provide migration habitat on a rare occasion.
Double-crested Cormorant	*Phalacrocorax auritus*	G5	S3	Habitat includes: lakes, ponds, rivers, lagoons, swamps, coastal bays, marine islands, and seacoasts; usually within sight of land. Nests on the ground or in trees in freshwater, and on coastal cliffs.
Dusky Canada Goose	*Branta canadensis occidentalis*	G5T3	S3B	Breeding range restricted to the Cooper River Delta. Common on tidal marshes, uplifted tidal marshes and barrier islands.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Eurasian Wigeon	*Anas penelope*	G5	S3N	Winters primarily in freshwater (marshes, lakes) and brackish situations in coastal areas but migrates through inland regions. Rare in Southcoastal Alaska.
Great Blue Heron	*Ardea herodias*	G5	S2S3	Nest in tall trees of wetlands near tidal and freshwater. Tidal marshes of southern Alaska provide hunting habitat.
Hooded Merganser	*Lophodytes cucullatus*	G5	S3B	Streams, lakes, swamps, marshes, and estuaries; winters mostly in freshwater but also regularly in estuaries and sheltered bays (AOU 1983).
Hudsonian Godwit	*Limosa haemastica*	G4	S2S3B	Nests on grassy tundra, near bogs and marshes or near coast/rivers. Nonbreeding habitat includes marshes, beaches, flooded fields, and tidal mudflats (AOU 1983); lake and pond shores, inlets.
Lesser Scaup	*Aythya affinis*	G5	S3N, S5B	Breeds in marshes, ponds, and small lakes (AOU 1998). Usually nests near small ponds and lakes, sedge meadows, creeks with some cover.
Marbled Murrelet	*Brachyramphus marmoratus*	G3G4	S2S3	Nest in old-growth hemlock and Sitka spruce on moss-covered trunks, or on ground near sea-facing talus slopes or cliffs. Forages in nearshore waters and less frequently in tidal marshes ().
McKay's Bunting	*Plectrophenax hyperboreus*	GU	S3	May use coastal habitat in the Bering Sea including Nunivak Island during migration. This species is only known to breed on St. Matthews and Hall islands in rocky areas and beaches. The McKay's bunting would be a rare spring migrant through Southcoastal Alaska.
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	G5	S3B	Rare visitor to southern southeast Alaska. Likely uses tidal marshes for feeding habitat.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Peale's Peregrine Falcon	*Falco peregrinus pealei*	G4T3	S2S3	Utilizes coastal beaches, tidal flats, islands, marshes, estuaries, and lagoons. Nests primarily on ledges of vertical rocky cliffs in the vicinity of seabird colonies.
Pribilof Rock Sandpiper	*Calidris ptilocnemis ptilocnemis*	G5T3	S2N, S3B	Winter range includes intertidal habitats along the Gulf of Alaska and Cook Inlet.
Queen Charlotte Goshawk	*Accipiter gentilis laingi*	G5T2	S2	Primarily a forest dwelling species, this goshawk likely uses tidal marshes on occasion for hunting.
Redhead	*Aythya americana*	G5	S3S4B	Nest in Interior Alaska (ponds, lakes) but could rarely use tidal marshes in southeast Alaska during migration.
Red Knot	*Calidris canutus*	G5	S2S3B	Nests on ground of barren tundra and well vegetated moist tundra in Northwest Alaska including the Seward Peninsula and less commonly near Point Barrow. Likely uses barrier island and spits for migration and staging.
Ring-billed Gull	*Larus delawarensis*	G5	S3N	Prefers nearshore coastal or freshwater habitat. Nests rocky, sandy, and grassy islets or isolated shores, occasionally on marshy lands, often with other water birds; mainly at inland lakes.
Ring-necked Duck	*Aythya collaris*	G5	S2N, S3B	Nests in freshwater marshes and wooded ponds/lakes. Likely uses tidal marshes as wintering habitat.
Rock Sandpiper	*Calidris ptilocnemis*	G5	S3N, S4B	Winters on rocky seacoasts, breakwaters, and mudflats. Nests in the open on the ground, prefers grassy or mossy tundra in coastal or montane areas (AOU 1983).
	Calidris alba	G5	S2B	Breeds in small area of high arctic tundra on the Arctic Coastal Plain near Barrow. Likely uses tidal marshes near the Copper River Delta during migration.
Smith's Longspur	*Calcarius pictus*	G5	S3S4B	Smith's Longspur breed in dry tundra. Tidal marshes could be used during migration in the Yakutat area.
Stilt Sandpiper	*Calidris himantopus*	G5	S3B	Breeding range from Canadian border to Barrow, Alaska along coastal plain at least several km inland. Suspected to use nearshore marine habitat for migration.
Surfbird	*Aphriza virgata*	G5	S2N, S3B	Nests on dry alpine tundra. Winter habitat could include coastal tidal marshes but prefers rocky habitat.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Whimbrel	*Numenius phaeopus*	G5	S3S4B	Feeds on sandy beaches and spits during breeding season. Nests in nearby dwarf shrub tundra. Uses nearshore marine waters in Southcoastal Alaska during migration.
White-rumped Sandpiper	*Calidris fuscicollis*	G5	S3B	Grassy or mossy tundra, often not far from water; wet tundra, with nest sites on tops of hummocks. Tidal marshes are likely used as feeding, staging, and migration habitat.

Table 59. Plant species of conservation concern within the Pacific Tidal Marsh Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Bolboschoenus maritimus	G5	S3	Brackish to saline coastal shores and marshes.
Carex glareosa ssp. *pribylovensis*	G4G5T2T3	S2	An Alaskan endemic, known only from 6 locations in salt marshes and gravelly seashores of the Pribilof and Aleutian islands.
Carex stipata	G5	S1	Seasonally saturated or inundated soils in wet meadows, marshes, edges of tidal marshes, swamps, alluvial bottomlands
Cochlearia sessilifolia	G1G2Q	S2Q	Grows in intertidal gravel and fines that typically are submersed at high tide.
Phyllospadix serrulatus	G4	S3	Known from widely scattered rocky tidal and subtidal sites along the coast.
Plagiobothrys orientalis	G3	S3	Found in open mud at margin of Carex lyngbyei zone
Sidalcea hendersonii	G3	S1	Known from the Juneau area, where it occurs in upper tidal marshes and raised beach meadows.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 60).

Table 60. Plant associations of conservation concern within the Pacific Tidal Marsh Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Shrubs			
Myrica gale/Carex lyngbyei	G3	S3	DeVelice et al.1999, Boggs 2000
Myrica gale-Salix hookeriana	G3	S3	DeVelice et al. 1999
Salix arctica/Carex lyngbyei	G3	S3	DeVelice et al.1999, Boggs 2000
Herbaceous			
Agropyron trachycaulum- Festuca rubra-Achillea borealis-Lathyrus palustris	G3	S3	Hanson 1951
Carex glareosa	G3	S3	Boggs 2000
Carex lyngbyei-Cicuta mackenziana	G3	S3	Crow 1968
Carex pluriflora-Carex lyngbyei	G3	S3	Hanson 1951
Cochlearia officinalis	G3	S3	Wiggins and Thomas 1962
Cochlearia officinalis-Achillea borealis	G3	S3	Byrd 1984
Cochlearia officinalis-Lathyrus maritimus	G3	S3	Bank 1951

Name	Global Rank	State Rank	Concept Source
Cochlearia sessilifolia	G1G2	S1S2	Boggs et al. 2008
Deschampsia caespitosa	G4	S3	DeVelice et al. 1999
Puccinellia glabra-Plantago maritima	G3	S3	Hanson 1951
Puccinellia phryganodes – Cochlearia officinalis	G3	S3	Thomas 1951
Puccinellia phryganodes – Salicornia europaea	G3	S3	Hanson 1951

Classification Concept Source

The classification concept for this biophysical setting is based on Crow (1968).

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Pacific Uplifted Tidal Marsh Biophysical Setting

Pacific Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

The Pacific Uplifted Tidal Marsh Biophysical Setting is characterized by a mosaic of lush herbaceous meadows, shrub associations and ponds on landscapes that were historically subject to tidal influence (Figure 120). Uplifted marshes are formed when a tidal marsh is slowly (due to isostatic rebound) or abruptly (due to earthquake-induced tectonic movement) lifted to the edge of, or above the tidal zone. Although uplifted tidal marshes occupy a small total area, they represent a unique habitat supporting several animal and plant taxa of concern, such as the Dusky Canada Goose (Figure 124; *Branta Canadensis occidentalis*) and the Yakutat moonwort (*Botrychium yaaxudakeit*). Uplifted tidal marshes are also one of Alaska's more impacted biophysical setting due to the location of towns adjacent to, and often on, these flat, yet fragile habitats. Tidally-influenced habitats along Southcentral and Southeast Alaska coastlines are considered unique from tidal marshes found in northern Alaska due to their wet, mild maritime climate, lack of permafrost, and the general dominance of tall forbs, grasses and sweetgale (*Myrica gale*) as opposed to crowberry (*Empetrum nigrum*) in the Arctic.

Figure 120. Uplifted tidal marsh near Gustavus, Alaska.

Distribution

This is an incidental biophysical setting found in coastal environments of Southeast Alaska occurring primarily as small- to mid-size patches. The largest area of occupancy is on the Copper River Delta, but other large systems occur on the Stikine Delta, Gustavus Forelands, Yakutat Forelands, Dyea Flats, and in the Juneau region. The distribution of uplifted tide marshes in Alaska was hand digitized over remotely-sensed imagery (Figure 121). Delineation was informed by literature references (Boggs and Shepard 1999, del Moral and Watson 1978, Flagstad and Boucher 2014), landform elevation, as well as vegetation type and pattern.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). Mean annual total precipitation in the coastal rainforest ranges from 135 to 390 cm, with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C. Rainfall and temperature show highly variable patterns dependent upon proximity to mainland ice-fields, the Pacific Ocean, topography and regional weather patterns.

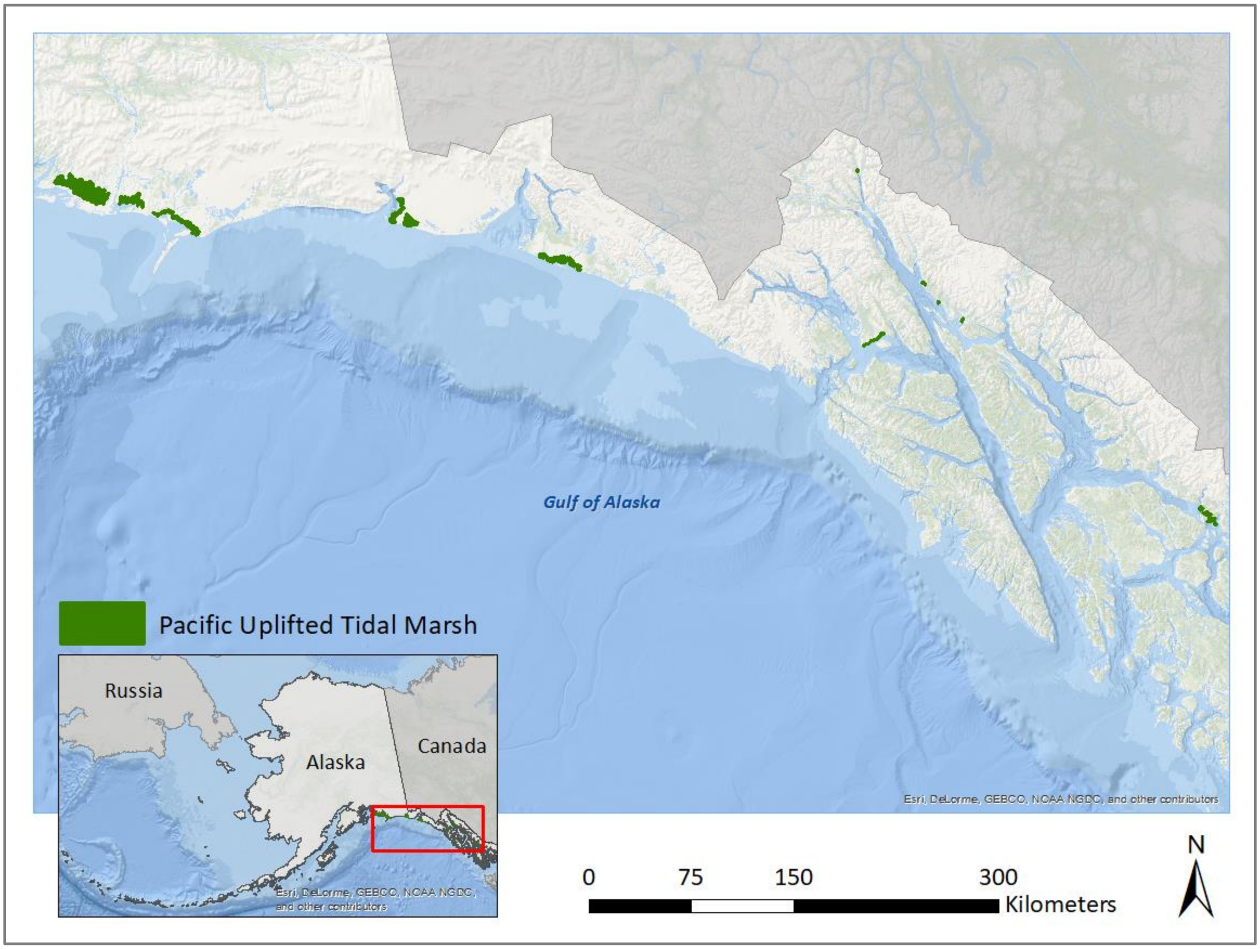

Figure 121. Distribution of the Pacific Uplifted Tidal Marsh Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

Environmental Characteristics

Uplifted marshes are formed when a tidal marsh is slowly (due to isostatic rebound) or abruptly (due to earthquakes) lifted to the edge of, or above the tidal zone. Sites may also be raised due to sedimentation from tidal surges or from tidal rivers (Turner 2010). Consequently, these uplifted tidal marshes typically occupy the landward edge of tidal marshes.

Young, uplifted tidal marshes tend to be flat and dissected by creeks that may retain tidal influence (Figure 122; Batten et al. 1978, Stone 1993, Shephard 1995, Boggs et al. 2008, Streveler et al. 2003 and Turner 2010). Uplifted tidal marshes also occur as small patches on back beach dunes and marginal to tidally influenced floodplains. Elevations range from near the maximum high tide to 8 m.

Tidal marshes that are mature prior to uplift often retain developed tidal channels, levees and large ponds (Figure 123). The best example of this is on the Copper River Delta where a mature tidal marsh was abruptly lifted about two meters above the tidal zone by the Good Friday Earthquake in 1964 and retains nearly the same pattern of channels, levees and large ponds (Crow 1968, Thelenius 1995, Boggs 2000). Subsidence rate estimates on the Copper River Delta have ranged from 4.5-6.5 mm/year for the past 5,600 years (Plafker et al. 1990) to approximately 1.2 mm/year over the mid to Late Holocene (Garrett et al. 2014). Consequently it may require a minimum of 300 years for the Copper River Delta uplifted tidal marsh to regain tidal influence.

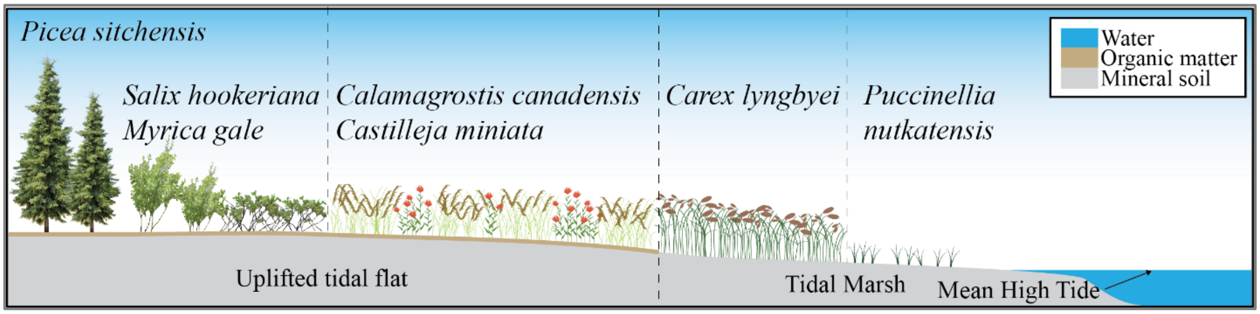

Figure 122. Schematic physiography and vegetation profile of a young tidal marsh uplifted above the tidal zone.

Within the uplifted tidal flat, mesic site soils are typically organic matter (2-10 cm) over silt or sand, drainage is moderate to poor, and the water table ranges from 20 to 80 cm deep (Boggs 2000). On wetter sites such as ponded basins, soils may have a saturated organic mat 6 to 40+ cm thick over silt.

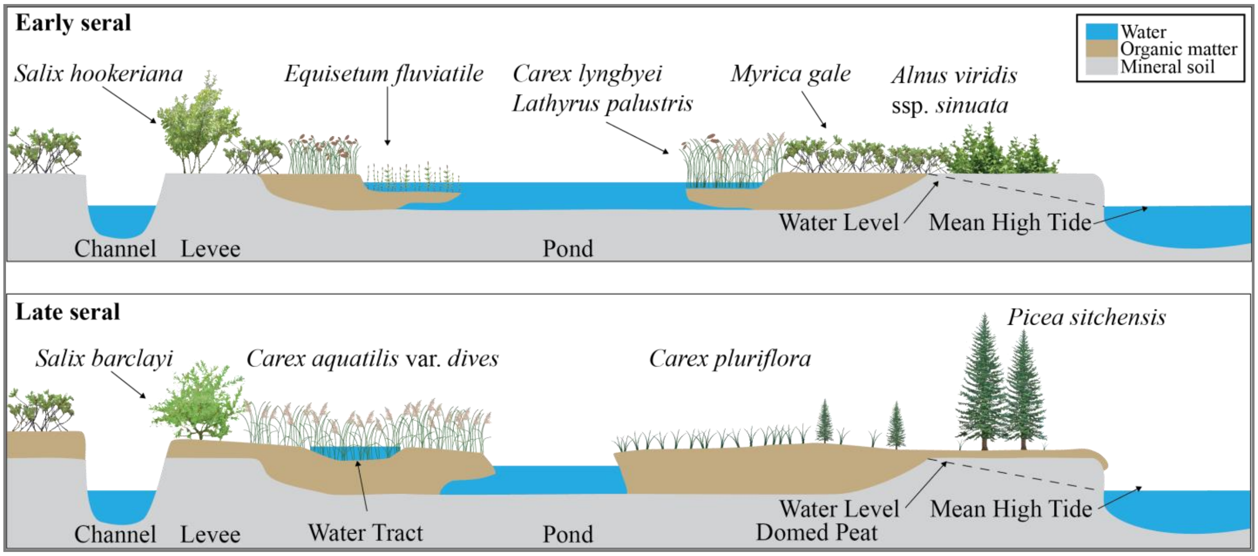

Figure 123. Schematic physiography and vegetation profile of a mature tidal marsh lifted above tidal zone influence depicting two stages of succession; early-seral at 28 years after uplift and late-seral at 200+ years after uplift (Boggs and Shephard 1999).

Vegetation

Young marshes lifted above the tidal zone support lush forb and grass meadows bordered by or mosaicked with shrubs. Associations in these herbaceous meadows include near monocultures of *Calamagrostis canadensis*, *Deschampsia beringensis* and *Festuca rubra*, to species-rich forb and grass associations including the grass *Leymus mollis* and the forbs *Castilleja miniata*, *Plantago macrocarpa*, *Achillea millefolium*, *Heracleum maximum*, *Angelica lucida*, *Lathyrus japonicus* and *Lupinus nootkatensis* (Streveler et al. 2003, Turner 2010). Shrub associations include *Alnus viridis* ssp. *sinuata*, *Myrica gale*, *Salix hookeriana* and *S. barclayi*.

Mature, uplifted tidal marshes that retain their pre-uplift pattern of levees, basins and channels may show a zonation of vegetation that is consistent with basin depth. Here vegetation transitions from shrub (*Alnus viridis* ssp. *sinuata/Equisetum arvense*) or forb (*Calamagrostis canadensis/Lupinus nootkatensis*) associations on levees to shrub/herbaceous (*Myrica gale/Carex lyngbyei/Equisetum pratense*) associations on shallow peat deposits bordering the levees, to sedge (*Carex lyngbyei/Lathyrus palustris/Sphagnum* and *Carex lyngbyei*) and emergent forb associations (*Equisetum fluviatile* and *Hippuris vulgaris*) on thicker peat to open water in the center of the basin. *Populus trichocarpa* and *Picea sitchensis* saplings are common on levees (Boggs and Shephard 1999).

Figure 124. Dusky Canada Geese (*Branta canadensis occidentalis)* on an uplifted tidal marsh pond of the Copper River Delta (photo by T. Bowman).

Succession

Studies describing succession have been conducted in Southcentral and Southeast Alaska (Shephard 1995, Boggs and Shephard 1999, Turner 2010). Succession is similar for both young and mature uplifted tidal marshes. Prior to uplift, tidal species dominance is typically *Carex lyngbyei* and other tidal associations. The loss of tidal water results in a massive shift in species dominance from salt-tolerant species to freshwater and upland herbaceous or shrub species. However, some tidal species that also flourish in freshwater such as *Carex lyngbyei* may persist for 200 or more years (Shephard 1995, Boggs and Shephard 1999, Turner 2010). On wet sites or ponds, *Sphagnum*, *Carex aquatilis* var. *dives* and *Myrica gale* invade and an organic matter horizon develops. On drier sites, such as levees and the inland portion of the uplifted surface, shrubs such as *Alnus viridis* ssp. *sinuata*, *Salix hookeriana* and *S. barclayi* dominate (Turner 2010, Shephard 1995). Over hundreds of years peatlands develop on wet sites or ponds whereas rainforests develop on mesic sites (Boggs and Shephard 1999).

Conservation Status

Rarity: Six areas of uplifted tidal marsh are identified along the coastline of Southeast Alaska. Despite their wide distribution, their small total area (less than 600 km^2) make this biophysical setting one of conservation concern.

Threats: Due to their landscape position, uplifted tidal marshes are susceptible to damage from development, earthquake-induced slides and tsunamis, and sea level rise. Because uplifted tidal marshes in Southeast Alaska provide flat land along an otherwise rocky coastline, towns and villages are located adjacent to, and sometimes on, these habitats (e.g. portions of Gustavus, Juneau and Dyea).

Trend: Short-term decline due to development and human activity is expected; long-term trend is more difficult to predict. The long-term loss of coastal habitat due to climate-induced sea level rise is difficult to predict as projections must account for local trends of tectonic uplift and subsidence, the potential for seismic repositioning of the shoreline and glacial rebound in relation to global sea level rise. The average global sea level rose about 18 cm over the 20th century, 10 times faster than the average rate of sea-level rise during the previous 3,000 years (Haufler et al. 2010). Since 1990, sea level has been rising 0.4 cm/year, twice as fast as the average over the 20th century and projections show the rate will continue to accelerate (Haufler et al. 2010, Garrett 2014). Sea level, however, has rarely been constant in southern Alaska and the Aleutian Islands. Some land is currently rising due to isostatic rebound and tectonic uplift, while other coastlines are falling due to tectonic down-warping. The occurrence of deep subduction zone earthquakes and their attendant disturbances are notoriously difficult to predict. For southern Alaska the reoccurrence time for these large-magnitude earthquakes is estimated to be on the order of 500 to 1,350 years (Plafker and Rubin 1978). Considering the relative recentness of the 1964 Good Friday Earthquake, impacts from this threat are only expected in the extreme long-term.

Species of Conservation Concern

The bird and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 61, Table 62). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 61. Bird species of conservation concern within the Pacific Uplifted Tidal Marsh Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Birds				
Aleutian Tern	*Sterna aleutica*	G4	S3B	Nests usually on sand spits, sandbar islands, sand dunes, and flat vegetated summits of more rugged islands; on low wet coastal marsh and tundra in some areas.
Beringian Marbled Godwit	*Limosa fedoa beringiae*	G5T2T3	S2B	The entire breeding population is thought to move to intertidal and estuarine habitats of the Alaska Peninsula after breeding.
Dusky Canada Goose	*Branta canadensis occidentalis*	G5T3	S3B	Breeding range restricted to the Cooper River Delta. Common on tidal marshes, uplifted tidal marshes and barrier islands.
Peale's Peregrine Falcon	*Falco peregrinus pealei*	G4T3	S2	Utilizes coastal beaches, tidal flats, islands, marshes, estuaries, and lagoons. Nests primarily on ledges of vertical rocky cliffs in the vicinity of seabird colonies.

Table 62. Plant species of conservation concern within the Pacific Uplifted Tidal Marsh Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Bolboschoenus maritimus	G5	S2?	Brackish to saline coastal shores and marshes.
Botrychium yaaxudakeit	G2	S2	In its coastal habitats this fern grows on beach sand deposits sparsely to densely vegetated by bryophytes and herbaceous plants.
Carex stipata	G5	S1	Seasonally saturated or inundated soils in wet meadows, marshes, edges of tidal marshes, swamps, alluvial bottomlands
Salix hookeriana	G5	S2S3	Coastal beaches and sand dunes, interdunal depressions, tide marshes, floodplains, ravines, wet sedge meadows, and lakeshores. Alaska to California.
Sidalcea hendersonii	G3	S1	Known from the Juneau area, where it occurs in upper tidal marshes and raised beach meadows.
Phyllospadix serrulatus	G4	S3	Known from widely scattered rocky tidal and subtidal sites along the coast.

Plant Associations of Conservation Concern

The plant associations listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 63).

Table 63. Plant associations of conservation concern within the Pacific Uplifted Tidal Marsh Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Shrub			
Myrica gale-Salix hookeriana	G3	S3	DeVelice et al. 1999
Myrica gale/Carex lyngbyei	G3	S3	DeVelice et al.1999, Boggs 2000
Salix barclayi/Equisetum variegatum	G3	S3	Boggs 2000
Salix hookeriana	G3	S3	Shephard 1995
Herbaceous			
Calamagrostis canadensis-Carex pluriflora	G3	S3	Turner 2010
Carex pluriflora-Carex lyngbyei	G3	S3	Hanson 1951
Castilleja miniata-Plantago macrocarpa-Achillea millefolium	G3	S3	Turner 2010
Fritillaria camschatcensis-Thalictrum sparsiflorum-Iris setosa	G3	S3	Turner 2010

Classification Concept Source

The classification concept for this biophysical setting is based on Crow (1968) and Batten and others (1978).

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Picea sitchensis/Calamagrostis nutkaensis Plant Association

Sitka Spruce/Pacific Reedgrass Plant Association

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Picea sitchensis/Calamagrostis nutkaensis* (Sitka spruce-Pacific reedgrass) Plant Association is characterized by open coastal forests, dominated by the coniferous tree *Picea sitchensis* in the overstory and the grass *Calamagrostis nutkaensis* in the understory (Figure 125). This association occurs as a narrow, discontinuous band along exposed portions of the Gulf of Alaska coastline that are subject to salt spray. This unique habitat occupies a small total area, yet supports several taxa of conservation concern. Impacts are generally low, but some villages, towns and cities occur adjacent to, and often within, this association.

Figure 125. *Picea sitchensis/Calamagrostis nutkaensis* Plant Association near Sitka, Alaska.

Distribution

The *Picea sitchensis/Calamagrostis nutkaensis* association forms a discontinuous fringe along the coastline of Southeast Alaska (DeMeo et al. 1992, Martin et al. 1995). It appears in limited areas on the outer shores of Glacier Bay National Park and Preserve (Boggs et al. 2008a), in a few rocky areas of the Copper River basin, likely occurs in Prince William Sound and is most common in Kenai Fjords National Park (Figure 126; Boggs et al. 2008b). The distribution of this plant association was developed from *Picea sitchensis* landcover classes of the Alaska Landcover Map (Boggs et al. 2015) occurring within 1,000 m of a rocky shoreline delineated by the National Oceanic and Atmospheric Association's ShoreZone project (NOAA 2015). Occurrence data is derived from herbarium records of *Calamagrostis nutkaensis* occurring in coastal, Sitka spruce forests (CPNWH 2016).

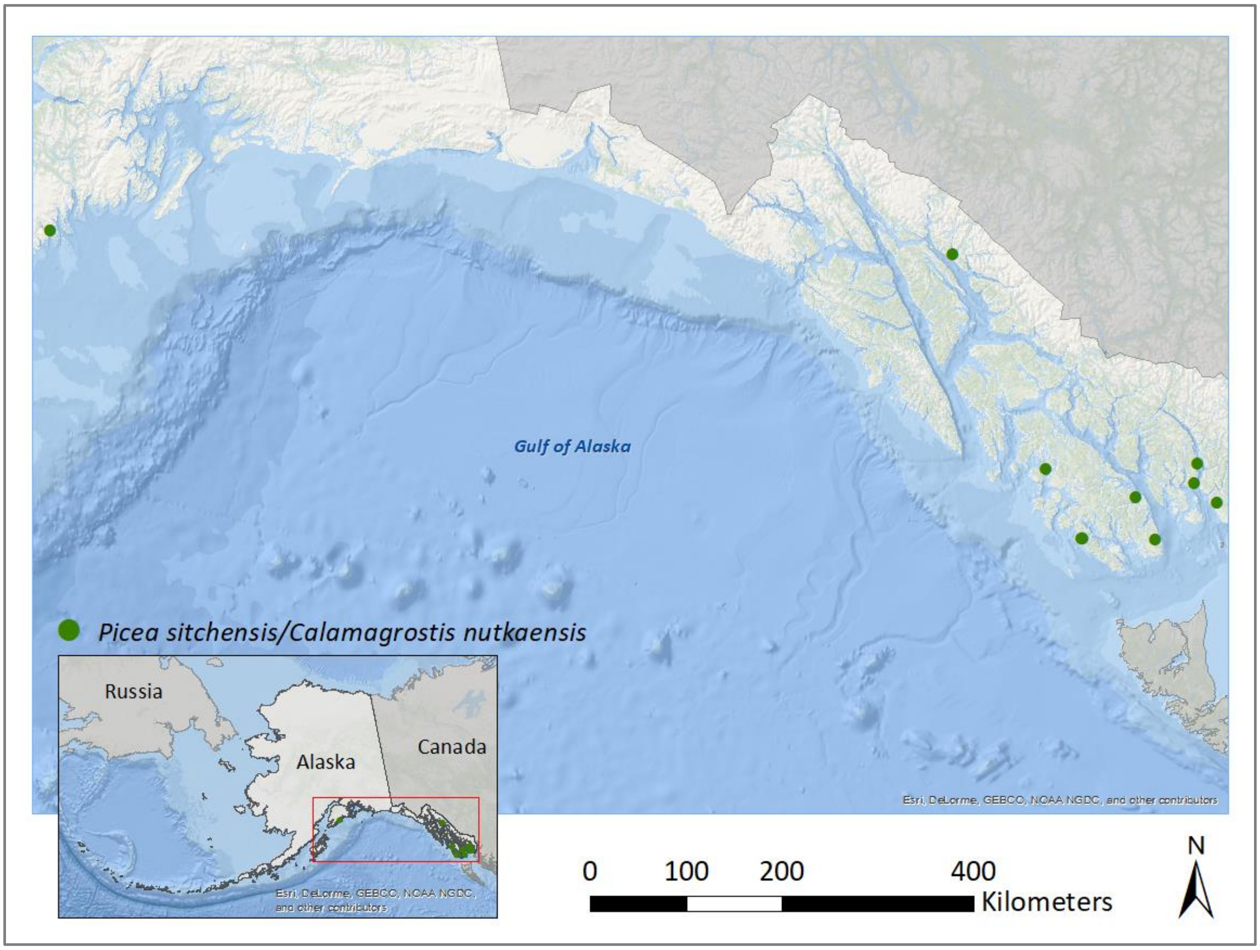

Figure 126. Distribution of the *Picea sitchensis/Calamagrostis nutkaensis* Plant Association in southern Alaska. Note that point occurrences in this map are buffered for greater visibility.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). The mean annual precipitation in coastal rainforests ranges from 135 to 390 cm, with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures range from -3 to 3 °C. Consequently, this forest association has developed under relatively short, cool and extremely wet growing seasons. Rainfall and temperature show highly variable patterns dependent upon proximity to mainland ice fields, the Pacific Ocean, topography and regional weather patterns.

Environmental Characteristics

This association is a beach fringe habitat most common on exposed, rocky headlands, uplifted beach ridges, and rocky platforms that are subject to salt spray (DeMeo et al. 1992, Martin et al. 1995). It sometimes occurs on floodplains and alluvial fans adjacent to saltwater. Soils are well drained but often skeletal (DeMeo et al. 1992, Martin et al. 1995). Rock outcrops are common. Soils are typically derived from the local bedrock, but may develop from beach gravels imported from remote parent materials.

Vegetation and Succession

This forested association is dominated by the coniferous tree, *Picea sitchensis* and by the salt-tolerant grass *Calamagrostis nutkaensis* the understory (DeMeo et al. 1992, Martin et al. 1995). Stands are open with an average canopy cover of 44% and an average tree height of 39 m. The most common herbaceous species found in this association are *Maianthemum dilatatum* (24%) and *Calamagrostis nutkaensis* (10%; DeMeo et al. 1992). Total shrub cover is about 1% and may include *Gaultheria shallon, Menziesia ferruginea* or *Vaccinium* species such as *V. alaskaense, V. ovalifolium,* or *V. parvifolium*. Both *Tsuga heterophylla* (western hemlock) and *Picea sitchensis* seedling and saplings occur in the understory.

Moving inland from the shore, *Picea sitchensis* and *Calamagrostis nutkaensis* cover decrease and *Tsuga heterophylla* and *Vaccinium* spp. increase, a transition that presumably relates to decreased disturbance and exposure to salt spray. The dominance of grass in the understory and a greatly reduced shrub cover differentiate this association from all other spruce-dominated associations in the region.

Small-scale windthrow is common, usually to within 30 m of the beach. Although succession studies have not been explicitly conducted within this type, the broad trends of forest gap succession likely apply.

Conservation Status

Rarity: Although this plant association is widely distributed along the coastline of Southeast Alaska, its potential range is small (324 km^2) and only 10 occurrences have been identified.

Threats: The mature *Picea sitchensis* present at these sites, and their accessibility, makes them susceptible to timber harvest. Spruce bark beetle *(Dendroctonus rufipennis)* infestation is an additional threat.

Trend: The extent and condition of this association is not expected to change in the short- or long-term.

Species of Conservation Concern

The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this plant association (Table 64, Table 65). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 64. Mammal and bird species of conservation concern within the *Picea sitchensis/Calamagrostis nutkaensis* Plant Association.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Birds				
Queen Charlotte Goshawk	*Accipiter gentilis laingi*	G5T2	S2	Nest in either Sitka spruce or western hemlock. Typically hunt in continuous forests.
Marbled Murrelet	*Brachyramphus marmoratus*	G3G4	S2S3	Nest in old-growth hemlock and Sitka spruce on moss-covered trunks, or on ground near sea-facing talus slopes or cliffs.
Mammals				

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Alexander Archipelago wolf	*Canis lupus ligoni*	G4T2T3	S3	Primarily found in rugged coastal spruce-hemlock forests supporting prey such as deer, small mammals, and spawning salmon.
California myotis	*Myotis californicus*	G3G4	S2	In SE Alaska, occur primarily in closed forests with snags and fallen logs.
Keen's myotis	*Myotis keenii*	G2G3	S1S2	In SE Alaska, occur primarily in coniferous forests with females preferring old-growth forests and cedar trees in riparian areas for day roosts.
Prince of Wales flying squirrel	*Glaucomys sabrinus griseifrons*	G5T2?	S2	Old growth western hemlock-Sitka spruce forests, and peatland scrub-mixed-conifer forests. Dens in tree cavities and woodpecker holes
Admiralty Island ermine	*Mustela erminea salva*	G5T3T4	S2S3	Occurs in forests, shrublands and alpine. May favor forest-wetland ecotones.
Prince Of Wales Island ermine	*Mustela erminea celenda*	G5T3	S3	See Admiralty Island Ermine description.
Baranof Island ermine	*Mustela erminea initis*	G5T3T4	S3	See Admiralty Island Ermine description.
Suemez Island ermine	*Mustela erminea seclusa*	G5T2T3	S3	See Admiralty Island Ermine description.
Kupreanof red squirrel	*Tamiasciurus hudsonicus picatus*	G5T3?	S3	Variety of coniferous and mixed habitats. Nests in holes in tree trunks or in a mass of twigs, leaves, mosses, and lichens in densest foliage of a tree.
Warren Island dusky shrew	*Sorex monticolus malitiosus*	G5T3	S3	Occurs in meadows, peatlands, coniferous forest, and alpine. Rarely found more than a few meters from water in summer. Requires moist soil and dense understory.

Table 65. Plant species of conservation concern within the *Picea sitchensis/Calamagrostis nutkaensis* Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Ligusticum calderi	G3G4	S2	Known principally from the Queen Charlotte Islands and northern Vancouver Island in British Columbia. In Alaska occurs on moist, rocky, limestone at high elevations on Kodiak Island, Dall Island and southern Prince of Wales Island.
Ranunculus orthorhyncus	G5T5	S2S3	Wetland plant found uncommonly in variable habitat of southern Alaska. Prefers moist meadows, streambanks and shores, including sea beaches and upper tidal marshes (Pojar and MacKinnon 1994).

Classification Concept Source

The classification concept for this plant association is based on DeMeo and others (1992) as well as Martin and others (1995).

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Picea sitchensis Floodplain Old-growth Forest Biophysical Setting

Sitka Spruce Floodplain Old-Growth Forest Biophysical Setting

Pacific Alaska

Conservation Status Rank: S3 (vulnerable)

Introduction

Old-growth *Picea sitchensis* (Sitka spruce) forests on flood and outwash plains are characterized by a closed, multilayered canopy of mature *Picea sitchensis,* an abundance of snags and downed wood, and a diverse shrub and forb layer (Figure 127; DeVelice et al. 1999, Old-Growth Definition Task Group 1991). The floodplains of Southeast Alaska may contain the highest densities of the largest old-growth *Picea sitchensis* trees in North America. As important winter refuge for birds and mammals, and the terrestrial backdrop to unequaled anadromous fish habitat (Samson et al. 1989, Dellasala et al. 1994 and 1996), these forests are recognized as reservoirs of biodiversity (Franklin 1989), with relatively high levels of endemism and species richness.

Figure 127. Old-growth *Picea sitchensis* floodplain forests along the Stikine River, Alaska.

Distribution

Picea sitchensis occurs in varied forest types ranging from northern California through Southeast and Southcentral Alaska to Kodiak Island. In Washington and Oregon, *Picea sitchensis* occurs within the coastal fog drip zone at elevations below 150 m, a distribution that is often restricted to a few-kilometer wide strip along the coast (**Error! Reference source not found.**; Franklin and Dyrness 1973, Hemstrom nd Logan 1986). In Alaska, the *Picea sitchensis* zone is wider, extends to higher elevations (up to 700 m), and includes well-drained alluvial fans, floodplains, outwash plains, coastal beach fringes and steep erosional slopes. *Picea sitchensis* achieves dominance in climax old-growth stands on only a small portion of the landscape (Martin 1989). Albert and Schoen (2006) estimate that there are 2,350 km² of productive old-growth on valley floors in the Alexander Archipelago, much of which may include *Picea sitchensis* forest on floodplains. The *Picea sitchensis* floodplain old-growth forest distribution map was developed from the intersection of *Picea sitchensis*-dominated landcover classes of the Alaska Landcover Map (Boggs et al. 2015) with riverine systems delineated by the National Wetland Inventory (USFWS 2015).

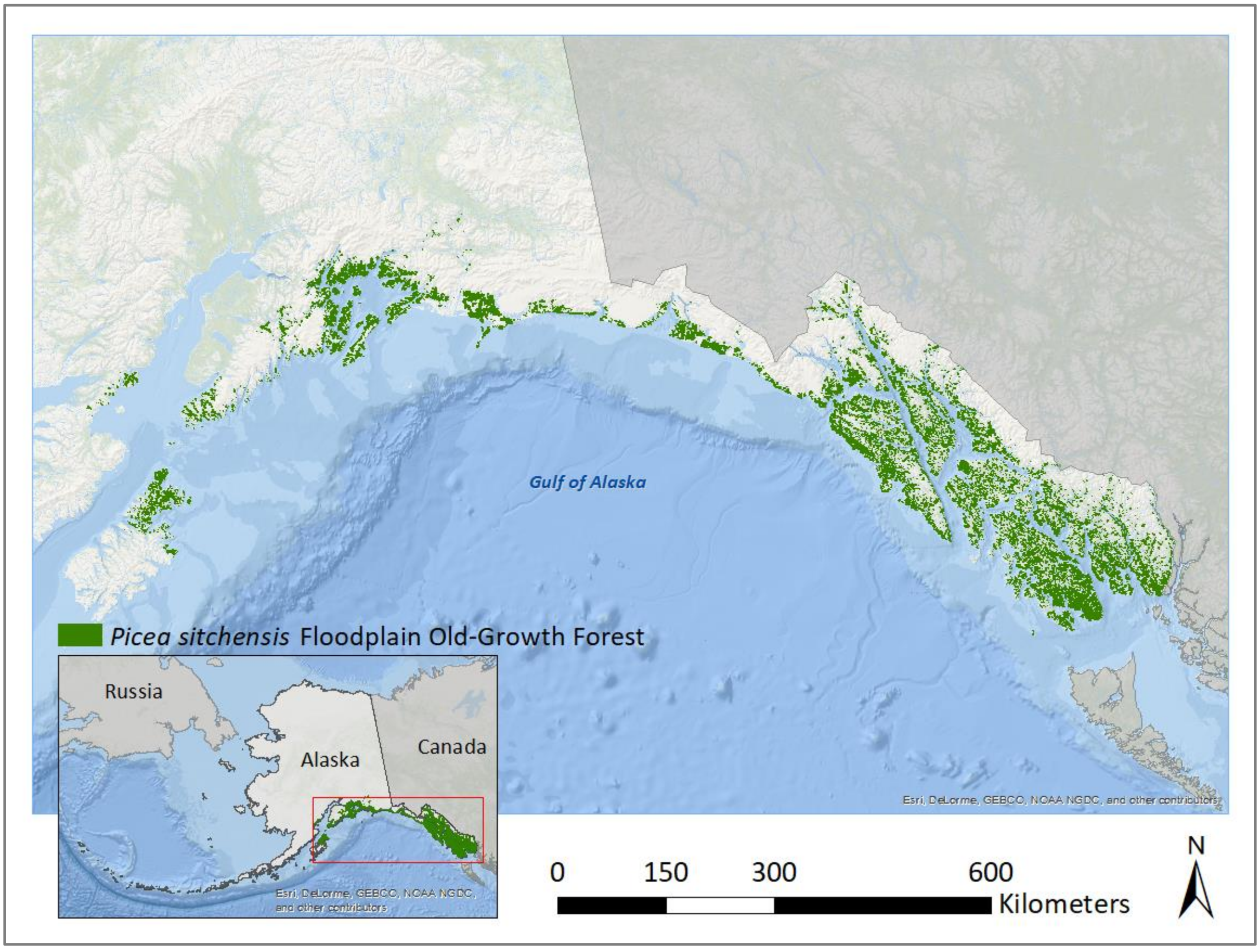

Figure 128. Distribution of the Picea sitchensis Floodplain Old-growth Forest Biophysical Setting in Southern Alaska. Note that the areas of occupancy shown in this map are buffered for greater visibility.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). Mean annual total precipitation in the coastal rainforest ranges from 135 to 390 cm, with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C. Consequently, these forests have developed under relatively short, cool and extremely wet growing seasons. Rainfall and temperature show highly variable patterns dependent upon proximity to mainland ice-fields, the Pacific Ocean, topography and regional weather patterns.

Environmental Characteristics

Old-growth *Picea sitchensis* forests form on both outwash plains and floodplains. Outwash plains are formed by glacial streams that deposit sediment across wide areas. Two primary factors create and sustain outwash plains: (1) rapid and drastic changes in water discharge rates from glaciers during the summer and (2) a large sediment supply in the river. In contrast, floodplains are mostly nonglacial and consist of meandering or straight streams, abandoned channels and alluvial terraces. Mainland river systems of Southeast Alaska are typically fed by large glaciers of the Coastal Range. Due to their smaller watersheds, streams within the Alexander Archipelago are generally very short (less than 25 km) and most originate from high rainfall rather than glaciers.

The formation of new land and the initiation of primary successional processes in floodplain ecosystems is well documented (Leopold et al. 1964). Along a meandering river, alluvium typically is deposited on the inner, point bank the river channel. The opposing bank is cut, providing sediment for downstream deposition and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain. Vegetation growing on new deposits near the river may be contrasted with that on older deposits inland to recognize and measure successional processes. Alluvium also is deposited on the soil surface during flooding, further raising the soil surface height.

Soils are mostly comprised of well-drained alluvial sand and gravel deposited during flooding events. Due to frequent alluvial disturbance, soils in the active floodplain show little development and are often classified as inceptisols or entisols (Martin et al. 1995); older sites elevated above the active floodplain may support spodisols.

Water availability plays a major role in plant community structure and composition on floodplain terraces. Water is input from overbank flow (flooding), groundwater and precipitation, with terraces becoming progressively drier with increasing vertical and horizontal distance from the active channels. Within the stands, soil and air moisture are high, and as a result, fires are rare. When they do occur, fires burn out in the humid understory and rarely reach the spruce canopy.

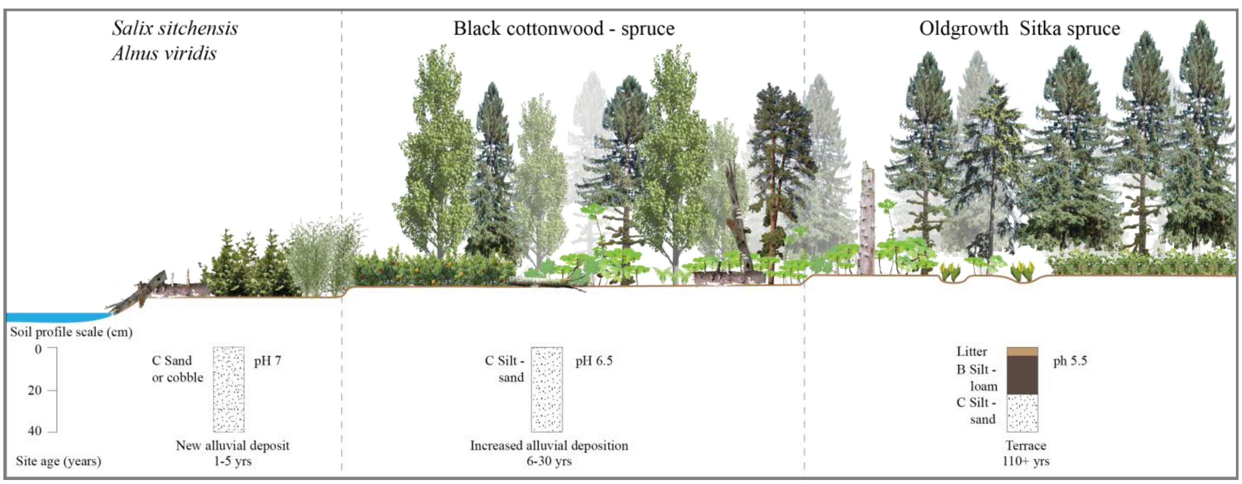

Figure 129. Schematic physiography and vegetation profile of a *Picea sitchensis* Floodplain Old-growth Forest Biophysical Setting.

Vegetation

Old-growth floodplain forests in Southeast Alaska are dominated by *Picea sitchensis* in the overstory, with *Tsuga heterophylla* (western hemlock) sub- to codominant, usually providing less than 25% cover (Figure 129 and Figure 130). When codominant, *Tsuga heterophylla* occupies a stratum beneath the spruce (Martin 1989, Viereck et al. 1992). *Alnus rubra* (red alder) and *Populus trichocarpa* (black cottonwood) are occasional components of the overstory. Understory composition is directed by disturbance regimes and moisture conditions (Martin 1989). An abundance of *Alnus* shrubs and predominance of undeveloped soils are indicative of younger sites or sites with recent sediment deposition from flooding. Where lower flood volumes allow limited soil development, shrubs such as *Vaccinium* species and *Oplopanax horridus* provide high cover. Herbaceous species include *Calamagrostis nutkaensis, Tiarella trifoliata, Rubus pedatus, Streptopus* species and the ferns *Athyrium filix-femina, Dryopteris dilitata* and *Gymnocarpium dryopteris*. Bryophytes are usually abundant on the forest floor and within the canopies. The wetland indicator, *Lysichiton americanum* is often present in poorly-drained and seasonally-wet soils. The shrub layer may be sparse or absent and the herb layer dominated by *Calamagrostis nutkaensis* in floodplains and deltas subject to salt spray, high winds and storms.

Figure 130. Old-growth *Picea sitchensis* floodplain forests along the Stikine River, Alaska.

Succession and Disturbance

On both outwash plains and floodplains, new alluvial bars or abandoned stream channels are colonized by tree, shrub and herbaceous species, including *Populus trichocarpa, Picea sitchensis, Alnus* and *Salix* species. The next seral stage includes *Populus trichocarpa* and/or *Picea sitchensis* forests with an *Alnus* or bryophyte understory. The tall shrub component of the early-seral stages diminishes rapidly, likely due to decreased light from the dense tree overstory. *Populus trichocarpa* does not regenerate and, consequently, dies out within 150 years; *Picea sitchensis* exhibits abundant regeneration and dominates the sites with a multilayered old-growth tree canopy. *Tsuga heterophylla* ultimately invades the sites, typically becoming codominant with *Picea sitchensis*.

Wind is an important factor causing change in the vegetation on floodplains. While individual treefall due to high wind speed is common throughout the forest, stand-level disturbances are less common (Martin

1989) and are usually associated with more powerful fall and winter storms (Ott 1995, Nowacki and Kramer 1998, Kramer et al. 2001). High rainfall and shallow root systems contribute to the susceptibility of *Picea sitchensis* and *Tsuga heterophylla* to windfall. Treefall results in canopy gaps and alteration of the microclimate for the understory plants below. Although seedlings of both spruce and hemlock are common, conditions generally favor spruce regeneration. Most regeneration of spruce and hemlock occurs on logs (Schrader 1998), which are nutrient-rich and protected habitats where seedlings are less susceptible to floods and competition from forest floor mosses (Harmon 1986, Harmon and Franklin 1989).

Large spruce trees often develop heart-rot (*Neolentinus kauffmanii*), causing trunks to break (Boughton et al. 1992). As compared with other old-growth conifer forests, old-growth *Picea sitchensis* forests have more large downed logs and fewer standing dead trees (snags). Through their capacity to sequester and store carbon, these forests have significant impacts on regional and global climate (Waring and Franklin 1979, Alaback 1991).

Conservation Status

Rarity: In coastal Southeast Alaska, old-growth forests growing on well-drained alluvial and riparian soils are relatively rare (potential range estimated at 208 km^2), and it is highly probable that the largest big tree stands of this forest types have already been eliminated from the region (Albert and Schoen 2006).

Threats: Old-growth *Picea sitchensis* forests on floodplains are susceptible to damage from timber harvest and spruce bark beetle (*Dendroctonus rufipennis*) infestation.

Trend: Past logging practices, including the broad-scale clearing of riparian forests, occurs disproportionately in low elevation old-growth *Picea sitchensis* forests on floodplains and alluvial fans. It has been estimated that the percentage of big-tree old-growth forest logged in Southeast Alaska is between 28-50% (Albert and Schoen 2006). Short- and long-term declines are expected where logging continues to target old-growth systems.

Species of Conservation Concern

These forests are recognized as reservoirs of biodiversity (Franklin 1989), with relatively high levels of endemism and species richness. Timber harvest in old-growth forests has a negative impact on several species, including the Alexander Archipelago wolf (*Canis lupus lingoni*), brown bear (*Ursus arctos*; Suring et al. 1993), marten (*Martes americana*), northern flying squirrel (*Glaucomys sabrinus*), Marbled Murrelet (*Brachyramphus marmoratus*; Piatt et al. 2007), Northern Goshawk (*Accipiter gentilis laingi*) and some neotropical and resident birds (Dellasala et al. 1996).

The mammal, bird, and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 66, Table 67). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 66. Mammals, birds, and amphibian species of conservation concern within the *Picea sitchensis* Floodplain Old-growth Forest Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Mammals				
Alexander Archipelago wolf	*Canis lupus ligoni*	G4T2T3	S3	Primarily found in rugged coastal spruce-hemlock forests supporting prey such as deer, small mammals, and spawning salmon.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Keen's myotis	*Myotis keenii*	G2G3	S1S2	In SE Alaska, occur primarily in coniferous forests with females preferring old-growth forests and cedar trees in riparian areas for day roosts.
Prince of Wales river otter	*Lontra canadensis mira*	G5T3T4	S3	In SE Alaska, occur primarily in uneven aged old-growth dominated by hemlock/spruce and hemlock.
Prince of Wales flying squirrel	*Glaucomys sabrinus griseifrons*	G5T2?	S2	Old growth western hemlock-Sitka spruce forests, and peatland scrub-mixed-conifer forests. Dens in tree cavities and woodpecker holes.
Birds				
Marbled Murrelet	*Brachyramphus marmoratus*	G3G4	S2S3	Nest in old-growth hemlock and Sitka spruce on moss-covered branches or on ground near sea-facing talus slopes or cliffs.
Northern Saw-whet Owl	*Aegolius acadicus*	G5	S3	Nest in old woodpecker cavities or tree holes of dense coniferous or mixed forests in Southeast Alaska.
Queen Charlotte Goshawk	*Accipiter gentilis laingi*	G5T2	S2	Nest in either Sitka spruce or western hemlock. Typically hunt in continuous forests.
Amphibians				
Western Toad	*Anaxyrus boreas*	G4	S3S4	Found in rainforest and riverine habitats in southeast Alaska.

Table 67. Plant species of conservation concern within the *Picea sitchensis* Floodplain Old-growth Forest Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Melica subulata	G5	S2S3	Behind beach under *Picea sitchensis.*
Polystichum setigerum	G3	S3	Endemic to coastal northwest British Columbia and southeastern Alaska. Disjunct populations occur on Attu Island at the western tip of the Aleutian Archipelago. It grows on forest floors in lowland coastal forests, forest edges, and along run-off channels at elevations ranging from sea level to 250 meters.
Tiarella trifoliata var. *laciniata*	G5T5?	S3	Moist woods in the islands of southern Alaska.
Lobaria amplissima	GNR	S1S3	This foliose lichen is found on the trunks and branches of old-growth Sitka spruce and western hemlock.

Classification Concept Source

The classification concept for this biophysical setting is based on Martin (1989) and Albert and Schoen (2006).

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Picea sitchensis/Oplopanax horridus/Circaea alpina Plant Association

Sitka Spruce/Devil's Club/Enchanter's Nightshade Plant Association

Pacific Alaska

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Picea sitchensis/Oplopanax horridus/Circaea alpina* (Sitka spruce/devil's club/enchanter's nightshade) Plant Association is a forested type codominated by *Picea sitchensis* and *Tsuga heterophylla* (western hemlock) in the overstory and *Oplopanax horridus* and *Circaea alpina* in the understory, occurring on loess-covered hills. This association has been described from hillslopes adjacent to the Stikine River Delta in Southeast Alaska (Figure 131) and has been identified as one of conservation concern by the Tongass National Forest (Pawuk and Kissenger 1989). Despite its apparently restricted occurrence, impacts are thought to be low.

Figure 131. Typical setting of the *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association at the mouth of the Stikine River, Alaska (photo by Wayne Nicolson).

Distribution

This association is known only from hillslopes adjacent to the Stikine River Delta, however it is suspected to occur on other loess-covered hills adjacent to river valleys in Southeast Alaska (Figure 132). The *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association distribution was developed from Sitka spruce-dominated landcover classes of the Vegetation Map of Southern Alaska and the Aleutian Islands (Boggs et al. 2016b). Occurrence records are derived from herbarium records of *Circaea alpina* explicitly collected from *Picea sitchensis* forests (CPNWH 2016)

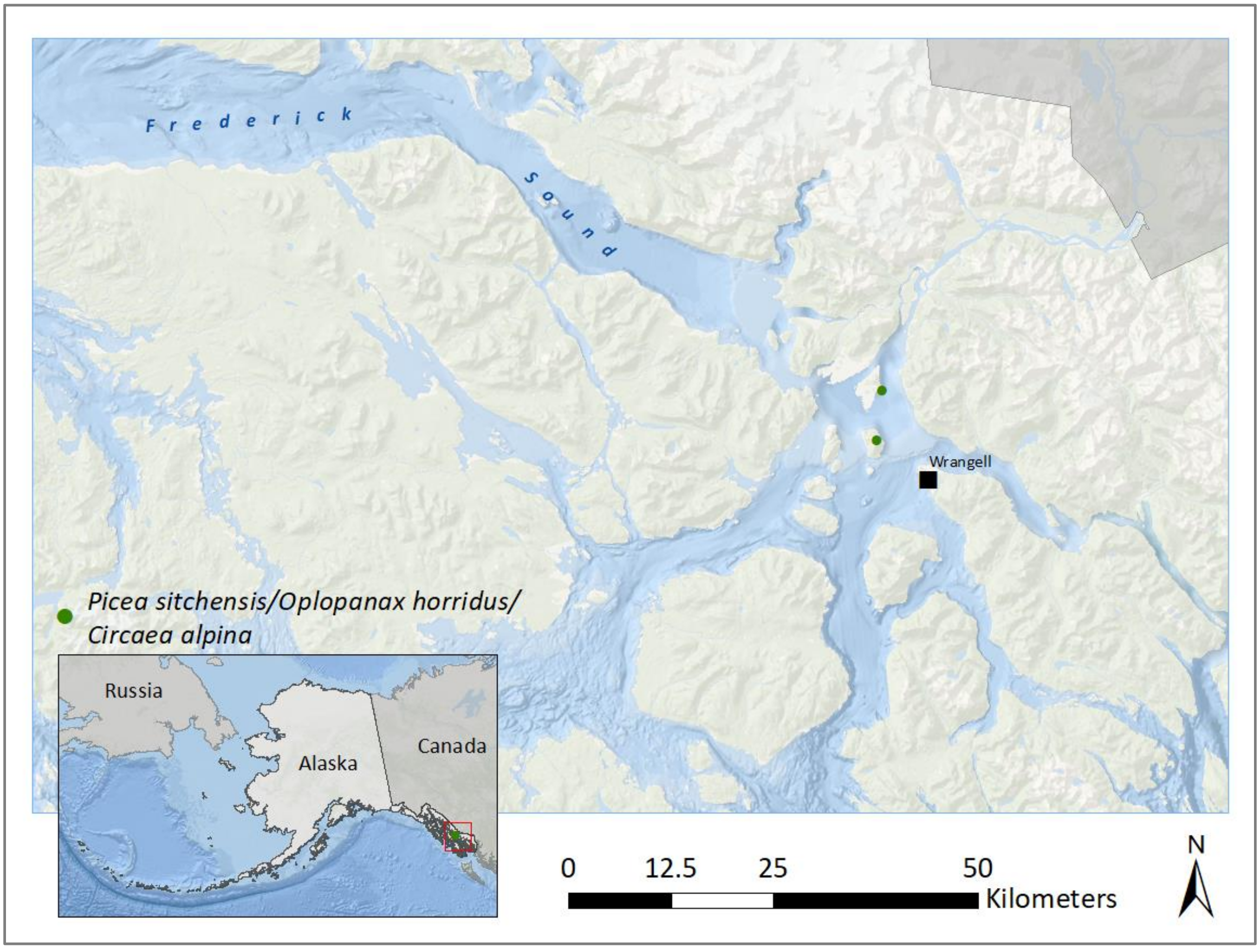

Figure 132. Distribution of the *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association. Note that point occurrences in this map are buffered for greater visibility.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). Mean annual total precipitation in the coastal rainforest ranges from 135 to 390 cm, with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C. Consequently, these forests have developed under relatively short, cool and extremely wet growing seasons. Rainfall and temperature show highly variable patterns dependent upon proximity to mainland ice-fields, the Pacific Ocean, topography and regional weather patterns.

Environmental Characteristics

The *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association occurs on loess-covered hills adjacent to river valleys. Windblown silt is deposited on these sites throughout the year, with most deposition likely occurring during the winter. Site elevations are less than 152 meters. Soils are classified as typic lityic cryumbrepts. While soil development is minimal, layers are deep. Soils are well to moderately well drained, and have a thin organic duff layer. Likely due to the input of loess, surface layers have a pH of 5.5.

Vegetation and Succession

The trees *Picea sitchensis* and *Tsuga heterophylla* codominate this type. Overstory height averages 47 meters; *Picea sitchensis* and *Tsuga heterophylla* provide approximately 60% coverage with *Picea sitchensis* more common. Understory tree coverage is 10% with *Tsuga heterophylla* more common. Shrub cover averages 60% and is dominated by *Oplopanax horridus*; *Rubus spectabilis* sometimes codominates, and *Menziesia ferruginea, Sambucus racemosa* and *Vaccinium* species occur as scattered plants. The forb layer averages 25% cover. *Circaea alpina* is well represented and occupies both low and raised microsites; *Streptopus amplexifolius, Streptopus lanceolatus* var. *roseus* and *Tiarella trifoliata* are also common. Fern cover averages 60% and includes *Athyrium filix-femina*, *Dryopteris austriaca* var. *spinulosa*, *Gymnocarpium dryopteris, Polypodium glycyrrhiza* and *Thelypteris phegopteris*. Graminoids are typically absent (Pawuk and Kissinger 1989). Exposure of mineral subsurface layers favors the establishment of shrubs such as *Alnus* species, *Rubus spectabilis* and *Oplopanax horridus*. Young second growth stands consist primarily of *Picea sitchensis* with some *Tsuga heterophylla*.

Conservation Status

Rarity: This plant association has only been sampled on hillslopes adjacent to the Stikine River Delta; it likely occurs in other glacial river corridors that experience high winds and extensive aeolian deposition.

Threats: Timber harvest and spruce bark beetle (*Dendroctonus rufipennis*) infestations of *Picea sitchensis* could threaten this association.

Trend: Extent and condition of this association are not expected to change in the short- or long-term.

Species of Conservation Concern

Only one bird, one plant, and no mammal or amphibian species of conservation concern are known or suspected to occur in the *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association (Table 68, Table 69). Additional study is required to evaluate whether this plant association supports species of conservation concern. Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 68. Bird species of conservation concern within the *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Black-backed Woodpecker	*Picoides arcticus*	G5	S3	Found in coniferous forests of southcentral Alaska, these woodpeckers prefer standing dead trees near bogs or from forest fires.

Table 69. Plant species of conservation concern within the *Picea sitchensis/Oplopanax horridus/Circaea alpina* Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Tiarella trifoliata var. *laciniata*	G5T5?	S3	Moist woods in the islands of southern Alaska.

Classification Concept Source

This association was first defined and ranked by the USDA Tongass National Forest (Pawuk and Kissinger 1989).

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Pinus contorta var. *latifolia/Cladina* species Plant Association

Lodgepole Pine/Reindeer Lichen Plant Association

Pacific Alaska

Conservation Status Rank: S2 (imperiled)

Introduction

The *Pinus contorta* var. *latifolia/Cladina* species (lodgepole pine/reindeer lichen) Plant Association occurs on mountain sideslopes and knolls underlain by shallow bedrock. One occurrence has been documented from Klondike Gold Rush National Historical Park but is likely to occur elsewhere in Southeast Alaska (Figure 133; Flagstad and Boucher 2014). This association is considered rare in Southeast Alaska and in neighboring regions of British Columbia, where it is found only on the driest bedrock outcrops with thin soils (Banner et al. 1993, Flagstad and Boucher 2014).

Figure 133. The *Pinus contorta* var. *latifolia/Cladina* species Plant Association in Klondike Gold Rush National Historical Park, Alaska (photo by L. Flagstad).

Distribution

This association has been sampled in Klondike Gold Rush National Historical Park and in British Columbia (Figure 134; Banner et al. 1993, Flagstad and Boucher 2014). The *Pinus contorta var. latifolia/Cladina* species Plant Association distribution map was developed from the Lodgepole Pine Open Forest landcover class mapped by Flagstad and Boucher (2014).

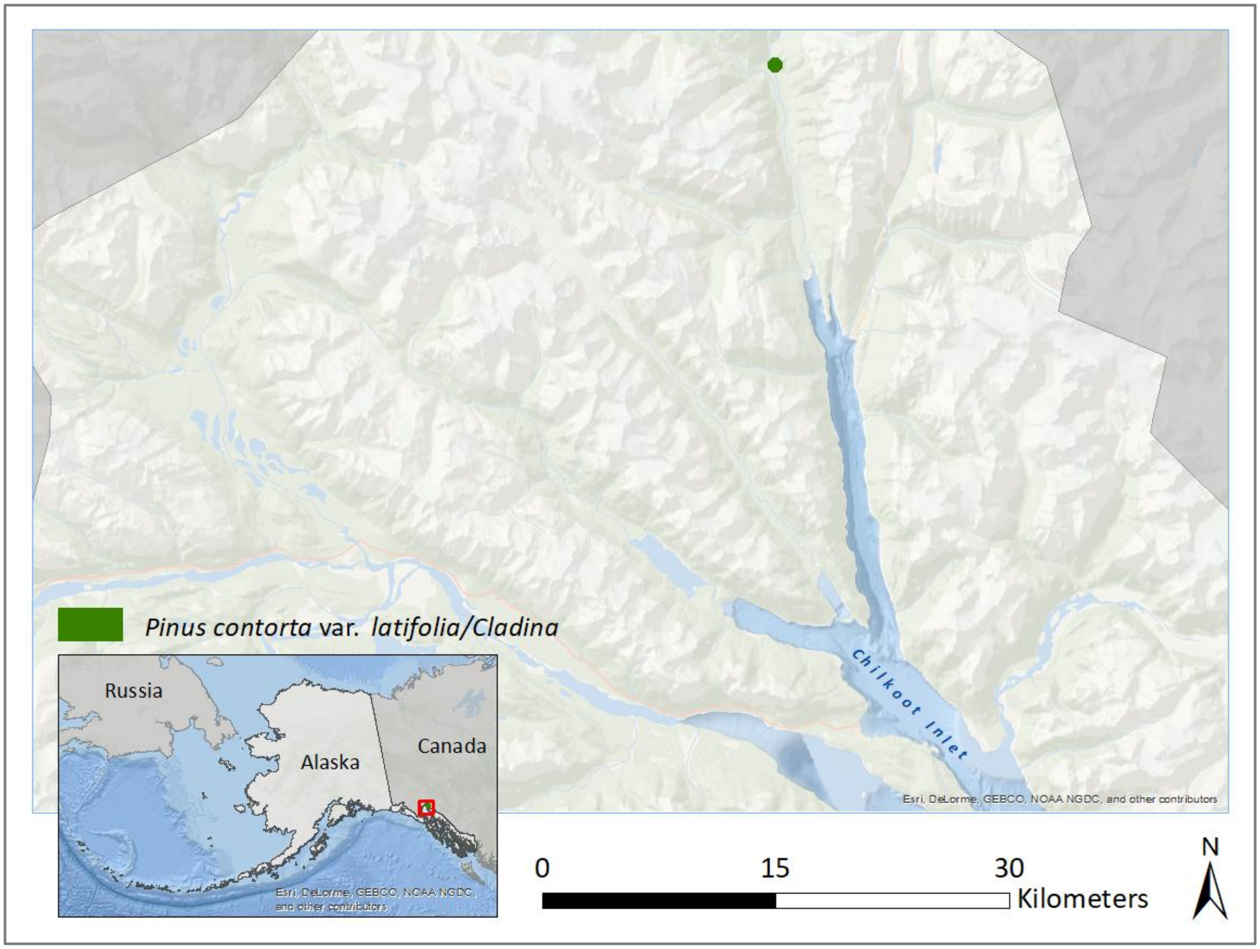

Figure 134. Distribution of the *Pinus contorta* var. *latifolia/Cladina* species Plant Association. Note that the area of occupancy in this map is buffered for greater visibility.

Climate

The Klondike region is characterized by a mix of continental and maritime climates that interface from sea level to the high alpine (Nowacki et al. 2000). Similar to much of southeast Alaska, wetness and disturbance are major climatic drivers for the development and maintenance the local ecosystems. However, Klondike's relative remoteness from the open ocean lessens storm effects and its proximity to the continental interior increases inputs of cold and dry air (Davey et al. 2007, Nowacki et al. 2001). As a result, the Klondike region experiences less precipitation and greater fluctuation in annual temperatures relative to much of southeast Alaska. At Chilkoot Pass, mean monthly wind speeds reach 23.5 m/s, while temperatures dip to -27.9°C and snow reaches depths of over 4 m (for the highly discontinuous period of measurement from 2010 to 2013; RAWS 2014). Average annual precipitation (including water equivalent of snow) is 59.0 cm with 74.9 cm as snowfall. Mean monthly precipitation for September (wettest month) is 101.7 cm received entirely as rain. The mean monthly precipitation for November (driest month) is 15.3 cm, with 14.4 cm received as snow (for the periods of record from 2004 to 2014 [precipitation] and from 2009 to 2014 [snow]; SNOTEL 2014).

Environmental Characteristics

This association occurs on dry mountain sideslopes and knolls underlain by shallow bedrock. The elevation of the single site sampled in Klondike Gold Rush National Historical Park is 167 m. In British Columbia this association is found only on the driest bedrock outcrops with thin soils (Banner et al. 1993).

Vegetation and Succession

The *Pinus contorta* var. *latifolia/Cladina* species plant association is an upland, mid-elevation, open forest type where *Pinus contorta* var. *latifolia* (12 m tall) is the dominant tree species and *Tsuga heterophylla* (1.2 m) and *Picea sitchensis* (0.9 m) saplings are present at low cover (Figure 133) (Flagstad and Boucher 2014). Lichens blanket the forest floor, primarily *Cladina rangiferina*, *Cladina mitis*, and *Cladonia uncialis*. Shrubs and herbaceous plant species are not well represented. This association represents a late-seral type with no significant disturbance.

Conservation Status

Rarity: *Pinus contorta* var. *latifolia* is considered rare in Southeast Alaska and in neighboring regions of British Columbia (Viereck and Little 2007, Banner et al. 1993). A single occurrence of the species in association with a *Cladina*-dominated understory has been documented for Alaska (Flagstad and Boucher 2014).

Threats: The one occurrence in Alaska is located adjacent to a National Park Service work camp and is thus threatened by foot traffic and potentially invasive weeds. More broadly, this association may be susceptible to timber harvest, but is likely protected by its remote, mountainous locations.

Trend: Disturbance of these thin soils could result in erosion and thus short- and long-term declines in extent.

Species of Conservation Concern

No animal or plant species of conservation concern are known or suspected to occur within this plant association. Additional study is required to evaluate whether this association supports species of conservation concern.

Classification Concept Source

This association was first described by Banner et al. (1993) and subsequently by Flagstad and Boucher (2014).

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Pohlia wahlenbergii–Philonotis fontana Seep Plant Association

Wahlenberg's Pohlia Moss-Philonotis Moss Seep Plant Association

Pacific Alaska

Conservation Status Rank: S3S4 (vulnerable to apparently secure)

Introduction

The *Pohlia wahlenbergii–Philonotis fontana* (Wahlenberg's pohlia moss-philonotis moss) Seep Plant Association is dominated by the two nominal mosses and occurs as small patches downgradient from seeps and springs (Figure 135). While this association has only been formally described from the western Alaska Peninsula, its dominant species, are known to be associated with calcareous seeps across western North America (Vitt et al. 1988). Impacts are presumed to be low.

Figure 135. *Pohlia wahlenbergii–Philonotis fontana* Seep Plant Association near the Aniakchak Volcano, Alaska.

Distribution

This association occurs as small patches along the Alaska Peninsula (Boucher et al. 2012, Bosworth 1987). While less than 20 occurrences are known from Aniakchak National Monument and Preserve, both moss species occur throughout the state. It is thought that this association has been undersurveyed and is likely to be more widely distributed along the Aleutian Islands and greater Southern Alaska. Due to a paucity of collection locations and related geospatial data, the distribution of this plant association has not been mapped.

Climate

Southeast Alaska has a cool, wet maritime climate (Gallant et al. 1995, Nowacki et al. 2001). Mean annual total precipitation in the coastal rainforest ranges from 135 to 390 cm, with 80 to 600 cm falling as snow. Average summer temperatures range from 7 to 18 °C; average winter temperatures are between -3 and 3°C. Rainfall and temperature show highly variable patterns dependent upon proximity to mainland ice-fields, the Pacific Ocean, topography and regional weather patterns.

Environmental Characteristics

This association occurs as a small patch type on alpine benches and valleys associated with seeps and springs. Surface water pH is 7.5.

Vegetation

This wet bryophyte association is dominated by the mosses *Pohlia wahlenbergii* and *Philonotis fontana* both of which area associated with calcareous seeps and springs (Boucher et al. 2012, Vitt et al. 1988). Associated vascular plant species include *Epilobium anagallidifolium, Cardamine oligosperma* var. *kamtschatica*, *Claytonia sarmentosa, Koenigia islandica, Saxifraga lyallii* and *S. rivularis*. No vegetation succession studies have been conducted.

Conservation Status

Rarity: This association is documented only from the flanks of the Aniakchak Volcano where it is represented by less than 20 occurrences. However it is presumed to be undersampled and likely occurs at additional locations throughout the Alaska Peninsula.

Threats: Renewed volcanic activity threatens this association in so far that its hydrology could be altered or the entire system could be buried by lava, pumice or ash.

Trend: Short-term declines are not expected but long-term impacts are inevitable. Aniakchak erupted catastrophically 3,500 years ago with at least 12 lesser eruptions since with the most recent occurring in 1931. While the volcano shows no sign of current unrest, eruptions are fully expected to occur in the future (Neal et al. 2000).

Species of Conservation Concern

The plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 70). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016). Additional study is required to evaluate whether this plant association supports animal species of conservation concern.

Table 70. Plant species of conservation concern within the Pohlia wahlenbergii-Philonotis fontana Seep Plant Association.

Scientific Name	Global Rank	State Rank	Habitat Description
Romanzoffia unalaschcensis	G3	S3S4	Endemic to eastern Aleutians, Alaska Peninsula, Kodiak and scattered locations east to Sitka.
Rumex beringensis	G3	S3	Sandy and gravelly soil, shores, limestone outcrops. Yukon, Alaska and Russian Far East.

Classification Concept Source

This classification concept is based on Bosworth (1987) and Boucher and others (2012).

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Andreaea blyttii Snowbed Plant Association

Blytt's andreaea Moss Snowbed Plant Association

Statewide

Conservation Status Rank: S4 (apparently secure)

Introduction

The *Andreaea blyttii* (Blytt's andreaea moss) Snowbed Plant Association occurs in alpine environments on siliceous bedrock overlain by snow or flushed by upgradient snowmelt (Figure 136). While this association has only been formally described from the Klondike region, its dominant species, *Andreaea blyttii* has been collected from wet bedrock in alpine environments across Alaska. The same high physiological tolerances that enable *Andreaea blyttii* to survive extreme growing season variation in sunlight, temperature, and moisture are likely to promote its survival amidst rapid climate change (Murray 1988).

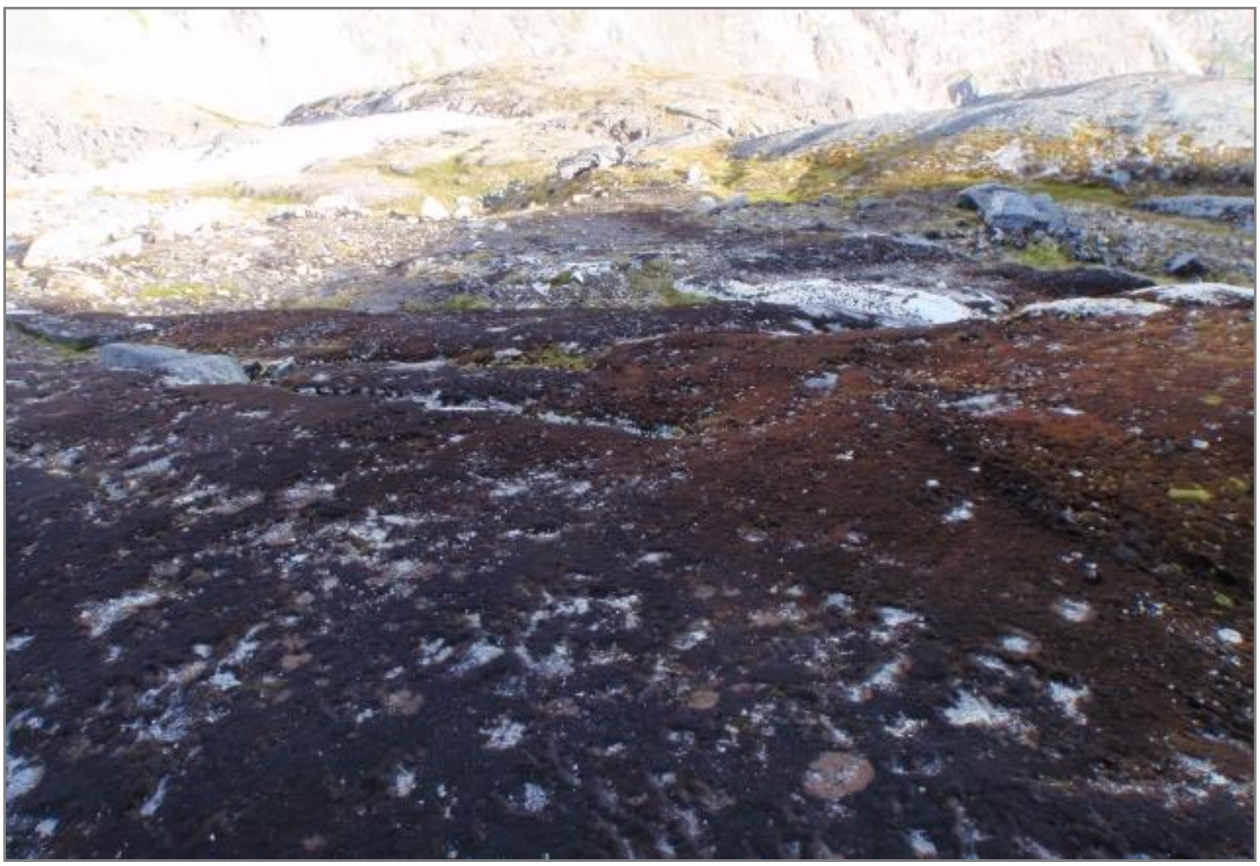

Figure 136. The *Andreaea blyttii* Snowbed Plant Association in Klondike Gold Rush National Historical Park, Alaska.

Distribution

The *Andreaea blyttii* Snowbed Plant Association is has been described from Newfoundland and Svalbard and occurs in the British Isles, Norway, and British Columbia (Beland 1982, Elvebakk 1984, Murray 1988, Schofield 1988). In Alaska the association has only been described from the Klondike region (Flagstad and

Boucher 2015) yet its dominant species, *Andreaea blyttii* has been collected from wet bedrock in alpine environments across Alaska. The distribution map for the *Andreaea blyttii* plant association (Figure 137) was developed from herbarium collections, a site visit to Klondike Gold Rush National Park (Flagstad and Boucher 2015) and select detailed landcover classes of the Alaska Vegetation Map (Boggs et al. 2015a, b) corresponding to wet bryophyte types; types corresponding to peatlands were excluded. Areas of occupancy shown in Figure 137 are candidate areas for this biophysical setting that have not been field-checked. The occurrences are herbarium records documenting the presence of *Andreaea blyttii*.

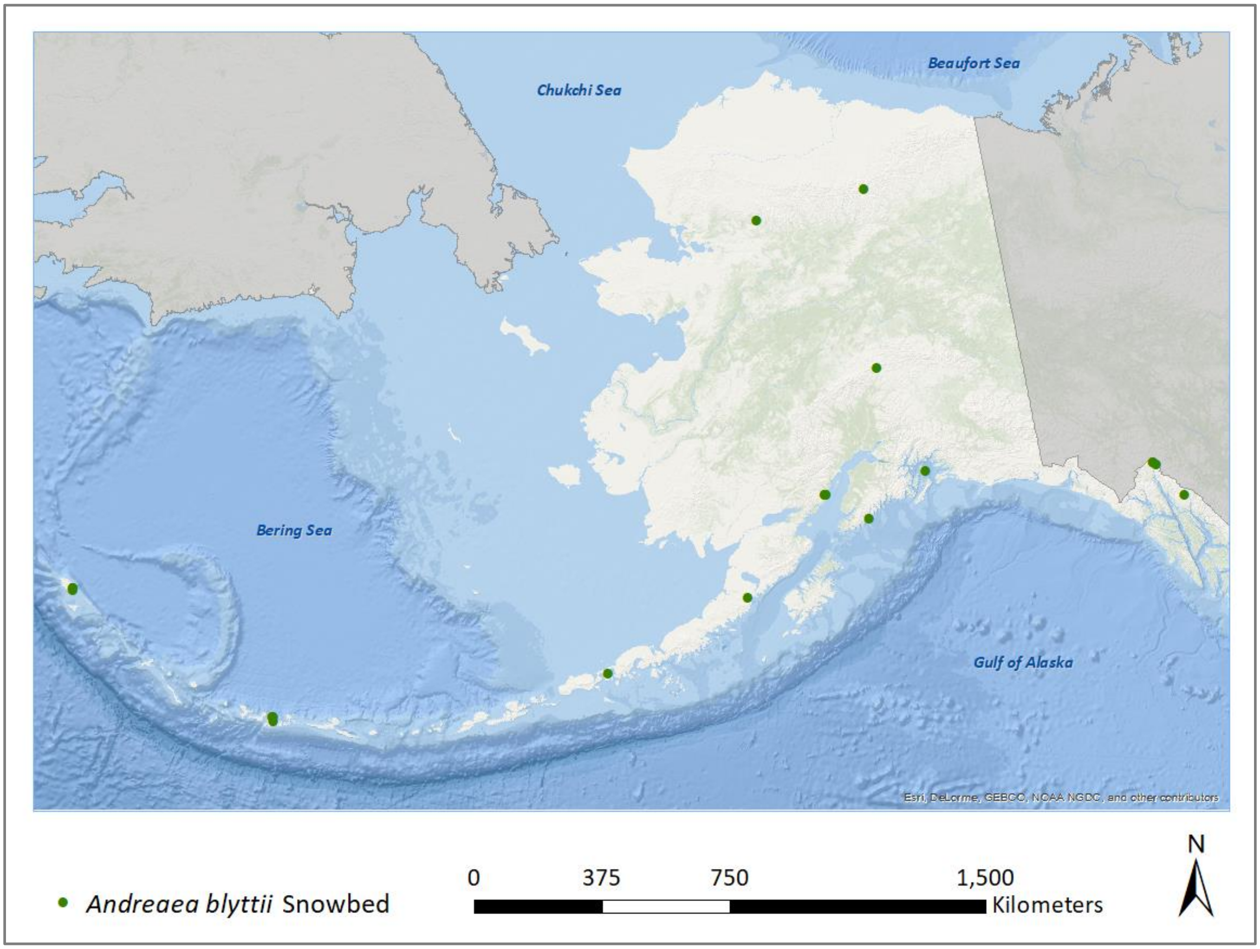

Figure 137. Distribution of the *Andreaea blyttii* Snowbed Plant Association. Note that point occurrences in this map are buffered for greater visibility.

Climate

While this association is expected to occur in alpine environments throughout Alaska, the climate description presented here is restricted to the Klondike region, which is the only location from which this association has been documented. The Klondike region is characterized by a mix of continental and maritime climates that interface from sea level to the high alpine (Nowacki et al. 2000). Similar to much of southeast Alaska, wetness and disturbance are major climatic drivers for the development and maintenance the local ecosystems. However, Klondike's relative remoteness from the open ocean lessens storm effects and its proximity to the continental interior increases inputs of cold and dry air (Davey et al. 2007, Nowacki et al. 2001). As a result, the Klondike region experiences less precipitation and greater fluctuation in annual temperatures relative to much of southeast Alaska. At Chilkoot Pass, mean monthly wind speeds reach 23.5 m/s, while temperatures dip to -27.9^{o}C and snow reaches depths of over 4 m (for the highly discontinuous period of measurement from 2010 to 2013; RAWS 2014). Average annual precipitation (including water equivalent of snow) is 59.0 cm with 74.9 cm as snowfall. Mean monthly precipitation for September (wettest month) is 101.7 cm received entirely as rain. The mean monthly precipitation for November (driest month) is 15.3 cm, with 14.4 cm received as snow (for the periods of record from 2004 to 2014 [precipitation] and from 2009 to 2014 [snow]; SNOTEL 2014).

Environmental Characteristics

This association occurs in alpine environments on siliceous bedrock overlain by snow or flushed by upgradient snowmelt. In Alaska, the association has been sampled on exposed, glaciated granite at 1,244 m elevation. In Svalbard the mean mineral soil pH underlying this association was 4.8 (Elvebakk 1984). Although shaded and saturated by snow early in the growing season, sites are exposed to full sun and become mesic to dry during the summer (Murray 1988. As such, desiccation is recognized as the primary threat to the maintenance of this association. While sites experience considerable annual variation in the persistence and distribution of snow, the dark coloration and pulvinate growth form of *Andreaea blyttii* provide some energetic compensation (Elvebakk 1984).

Vegetation and Succession

Plant associations developing over siliceous bedrock that is overlain or flushed by late-lying snow are often dominated by bryophytes, particularly acidophilopus species in the *Andreaea* genus (Elvebakk 1984). These snowbed communities are distinct in both their floristics and their spatial transition to adjacent types. Species composition is depauperate with respect to vascular plant taxa, is characterized by low overall diversity, and often includes disjunct occurrences (Beland 1982, Schofield 1969). The moss, *Andreaea blyttii* is dominant with the liverwort, *Anthelia juratzkana*, subdominant. Globally, both these species are characteristic of acidic granite flushed by late-lying snow (Beland 1982) with *Andreaea blyttii* showing extreme snowbed preference in arctic and alpine environments (Elvebakk 1984). In Alaska, *Anthelia juratzkana* may also represent a major component of cryptogamic crust forming over volcanic deposits (Boucher et al. 2012). Minor associates include the sedge, *Carex pyrenaica* ssp. *micropoda* and the lichen *Solorina crocea*.

This association is an early-seral type in avalanche paths and recently-deglaciated sites. Succession is thought to progress from colonization of bare rock by crustose lichens, which are overgrown by foliose lichens and mosses. This lush growth of mosses produces a humic layer and traps mineral soil that ultimately loosens pulvinate mosses such as *Andreaea blyttii* (Elvebakk 1984).

Conservation Status

Rarity: This association is uncommon in Alaska where only one occurrence of the association (Flagstad and Boucher 2015) and 19 collections of the dominant species, which are interpreted to represent occurrences of the association and have been documented.

Threats: This association could be threatened by change in snowfall and/or patterns of snow retention, however the physiological tolerances of the *Andreaea* genus enable its survival of extreme site conditions and through glacial and interglacial climatic swings (Murray 1988).

Trend: Short- and long-term change in extent and condition is not expected.

Species of Conservation Concern

No animal or plant species of conservation concern are known or suspected to occur within this plant association. Additional study is required to evaluate whether this plant association supports species of conservation concern.

Classification Concept Source

This association has been described in Newfoundland and Svalbard by Beland (1982) and Elvebakk (1984), respectively. The first documentation of the association in Alaska was by Flagstad and Boucher (2014).

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Geothermal Spring Biophysical Setting

Statewide

Conservation Status Rank: S4 (apparently secure)

Introduction

The Geothermal Spring Biophysical Setting are features where geothermally-heated groundwater emerges at the ground surface (Figure 138). Characteristics of geothermal springs vary widely and are largely dependent upon the subterranean thermal, physical and chemical conditions of origin. They are sensitive habitats that, in part due to diffuse geothermal heating of the ground and surface water, support rare and disjunct populations of plants and thermophilic microbial organisms. Only limited information is available on the plant associations and vegetation succession of Alaska's geothermal springs and thus threats and trends of the systems are not fully understood.

Figure 138. Granite Hotspring, Alaska (photo by M. Duffy).

Distribution

With small areas of occupancy and fewer than 150 known occurrences in Alaska, geothermal springs are an uncommon biophysical setting that is largely restricted to regions of current or historic volcanic activity (Figure 139; Miller 1994). Approximately half of the known geothermal springs in Alaska are associated with the Aleutian volcanic arc. The remaining springs are in interior and southeastern Alaska and have no apparent spatial or temporal association with recent volcanism. The geothermal springs distribution map (Figure 139) was developed from the occurrences mapped by Berry et al. (1980) and Miller (1994) and from the regions of known or potential geothermal resources (Laney & Brizee 2003).

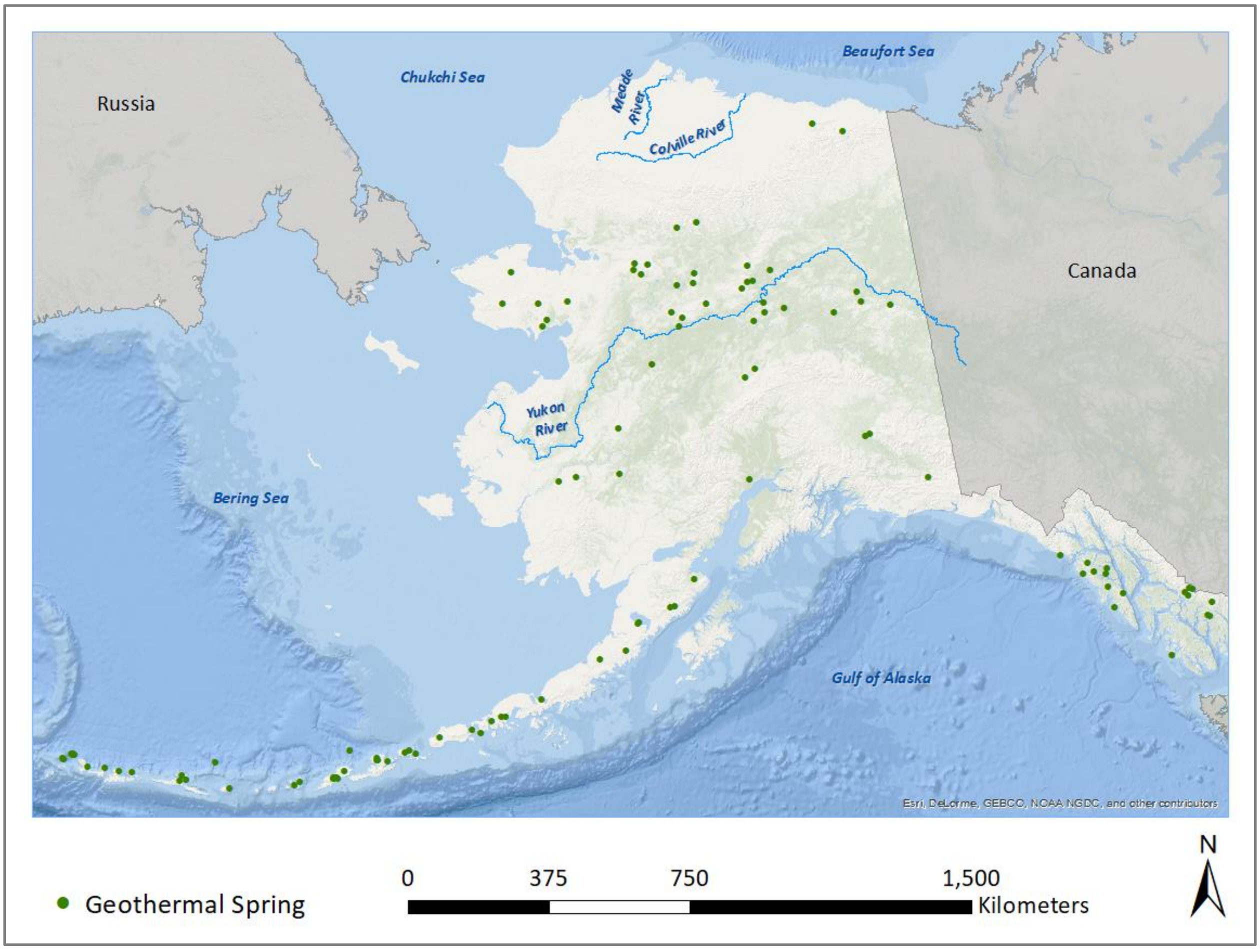

Figure 139. Distribution of the Geothermal Spring Biophysical Setting in Alaska. Note that point occurrences in this map are buffered for greater visibility.

Climate

Geothermal springs are widely distributed across Alaska and are thus characterized by considerable range in the climatic factors of latitude, continentality, and elevation. Because these systems represent phenomena tied to areas of geothermal activity, they transcend the constraints of local climate and instead create small, isolated microclimates where soil, water and air temperatures are significantly warmer on more moderate than the surrounding macroclimate.

Environmental Characteristics

Precipitation is the origin of almost all water emerging from geothermal springs. Below the ground surface, water infiltrates through faults or permeable layers to become heated by contact with hot rocks or magma before returning to the surface under hydrostatic pressure. In the Aleutian Islands and near the Wrangell Mountains, water can be heated by shallow magma, whereas geothermally-heated water emerging from the belt of springs across northcentral and within southeast Alaska is likely heated by still-warm rock at greater depth (Figure 140; Davis 1980).

The Aleutian volcanic arc extends some 2,500 km from the Hayes volcano (130 km west of Anchorage) to Buldir Island in the western Aleutians. Here springs are associated with major volcanic centers of Quaternary age, an association that is evidenced by the high surface temperatures of the spring water.

In the region north of the Alaska Range, 36 thermal springs have been reported, 32 of which are located in a 200 km wide east-west band extending across interior Alaska from the Seward Peninsula to within 160 km of the Canadian border. Additional, undocumented thermal springs may exist in this sparsely-populated area (Miller 1994). The majority of these geothermal springs are closely associated with the margins of granitic plutons and may be heated by these deep-seated intrusions of igneous rock. The origin of Pilgrim thermal springs on the Seward Peninsula is uncertain but may be related to a faulted margin of a Tertiary basin (Moll-Stalcup et al. 1994, Plafker and Berg 1994).

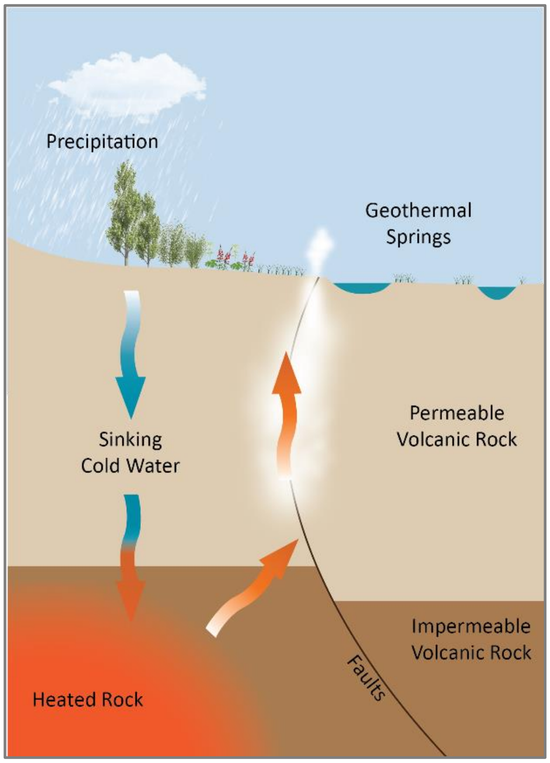

Figure 140. Geothermal springs water flow diagram.

Several geothermal springs occurring in the Wrangell Mountains are associated with a thick layer of calcareous-alkaline rocks that underlie about 10,000 km^2 of the mountains. These rocks range from basalt to rhyolite, range in age from Miocene to Holocene, and appear to be related to a nearby subduction zone (Miller and Richter 1994, Stephens et al. 1984).

Eighteen geothermal springs occur in Southeast Alaska, 13 of which also appear to be associated with the fractured margins of granitic masses (Waring 1917, Miller et al. 1975, Motyka et al. 1980). The thermal waters which are alkali-sulfate to alkali chloride in character are likely derived from the interaction of deeply circulating meteoric waters with subterranean granitic rock (Motyka et al. 1980).

Figure 141. Makushin Volcano Hotspring, Alaska (photo by T. Nawrocki).

Vegetation and Biotic Communities

Thermophilic microorganisms including photosynthetic, autotrophic cyanobacteria and heterotrophic and chemotrophic bacteria and archaea, inhabit the bottom of warm spring ponds and their runoff channels. Hot spring outflows typically exhibit marked temperature gradients and brilliant colors that are the product of thermophilic microorganisms, especially the highly-pigmented cyanobacteria species. Colorful microbes are partitioned in thermal waters by temperature, with white-colored bacteria thriving in the hottest water (about 100 °C), then light greens (71–75 °C), yellows (63–71 °C), oranges (57–63 °C), dark browns (50–57 °C) and darker greens in the coolest water (<50 °C) (Rinehart 1980).

Thermophilic algae in hot springs are most abundant at temperatures of 55 °C or below. The optimum growth temperature for cyanobacteria (e.g. *Synechococcus*), which have high fidelity to hot spring habitats in temperate or colder climates, is over 45 °C. Chemotrophic and heterotrophic bacteria in the genera *Hydrogenobacter, Sulfolobus*, and *Thermocrins*, grow at higher temperatures. Chemotrophic organisms include hydrogen sulfide (H_2S) and sulfur oxidizers (e.g., *Sulfolobus acidocaldarius*, *Thiobacilus thiooxidans*) found in highly acidic geothermal springs, sulfate reducers (e.g. *Desulfovibrio thermophilus*), and methane oxidizers (e.g. *Methylococcus capsulatus*). Archaea bacteria, including methane-producing bacteria and sulfur-dependent bacteria, can survive at temperatures greater than 110 °C.

Cold soils generally limit forest growth in many regions of Alaska (Van Cleve and Yarie 1986, Van Cleve et al. 1983). However, diffuse geothermal heating of the ground some distance from the immediate hot spring vents may promote lush growth of vegetation, often including plants typical of warmer soils and more southerly regions (Figure 141). In arctic Alaska, geothermal springs are often indicated by groves of *Populus balsamifera* (balsam poplar) surrounded by tundra (Bockheim et al. 2003). Halophytic plants of coastal environments may also occur at geothermal springs.

Figure 142. Lava Creek Hotspring, Seward Peninsula, Alaska (photo by J. Fulkerson).

Plants in the immediate vicinity of the thermal springs generally include salt-tolerant graminoids in the *Carex*, *Eleocharis*, *Juncus* and *Puccinellia* genera (Figure 142). Mosses may be present but substrate salinity reduces their development. While not halophytic, the forb, *Epilobium hornemannii*, consistently occurs in the wet ground near hot spring vents in Alaska and throughout the Chukchi Peninsula (Vekhov 1996).

Conservation Status

Rarity: Geothermal springs are uncommon both globally and within the state of Alaska. In Alaska, geothermal springs are of small extent with fewer than 150 known occurrences.

Threats: Geothermal springs may be developed for recreation, energy or agriculture (Miller 1994). In Alaska, the push to develop alternative energy sources, particularly geothermal, puts Alaska's geothermal springs at risk (K. Barrick pers. comm. 2013). For many geothermal springs, development threat is mitigated by their remote location.

Trend: Extent and condition of geothermal springs are not expected to change in the short- or long-term.

Species of Conservation Concern

The mammal and plant species listed below are designated critically imperiled or vulnerable either globally (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 71, Table 72). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 71. Mammal species of conservation concern within the Geothermal Springs Biophysical Setting.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
Keen's myotis	*Myotis keenii*	G2G3	S1S2	In southeast Alaska, this species occurs primarily in coniferous forests and also utilizes hot springs. On Hot Springs Island in the Queen Charlotte Islands, BC, bats roost among coastal boulders heated by runoff from local hot springs (Barclay, pers. com. 1992). This species has also been observed foraging over hot spring pools.

Table 72. Plant species of conservation concern within the Geothermal Springs Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Botrychium penduncolosum	G2G/3	S1	Found near hotsprings in Northwestern, Alaska and the Alaska Peninsula.
Botrychium virginianum	G5	S3	Found in the thermal influence near Manley Hot Springs, could occur within the thermal influence of other hot springs elsewhere in the state.
Cardamine pensylvanica	G5	S1	Coast Mountains, Chief Shakes Hot Springs. Hot spring bank.

Scientific Name	Global Rank	State Rank	Habitat Description
Carex deflexa var. deflexa	G5	S2S3	Dry herb meadows adjacent to hot springs in the Reed River valley of the Schwatka Mountains. The species is known from boreal North America and Greenland, and is found in the Yukon-Tanana uplands of interior Alaska. This record of C. deflexa is a northwestward range extension of over 400 km.
Chenopodium glaucum var. *salinum*	G5T5	S3S4	Found at several geothermal springs on the Seward Peninsula.
Crassula aquatica	G5	S1S2	Has a patchy, widespread distribution in North America, Europe, and eastern Asia. In Alaska, it is only known from warm springs on the Stikine River.
Cryptogramma stelleri	G5	S3S4	Grows at hot springs at Okpilak Lake.
Glyceria striata	G5	S3S4	Limited to isolated populations near two hot springs in interior Alaska, and several populations in coastal southeastern and southcentral Alaska.
Juncus nodosus	G5	S1S2	Obligate wetland plant along sandy shores of freshwater ponds/lakes and salt marshes.
Lycopus asper	G5	S1	Grows at hot springs at Circle.
Lycopus uniflorus	G5	S3S4	This species is widely distributed through North America and eastern Asia. In Alaska, it occurs in hot spring streams and margins and wet sedge meadow habitat at Shakes Hot Spring on the Stikine River and Granite Hotsprings in the Selawik Hills.
Polypodium sibiricum	G5?	S3	Boulder field adjacent to hot springs in the Reed River valley of the Schwatka Mountains.
Ranunculus monophyllus	G5	S2	Collected at Serpentine Hotsprings.
Schizachne purpurascens	G5	S2	Found growing in a dry meadow adjacent to Reed Hot Springs in Gates of the Arctic NPP. This grass of boreal Asia and North America is known from south of the Alaska Range, hence this record documents a northward range extension of approximately 600 km.
Schoenoplectus pungens	G4G5	S1	Marshy borders of hot springs.

Plant Associations of Conservation Concern

No plant associations of conservation concern are known or suspected to occur within this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports plant associations of conservation concern.

Classification Concept Source

This publication represents the first description of the Mud Volcano Biophysical Setting.

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Mud Volcano Biophysical Setting
Statewide

Conservation Status Rank: S4 (apparently secure)

Introduction
The Mud Volcano Biophysical Setting are surface expressions of semiliquid, gas-enriched mud originating from depth, with the structures produced varying markedly in size and topography (Dimitrov 2002, Kopf 2002). Alaska's mud volcanos occur in two clusters, the Tolsona group and the Klawasi group; both are located in the Copper River Basin near Glennallen (Figure 144). Here, successive exudations of fluid-rich, fine-grained sediments build domes up to 100 m tall and 2,500 m diameter (Figure 143). These biophysical settings represent sensitive habitats supporting disjunct populations of halophytic and salt-tolerant plants and thermophilic microbial organisms.

Figure 143. Aerial views of Lower Klawasi mud volcano showing the dome, crater and the delta formed by mud flow deposits (source: Google Earth, accessed September 2, 2015).

Distribution

Mud volcanism is known from 44 provinces worldwide, with approximately 50% (900) of mud volcanos occurring onshore (Kopf 2002, Dimitrov 2002). In Alaska, terrestrial mud volcanoes are known exclusively from the Copper River Basin. Offshore, mud volcanoes are expected to occur but have not been documented from the Aleutian Trench (Kopf 2002); marine occurrences are not considered here. The Copper River Basin volcanoes occur as two complexes; the Tolsona and Klawasi groups. Volcano morphology ranges from large domes (>5º slope) capped by a main, water-filled crater (Klawasi group) to low-relief (<5º slope) pies with numerous vents at their summit (Tolsona group). Mud Volcano biophysical setting occurrences were digitized from locations documented by Nichols and Yehle (1961). An average diameter of 542 m was determined from the maximum diameters provided by Pewe & Reger (1983) for the mud volcanos mapped in Figure 144.

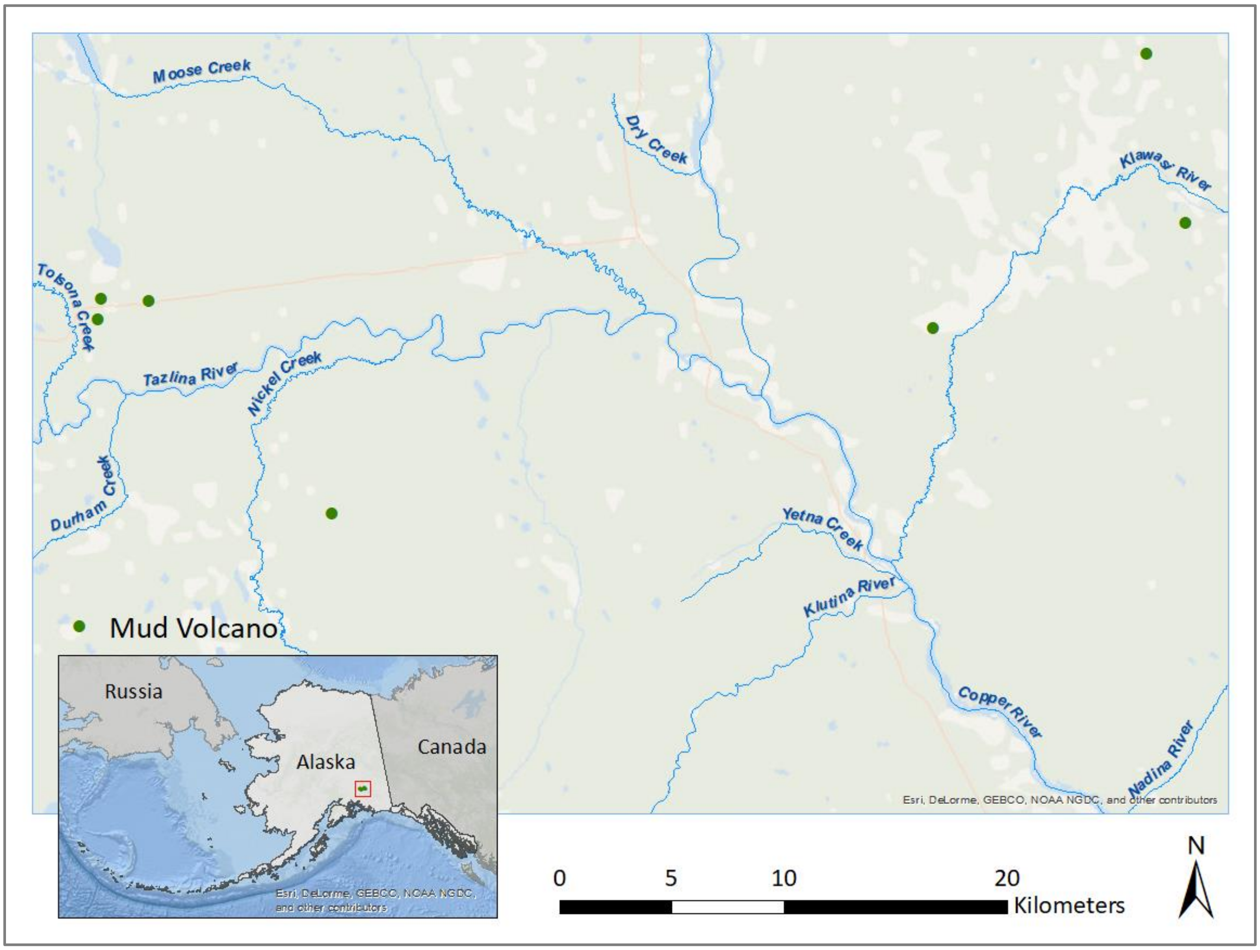

Figure 144. Distribution of the Mud Volcano Biophysical Setting. Note that point occurrences in this map are buffered for greater visibility.

Climate

In the interior Alaska region, the subarctic continental climate is dry and cold. It is characterized by short, warm summers and long, cold winters (Natural Resources Conservation Service 2006). The mean annual precipitation ranges from about 15 cm in the northwest lowlands to 254 cm in the Alaska Range. In summer, afternoon thunderstorms are common in valleys and lower mountain slopes. The mean annual temperature ranges from -13 to -2 ^{o}C and freezing temperatures may occur in any month in most of the region.

Figure 145. A recent mudflow at the summit of the Lower Klawasi mud volcano, Alaska.

Environmental Characteristics

Mud volcanism is produced by the rapid tectonic or structural loading of low-density, fine-grained sediment. Owing to this loading requirement, the majority of mud volcanos are concentrated along convergent plate margins in terrestrial or marine environments (Kopf 2002). Eruption or exudation results when the combined forces of buoyancy and pore fluid pressure exceed the shear strength of the overlying stratigraphy (Dimitrov 2002). While the buoyancy of the mobilized sediment is important to eruption, pore fluid pressure is thought to direct the energy and frequency of eruption and the morphology of the structure produced, with higher pore fluid pressure correlated to frequent, high-energy eruptions of low viscosity mud and the production of low-relief, domed structures (Dimitrov 2002).

The chemical composition of mud volcanos vary depending upon the architecture of their conduit and the lithological composition of their mobilized sediments (Kopf 2002). Analyses of water and gas discharged from the two Alaska complexes show marked differences in gas and fluid chemistries. The Klawasi group discharges nearly pure carbon dioxide gas with warm sodium bicarbonate and sodium chloride waters whereas the Tolsona group discharges methane, nitrogen and helium gas and cool sodium chloride and calcium chloride waters (Motyka et al. 1989, Nichols and Yhele 1961, Reitsema 1978). These compositions suggest that the Klawasi emissions originate from a mixture of ancient seawater and meteoric water, containing carbon dioxide derived from both magma and deeply buried limestone whereas the Tolsona emissions originate from the thermal decomposition of coal, theories that are consistent with regional geology (Reitsema 1978, Motyka et al. 1989, Rohs et al. 2004). In addition to carbon dioxide-rich gasses released from the central and side vents of the Klawasi group volcanos, carbon dioxide is also discharged through the soil (Sorey et al. 2000). Water temperatures range from about 12°C at Shrub to about 29°C at Upper Klawasi, with water pH ranging from 6.8 to 7.2, respectively. While all surface mud is derived from underlying glaciolacustrine sediments of the basin (Richter et al. 1998), the surprising lack of mixing of ejecta among the volcanos during vertical migration is thought to be prevented by permafrost (Reitsema 1978).

The Tolsona group is comprised of the Nickel Creek, Shepard (inactive), and Tolsona mud volcanos located north and south of the Glenn Highway west of Glennallen (Nichols and Yhele 1961). This group forms relatively small, low-slope pies. The Tolsona mud volcano is 8 m tall and 180 to 270 m wide. It appears to have grown following the retreat of glacial ice at the end of the Pleistocene (Rohs et al. 2004), and is now fully vegetated except for the caldera and some portions of the sideslopes.

The Klawasi Group consists of three mud volcanos: Upper Klawasi, Lower Klawasi (Figure 145), and Shrub located east of Glennallen on the lower slopes of Mt. Drum (Sorey et al. 2000). This group forms larger, more steeply sloping mud domes. The largest of the three is Shrub, rising 104 m above and extending 2,000 m across the surrounding terrain.

Upper Klawasi, Lower Klawasi and the Tolsona mud volcanos have periodically erupted over the past 40 years (Richter et al. 1998). In contrast, Shrub has remained relatively inactive for decades with only minor discharge observed in the mid-1950s (Nichols and Yehle 1961). Shrub regained activity in 1997 and has erupted periodically since (Sorey et al. 2000).

Vegetation

The Tolsona and Lower Klawasi mud volcanos were visited in July 2013 by the authors to document general ecology, plant associations, dominant plant species and soil characteristics. At Lower Klawasi, the most recent mudflows supported dead trees standing 3 m or more above the mudflow with their bases buried 1 to 2 m deep and coated with a white precipitate; some basal diameters exceeded 0.3 m (Figure 143). Open *Picea glauca*/*Shepherdia canaden*sis/ *Pleurozium schreberi* forests are common, extending from top to bottom of the dome sideslopes (Figure 146). The *Picea glauca/Empetrum nigrum* association also occurs, but is less common. The soils supporting both associations were characterized by some soil development (B horizon) and a pH of 8.7 at 10 cm depth. Common herbaceous plant associations included: *Plantago eriopoda*, *Plantago eriopoda-Hedysarum alpinum-Elymus trachycaulus* ssp. *trachycaulus*, and

Figure 146. Lower Klawasi crater showing the *Picea glauca/Shepherdia canadensis*/moss Plant Association near the rim.

seedling/sapling *Picea glauca/Hordeum jubatum*. The soil supporting each association was predominately unaltered parent material (C horizon) with pH of 9.0 at 10 cm depth. The *Juncus arcticus* ssp. *arter* association occurs on flat floodplains at the base of the dome and is characterized by 15 cm of peat overlying parent material with accumulated organics (A horizon) and pH of 8.9 at 10 cm depth (Figure 147). Biological crusts are uncommon, occurring on the Lower Klawasi caldera rim, and as small patches on barren mud flows.

Figure 147. *Juncus arcticus* ssp. *arter* Plant Association on the lower flanks of the Lower Klawasi mud volcano.

Beyond the dome, mudflow sediments dominated the floodplain and delta of the outflow stream to the Copper River (Figure 143). With the exception of forested associations, this narrow floodplain and terminal delta support the same plant communities found at the Lower Klawasi mud volcano. A novel plant association dominated by *Puccinellia nutkaensis* occurs on the delta. A variety of halophytic or salt-tolerant species that are typically associated with brackish tidal marshes occur on the mud deposits including the grasses: *Festuca rubra* ssp. *pruinosa* (Lower Klawasi) and *Puccinellia nutkaensis* (mudflow delta at the Copper River) and the forbs: *Plantago eriopoda* (Lower Klawasi), *Ranunculus cymbalaria* (Tolsona), *Triglochin maritimum* (mudflow delta at the Copper River) and *Triglochin palustre* (Tolsona).

Eruptions can directly kill vegetation. The 1997 eruption of the mud volcano Shrub flooded forests resulting in stands of dead trees encased in mud, similar to the Lower Klawasi mud plains (Sorey et al. 2000). Also at Shrub, narrow bands of alder and birch are browned to heights of 2 m, likely caused by discharges of carbon dioxide-rich gas from the caldera (Richter et al. 1998). Elevated concentrations of carbon dioxide in the root zone may also affect oxygen and nutrient uptake by the tree roots (Sorey et al. 2000).

Depending on the time since last eruption, volcano sideslopes may be barren or vegetated. More detailed information on the plant associations and successional processes of Alaska's mud volcanos is limited, however vegetation work on a Sakhalin Island mud volcano at a more southerly, yet comparable latitude (48^{o} North) documents the same (e.g. *Triglochin palustre*) or congeneric species (e.g. *Primula sachalinensis* in Sakhalin compared to *P. incana* in Alaska) associated with mud flow sediments. Also similar to vegetation patterns observed in Alaska, the Sakhalin Island study shows decreasing endemism and increasing plant abundance, diversity and cover with distance from the eruptive center (Korznikov 2015).

Conservation Status

Rarity: Although globally widespread (Kopf 2002), terrestrial mud volcanos are rare in Alaska. Only four clusters of mud volcanism are known from Alaska; their range is restricted to the Copper River Basin and their cumulative area is less than 10 km^2.

Threats: The Tolsona mud volcanoes are accessible via an established trail and is thus subject to moderate human visitation. Due to their remote location, the Klawasi and Shrub groups receive few visitors and are pristine condition. Potential threats include development, introduction of invasive species and change in thermohydrologic condition. Geothermal springs may be developed for recreation, energy or agriculture (Miller 1994).

Trend: In Alaska, the push to develop alternative energy sources puts Alaska's geothermal resources at risk (K. Barrick pers. comm. 2013). As a ruderal habitat this system is vulnerable to infestation by invasive plant species; this threat, however is likely mitigated by the remote locations of the volcanos. In the extreme long-term, there is the potential for large-magnitude earthquakes to irrevocably change the geothermal and hydrological conditions that currently support mud volcanism.

Species of Conservation Concern

Plantago eriopoda is considered a vulnerable plant species within Alaska. This halophytic, North American species is disjunct from the temperate zone in the southwest Yukon and adjacent southcentral Alaska (Cook and Roland 2002). The collection at Lower Klawasi represents the farthest western extent of its distribution. No animal species of conservation concern are known or suspected to occur within this biophysical setting. Additional study is required to evaluate whether this biophysical setting supports other species of conservation concern. Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Plant Association of Conservation Concern

The plant association listed below is designated vulnerable within Alaska (S3) and is known or suspected to occur in this biophysical setting (Table 73).

Table 73. Plant associations of conservation concern within the Mud Volcano Biophysical Setting.

Name	Global Rank	State Rank	Concept Source
Plantago eriopoda	G5	S3	L. Flagstad, K. Boggs (personal observation)

Classification Concept Source

The classification concept for this biophysical setting is based on Nichols and Yehle (1961).

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