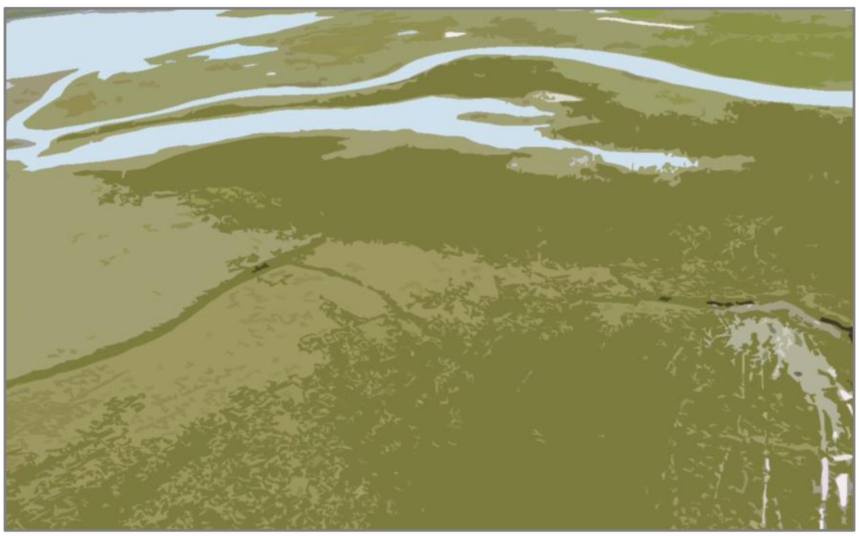
Wetlands across Alaska:
Statewide wetland map and
Assessment of rare wetland ecosystems



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Keywords: Alaska, biodiversity, conservation, rare ecosystems, terrestrial wetlands, wetland mapping

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Abstract

Mapping and conservation assessment of wetland ecosystems is a necessary step in promoting effective management of wetland habitats by providing a uniform and comprehensive inventory of both common and rare types. The statewide distribution of wetland, deepwater, and upland habitats presented here represents the first effort to map wetlands in accordance with the national wetland classification system at medium-scale resolution for Alaska. We inferred wetland and deepwater type and distribution using land cover and hydrographic data as proxy indicators. Additionally, rare wetland ecosystems are described, mapped, and conservation status ranked. The final map included 2,211 unique land cover classes and approximately 4,600 wetland and deepwater equivalents. Overall map accuracy was 69% with a Kappa statistic of 0.64, indicating fair accuracy. When assessed at the wetland system level, accuracy ranged from 50 to 93%, with the Marine system mapped with the lowest accuracy and with the Riverine system mapped with the highest accuracy. The statewide wetland, land cover and rare ecosystem maps are served through an interactive data portal administered by Alaska Center for Conservation Science at University of Alaska Anchorage.

Introduction

Wetland and Deepwater ecology

Wetlands are distinct ecosystems that conceptually bridge terrestrial and aquatic habitats (Tiner 2012). In general terms, wetlands are lands where saturation with water is the dominant factor determining the nature of substrate development and the types of associated plant and animal communities. The single feature common to most wetlands is a substrate that is at least periodically saturated with, or covered by, water. Such a water regime excludes plants and animals that are not adapted to those conditions (FGDC 2013). Due to their transitional character, wetland communities often support a diversity of plant species adapted to a range of moisture regimes and animal species whose life cycles require both aquatic and terrestrial habitats. Wetlands also perform unique ecosystem functions, such as groundwater recharge and discharge, nutrient storage, water quality maintenance, flood mitigation, and erosion reduction (Carter 1996).

With few exceptions, terrestrial habitats gain water from precipitation and surface- and ground-water inflow and lose water through evapotranspiration and surface- and ground-water outflow. Terrestrial wetland habitats represent a special case where water inputs either exceed or match outputs due to some combination of high inflow, storage capacity, and/or reduced outflow within the system. Both the relative contributions of atmospheric, surface-water, and ground-water, as well as the mechanism by which water flow may be retarded through the system, vary among wetland types. Wetlands with significant groundwater influence (fen type wetlands), for example, are more nutrient rich and are thus able to support more diverse plant communities relative to nutrient-poor wetlands (bog type wetland).

Deepwater habitats such as oceans, estuaries, lakes, and ponds are chiefly maintained by watershed inputs and their topographic positions at either sea level or local groundwater level. The development of terrestrial deepwater environments, often involves a physical barrier to outflow. Such barriers may relate to topographic position, stratigraphy, and/or permafrost. In Alaska, wetlands form in depressions, basins, valleys, or along slope breaks where the groundwater table is expressed at the ground surface. Often, low permeability layers formed by shallow bedrock, clay and silt horizons, or ice-rich permafrost, slow the infiltration of water and promote hydric soil regimes within these topographic features.

Wetlands in a changing climate

While less than one percent of Alaska's wetlands were estimated to have been lost between the 1780s and the 1980s (Dahl 1990) climate change is likely to alter the historic stability of wetland condition, particularly in the Arctic. Here, global sea-level rise, warming water and air temperatures, reduction in sea-ice cover and duration, and increased frequency and strength of storms, combine to amplify the effects of thermal erosion, salinization, and paludification (Jones et al. 2009, Ping et al. 2011). 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), while thaw subsidence renders much of the arctic coastal environment increasingly susceptible to salinization (Arp et al. 2010). Furthermore, warming in the discontinuous or 'warm' (0° to -3° C) permafrost zone accelerates the conversion of upland to wetland habitat via paludification (Jorgenson et al. 2001).

Plants as wetland indicators

The use of easily-interpreted surrogates to predict the condition of a system is a proven ecological method (Neimi and McDonald 2004). With respect to wetlands, the frequency and duration of saturation or inundation, as well as soil type (organic or mineral) and water chemistry (saline or fresh, acidic or basic), have large effects on the type and abundance of plant species able to grow and reproduce (Carter 1996). Wetland plants (hydrophytic vegetation) have developed morphological, physiological, and reproductive adaptations to saturated soil conditions (Tiner 2012). Common traits found in Alaska wetland plants include air-filled cavities in stems, roots and tissue (aerenchyma), capacity for anaerobic respiration, succulence, root thickening and lignification, growth and seed dormancy, and vegetative and viviparous reproduction. The degree of specialization and fidelity of resident plant species increases with the extremity of the hydrological regime. In this way, plant community composition can be used as a reliable indicator of wetland type (Tiner 2012). It is this relationship between plant community composition and wetland type that provides the basis for the Cowardin wetland classification system as well as the inference of wetland type from land cover characteristics employed here.

Status of wetland mapping in Alaska

Previous analyses estimate wetland habitats occupy 43% and deepwater habitats occupy 5% of Alaska's total area (Hall et al. 1994). By comparison, these habitats collectively occupy only 5% of the lower 48 states (Hall et al. 1994). Despite the dominance of wetland habitat in Alaska and the dramatic changes forecasted for their extent and condition, Alaska remains the only state that has not been fully mapped by the National Wetland Inventory (NWI) program. To date, just over 40% of the state has been mapped following NWI protocols (J. Harner, personal communication, July 12, 2018). The diversity and abundance of wetland habitat across the vast and remote state has, and will likely continue, to result in a slow rate of wetland mapping in accordance with our national standards. While several wetland maps have been produced for the state, the resolution of either their mapping (Whitcomb et al. 2009, 100 m resolution) or classification (Jin et al. 2013, two wetland classes) is too coarse to allow meaningful regional-scale assessment and monitoring. The Alaska Wetland Map presented here provides an alternate product that attempts to fill the gap between an incomplete fine-scale wetland inventory and existing coarser-scale image classifications by delineating wetland systems at medium-scale (30 m) resolution for all of Alaska.

Wetlands of conservation concern

Rare ecosystems support unique assemblages of specialized or diverse flora and fauna within a small geographic area or restricted range (Gaston 1994). In Alaska, many ecosystems have little to no measurable impacts from human development, yet some naturally-uncommon systems are in decline due to their intrinsic vulnerabilities or external threats. Preservation of rare ecosystems represent a substantial opportunity for conservation since they often contribute disproportionately to regional biodiversity. These same systems, however, are often poorly described and mapped, which hinders protection and long-term persistence (Williams et al. 2007). Here, we identify wetland ecosystems of conservation concern for Alaska, describe their ecology, map their distribution, and assess their conservation status (and see Flagstad et al. in prep). Prioritization of these rare ecosystems with respect to conservation status is intended to better inform decision making and enhance stewardship of these natural systems.

Methods

The type and distribution of wetland and deepwater were mapped in a GIS environment using a combination of land cover and hydrographic data as proxy indicators. Wetland areas were calculated for all of terrestrial Alaska plus a 10 km marine buffer. The resulting wetland map was assessed for accuracy using validation points derived from NWI Status and Trends digital and hardcopy data and National Water Information Systems (NWIS) data. As an additional yet related product, rare wetland ecosystems in Alaska are described, mapped, and ranked with respect to conservation status.

Land cover classification and mapping

Statewide land cover map

The Alaska Land Cover Map is a statewide land cover mosaic developed by ACCS (Boggs et al. 2016a, b), which we use as the basis for both the wetland map, as well as individual distribution maps for rare wetland types (Figure 1). The land cover map incorporates over 30 individual land cover datasets that have been developed within the last 31 years. The types of land cover maps sought for incorporation were those with high spatial resolution, a robust legend, and good accuracy, as well as those covering a large geographic area. For individual maps derived from satellite imagery we used only those with a 30 m pixel size or finer; for maps derived from aerial photography we used those with a scale of 1:63,360 or finer. Images selected for inclusion in the final map were processed in a GIS environment using the ArcGIS 10.5 and ERDAS IMAGINE 10 software packages. Regional land cover maps in vector format were converted to raster images with 30 m pixel resolution; if necessary, higher-resolution raster images (those with pixel size less than 30 m) were resampled to convert their resolution to 30 m. All regional maps were transformed to an Alaska Albers Equal Area Conic projection referencing the North American Datum set in 1983 (NAD83) and snapped to a default grid. Lastly, images were mosaicked in an order that promoted the most accurate and current land cover data. In areas of no data (due to cloud or terrain shadow) land cover type was informed by other, spatially-coincident digital maps.

Following mosaicking, we developed a two-tiered, uniform legend so that land cover classes that were similar in concept yet different in nomenclature could be reconciled. These hierarchical levels of land cover classes are represented by a coarse-scale class, which is analogous to level III of the Alaska Vegetation Classification and fine-scale class, which nest within the coarse-scale classes and are analogous to level IV of the Alaska Vegetation Classification (Viereck et al. 1992). The original land cover classes as defined by the authors of the source maps were preserved. This was done to: 1) retain the original map classes from each source map, 2) to maintain integrity of the final mosaicked image, and 3) to preserve areas of high accuracy within the map. For this reason, a given coarse-scale class is represented by multiple cell values in the final map. In its final form The Alaska Land Cover Map includes 2,083 unique land cover classes, which have been cross-walked to 726 fine-scale, and 59 coarse-scale land cover types.

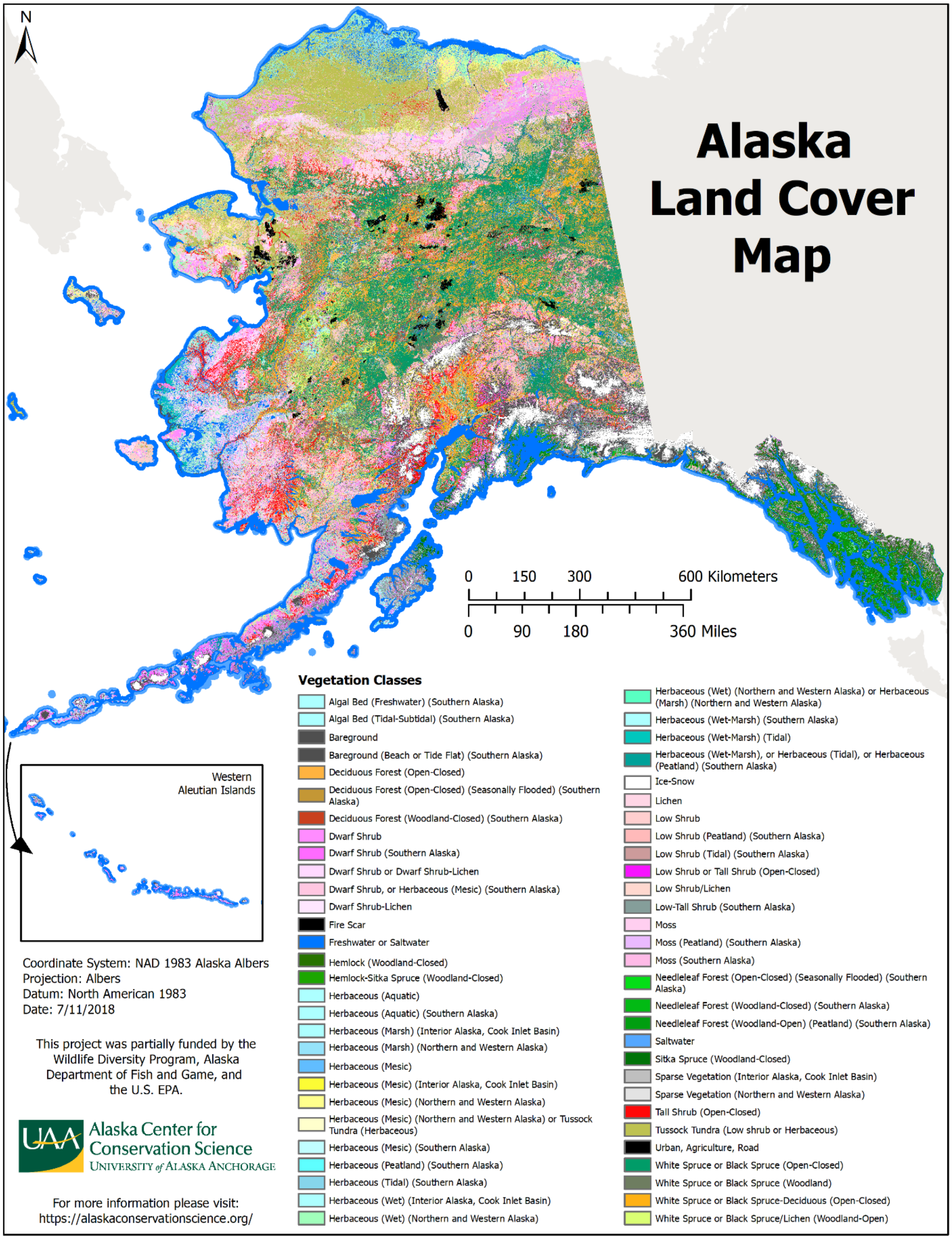

Figure 1. The Alaska Land Cover Map symbolized coarse land cover types.

Wetland classification and mapping

Statewide wetland map

Using the Alaska Land Cover Map as a proxy indicator we assigned the most appropriate deepwater or wetland class to each unique land cover class. The wetland classification system used here is that proposed by Cowardin and others (1979), formalized by the Federal Geographic Data Committee (FGDC 2013), and administered as the national standard for wetland mapping by the US Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI). This classification system requires wetlands to satisfy one or more of the following criteria: (1) at least periodically, the vegetation is dominated by hydrophytes (2) the substrate is predominantly undrained, hydric soil, and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. The classification of deepwater habitats is more straightforward; these are permanently flooded lands lying below the deepwater boundary of wetlands (Cowardin et al. 1979).

The Cowardin system is hierarchical (Figures 2 and 3). Wetland and deepwater habitats are separated into five major systems (marine, estuarine, riverine, lacustrine, and palustrine) represented by similar hydrological, geomorphological, chemical, and biological influences. The marine system consists of the open ocean overlying the continental shelf and its associated coastline. The estuarine system consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land with some access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. The riverine system includes all wetlands and deepwater habitats contained within a channel. The lacustrine system includes wetland and deepwater habitats that are situated in a topographic depression or a dammed river channel, lacking trees, shrubs, persistent emergents, emergent mosses or lichens with 30 percent or greater areal coverage; and total area of at least 8 hectares (ha) (20 acres). The palustrine system includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt (FGDC 2013). These systems are further divided into finer-scale subsystems and classes related to frequency of inundation and substrate and vegetation characteristics

To retain the highest accuracy, wetland codes were assigned to each unique land cover class (as determined by the original land cover mapping) at the finest hierarchical level possible without making assumptions regarding site condition. As an example, a land cover class described as ‘sedge wetland’ would be coded as a palustrine, emergent, persistent, wetland (PEM1) in accordance with the NWI system. A combination wetland code was used where a mosaic of wetland types was represented by a single land cover class. For example, a wetland code of PSS1/ML1B would be used for a land cover type described as ‘dwarf-shrub-sphagnum (peatland)’.

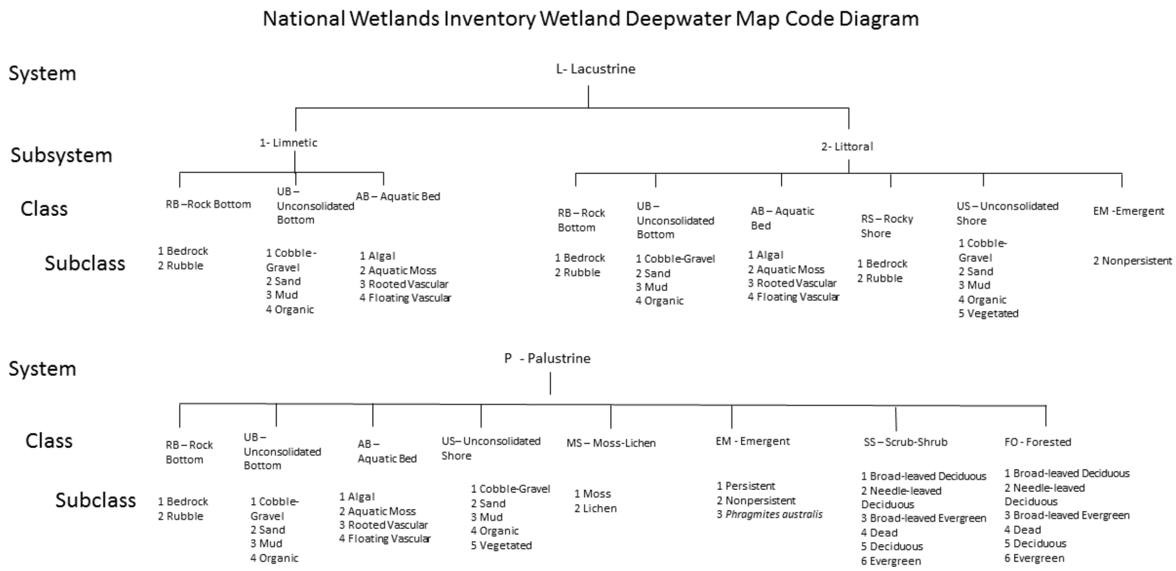

Figure 2. Classification hierarchy of wetlands and deepwater habitats, showing Lacustrine and Palustrine systems, subsystems, and classes (FGDC 2013). The Palustrine System does not include deepwater habitats.

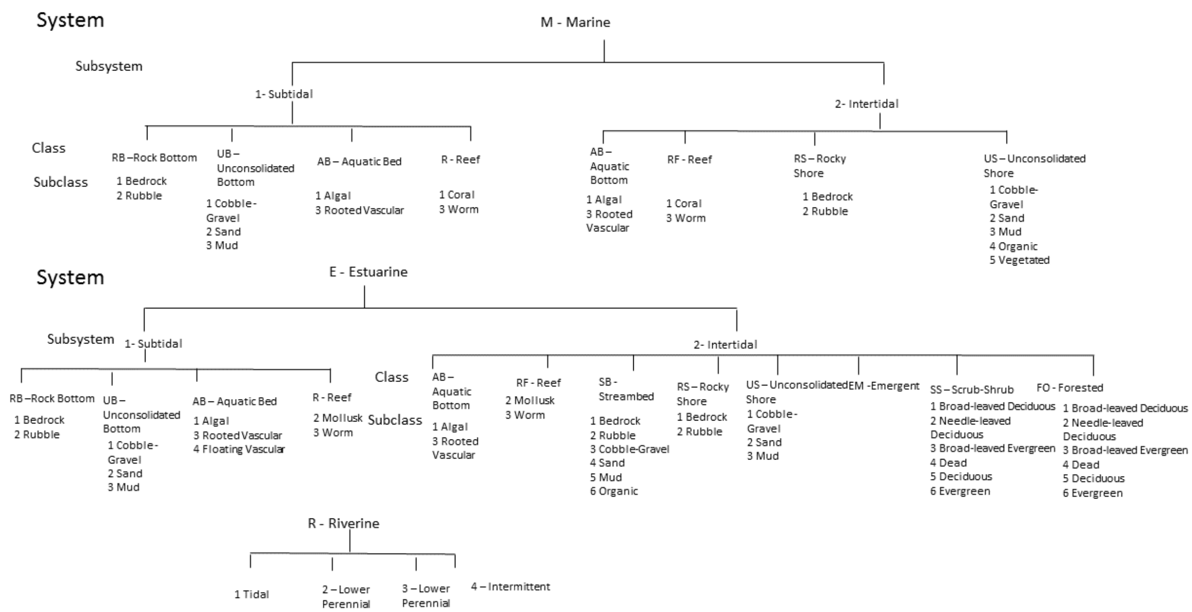

Figure 3. Classification hierarchy of wetlands and deepwater habitats, showing Marine, Estuarine and Riverine, systems, subsystems, and classes (FGDC 2013). The Palustrine System does not include deepwater habitats.

Wetland codes were collapsed into more generalized wetland categories to both provide a class-level legend and to give greater resolution to the palustrine system, which is the most common type in Alaska. Using the generalized categories, all subclasses of palustrine emergent wetlands (PEM) are collectively referred to as ‘Freshwater Emergent Wetlands’. Similarly, all subclasses of palustrine forested wetlands (PFO) or shrub (PSS) wetland are referred to as ‘Freshwater Forested/Shrub Wetlands’. Palustrine wetlands with unconsolidated bottoms, (PUB) or rock bottoms (PRB), shores (PUS) or algal beds (PAB) are collectively referred to as ‘Freshwater Pond’. Palustrine wetlands dominated by moss or lichen (PML) are referred to as ‘Freshwater Bryophyte’. Note that in the NWI generalized system ‘Freshwater Bryophyte’ is combined with ‘Freshwater Emergent’. We chose to split this class out as non-vascular plants tend to be more abundant and ecologically significant in northern climates. External to the palustrine system, all lacustrine (L) and riverine (R) types are referred to as ‘Lake’, and ‘Riverine’ respectively. All classes of intertidal estuarine (E2) and intertidal marine (M2) wetlands are collectively referred to as ‘Estuarine and Marine Wetland’ whereas all classes of subtidal estuarine (E1) and subtidal marine (M1) are referred to as ‘Estuarine and Marine Deepwater’. Non-wetland, terrestrial habitats are collectively referred to as ‘Upland’. Land cover class information was preserved for all upland habitats.

When a definitive wetland code could not be interpreted from the land cover class name, a variety of resources were consulted. Typically, the distribution of the land cover class was reviewed in the GIS environment to see where it occurred on the landscape; this step often involved comparing the occurrence of the land cover type to the underlying imagery or to a digital elevation model (DEM). When available, the original description of the land cover class was reviewed to glean information regarding landscape position, dominant plant species, hydrological regime, and soil condition. Where dominant species were listed, their wetland indicator status in the Alaska region was checked in the National Wetland Plant List (Lichvar et al. 2014).

Statewide wetland map revision

To give greater resolution to land cover classes that represented multiple wetland or deepwater systems, we intersected the Alaska Land Cover Map with hydrographic data derived from the National Hydrography Dataset (NHD) and the National Wetland Inventory (NWI). In this way we were able to split land cover classes such as ‘Clear Water’, ‘Turbid Water’, ‘Water’, and ‘Open Water’ to more specific designations of ‘Clear Water – Freshwater’, ‘Clear Water – Saltwater’, or ‘Clear Water – Brackish’. The delineation of coastline provided by NHD (i.e. the NHDSeaOcean and NHDBayInlet feature classes) was used to separate the ‘Saltwater’ and ‘Brackish’ condition from terrestrial (i.e. Freshwater) environments.

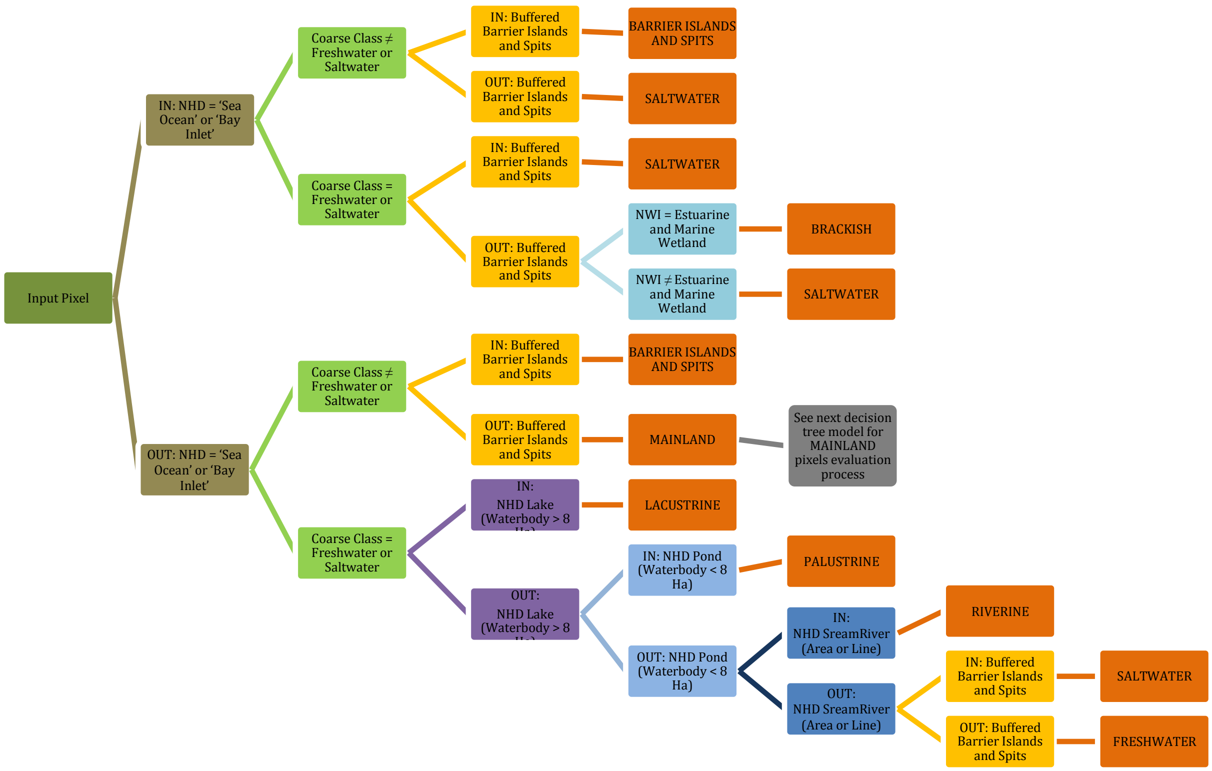

Figure 4. Decision Tree Model for determining wetland condition for the Alaska Wetlands Map.

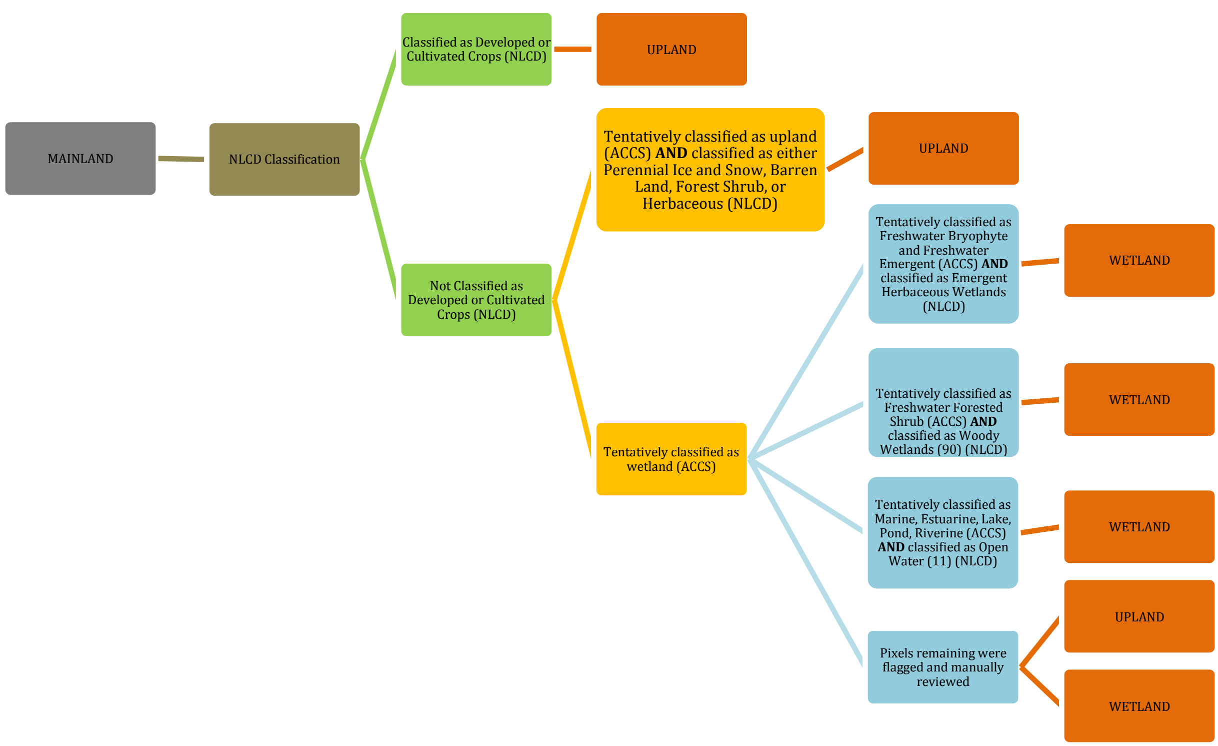

Figure 5. Decision Tree Model for determining wetland condition following separation of saltwater and freshwater for the Alaska Wetlands Map.

Because barrier islands and spits are small and dynamic features that are difficult to capture using unsupervised land cover mapping techniques, we developed an in-house coverage for their extent. Here we manually delineated the extent of barrier islands and spits on current remotely-sensed imagery (GINA BDL; AGC n.d.) using polygons mapped by NWI that corresponded to beach habitat (i.e. marine and estuarine intertidal unconsolidated shore - M2US and E2US) for reference. Where the NWI classes corresponded to mainland beaches, the attributed polygon was removed from the barrier island and spit distribution. The final barrier island and spit layer was used to further classify wetland condition in the 'Saltwater' and 'Brackish' environments. Lastly, the 'Brackish' environment was split from the 'Saltwater' environment using the NWI classification of estuarine or marine wetland (E2 or M2) to indicate 'Brackish'.

Wetlands of conservation concern

Conservation status ranking

Wetland ecosystems were ranked with respect to conservation status using a standard methodology developed by NatureServe and applied to ecosystems throughout the Americas (Faber-Langendoen et al. 2009, Master et al. 2012). Conservation status ranking assess the extirpation risk to a species or ecosystem at state and global levels. NatureServe's rank calculator (version 3.186) designates conservation status ranks by summing weighted values related to the geographic extent and factors related to area of occupancy, trends, and threats. Following preliminary ranking using the calculator, ranks were further evaluated through professional review and adjusted if deemed appropriate (Table 4). The resulting conservation status ranks range from 1 to 5 (1: critically imperiled, 2: imperiled, 3: vulnerable, 4: apparently secure - uncommon, 5: secure) and are preceded by a letter reflecting the geographic scale of the assessment (i.e., G = global, S = state). A range rank (e.g., S3S4) indicates uncertainty associated with the rank. This standardized, transparent, and repeatable ranking methodology produces credible assessments of status that are widely used in the conservation community and provide a valuable complement to legal status designations at federal and international levels. For the purposes of this project we considered wetland ecosystems with a state rank of S1-S4 to be of conservation concern.

Two levels of classification were used to describe wetland ecosystems of conservation concern: 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), whereas plant associations are the finest-level of vegetation classification and represent a community of definite floristic composition and uniform habitat (Flahault and Schroter 1910, Jennings et al. 2006). As plant associations lack a successional component, the concept differs from that of the biophysical setting such that plant associations may be used to describe stages within successional sequences, which are collectively represented by the biophysical setting. For brevity, we use the term 'ecosystem' or 'system' to include both biophysical settings and plant associations.

The wetland biophysical settings and plant associations of conservation concern 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 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 U.S. Department of Interior (USDI) National Park Service National Natural Landmarks Program (USDI 2009), USDI Bureau of Land Management Areas of Critical Environment Concern (USDI 2015), and U.S. Department of Agriculture Forest Service land and resource management plans (USDA 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 professionals with extensive experience in Alaska.

Distribution maps for rare wetland ecosystems were chiefly developed from our Alaska Land Cover Map (https://alaskaconservationscience.org/vegetation/). Where the land cover classes of the Alaska Land Cover Map were not informative to the distribution of a given biophysical setting or plant association, distribution maps were developed from alternate sources including: published descriptions of occurrences and extent, herbarium records of the component species, or geospatial datasets such as the Geologic Map of Alaska (Wilson et al. 2015), National Wetlands Inventory Maps (USDI 2015), glacial extent (GLIMS 2015), and ShoreZone coastline morphology (NOAA 2015).

Regional designations

Regional designations were assigned to rare wetland ecosystems in accordance with the boundaries of the Land Resource Regions of Alaska (Moore et al. 2004), which are intended to represent areas of broad regional climate conditions, patterns, and processes and as such, have good correlation with the natural floristic and hydrologic divisions of Alaska (Figure 6). Broad-ranging land cover types and wetland biophysical settings (i.e., those bridging more than one geographic region) with considerable regional variation in plant community composition were assigned regional designations. Land cover types and biophysical settings that are not modified by a regional designation can be assumed to have comparatively uniform floristics and to be restricted to a single geographic region. The Geothermal Spring and Mud Volcano biophysical settings are the only systems included here that occur across the state but have not received regional treatments since the microclimate and plant community composition are consistent among regions. Regional designations were also used to stratify the randomly selected verification plots used to assess the map accuracy; see following discussion for details. Generalized ranges and defining characteristics of these regions follow:

Arctic Alaska: This region has an arctic climate and includes the north slope of the Brooks Range, the western Brooks Range and the northern and western Seward Peninsula. The predominant vegetation is treeless arctic and alpine tundra dominated by low and dwarf scrub and herbaceous communities. The region is within the zone of continuous permafrost. Moore et al. (2004) refers to this area as Northern Alaska.

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 subarctic continental away from the coast and at higher elevations. The predominant vegetation is treeless arctic and alpine tundra dominated by low and dwarf scrub and herbaceous communities. The region is within the zone of discontinuous permafrost. Moore et al. (2004) refers to this area as Western Alaska.

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. Moore et al. (2004) refers to this area as Interior Alaska.

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* (Alaska cedar) present further south. Isolated pockets of permafrost occur in the northern part of the region. Moore et al. (2004) refers to this area as Southern Alaska.

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. Moore et al. (2004) refers to this area as Aleutian Alaska.

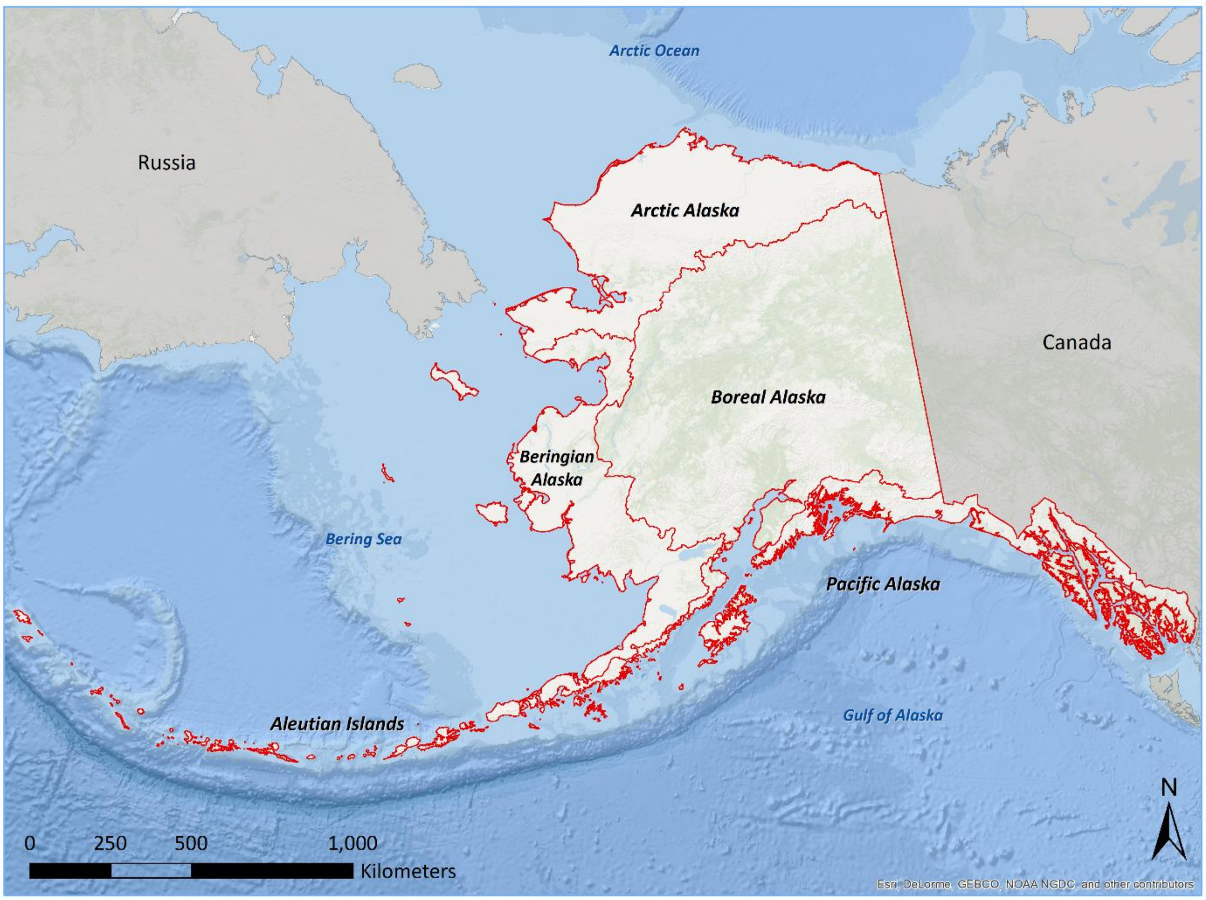

Figure 6. Regional designations based on Moore et al. (2004).

Accuracy Assessment

We assessed the accuracy of the statewide wetland map at the wetland system level using a set of verification points sourced NWI Status and Trend plot data, as well as stream gauge monitoring sites maintained by the National Water Information System (NWIS). In accordance with guidelines put forth by Thomlinson and others (1999) a total of 30 plots per system were selected for verification. An accuracy assessment of products derived from remotely-sensed imagery measures the correctness of a map and its accompanying classification (Foody 2002). To measure this 'correctness', verification points representing known types are overlain on a classified image and compared to the type attributed to the underlying pixel.

Selection of verification plots

The NWI maintains data for 2,250 status and trend plots placed randomly across Alaska. Wetland and deepwater types were mapped within these plots as part of a nationwide monitoring effort initiated in the early 1990s. For each 4 mi^2 plot, wetland and deepwater types were hand-delineated on mylar overlays using 1:60,000-scale, color-infrared aerial photography and USGS topographic maps for reference. A minimum mapping unit of 0.5 acre was adopted. The average date of photography was 1980 with 90 percent of the photos within three years of this date (Hall et al. 1994). Plots are georeferenced to a single point corresponding to their upper left-hand corner. Because this was the most defensible geospatial location, we used this point preferentially for verification data. However, to meet our requisite number of points per system, it was necessary to select 18 lacustrine occurrences from locations within the status and trends plot (i.e. not located at the upper left corner). The accurate geospatial location of these lacustrine points was confirmed through visual comparison with current remotely-sensed imagery and NHD coverages. For the status and trend mapping, the attribute 'OUT' was used for Upland and Marine systems. Thus, when the upper left-hand corner of a plot fell within a polygon that was attributed as 'OUT' and occurred in a location seaward of an estuarine wetland or obvious coastline the attribute of this point was revised to 'Marine'. Alternatively, when the upper left-hand corner was attributed as 'OUT' and occurred landward of an estuarine wetland or coastline, the point was revised to 'Upland'.

As the extent of riverine systems rarely satisfies the minimum mapping unit of 0.5 ac stipulated by the NWI, this system was intentionally omitted from status and trend plots in Alaska. To address the omission of riverine data, we supplemented the verification plot dataset with stream gauge locations from the National Water Information System (NWIS 2016). Stream gauge locations were selected for rivers of greater than 64 m in width as this width represents a feature of comparable scale to the minimum mapping area of 0.5 ac used for the status and trend plots (i.e., 64 m represents the hypotenuse of a square with area of 0.5 ac.). River width was measured orthogonal to the riverbank in a line that intersected the associated stream gauge location using the measurement tool in ArcGIS. A total of 30 of the 100 stream gauge location met the 64 m width requirement. Thus, all 30 of these riverine plots were advanced for use in the accuracy assessment.

The USFWS Alaska regional office maintains hard copies of all status and trend plots; 126 plots located exclusively in the Arctic and Beringian regions were available in digital format. As an initial selection, 60 points were randomly selected from the digital plots. Selection within this dataset continued until an approximately even distribution of points among wetland systems was achieved. Following the digitization of 184 'upper left-hand corner' geo-referenced points from the geospatial coordinates provided in hardcopy, 120 points were randomly selected from the Boreal, Pacific, and Aleutian Island regions until the 30 points per system (excluding riverine) requirement was satisfied for all of Alaska. A total of 180 verification plots, evenly distributed among deepwater, wetland, and upland systems (30 plots per system) were advanced for final accuracy assessment. These points were not evenly distributed among the ecoregions of Alaska (Table 1).

Table 1. Distribution of verification plots among ecoregions.

Region	Number of verification plots
Aleutian Islands	24
Boreal	44
Arctic	49
Pacific	24
Beringian	39
Total	180

We designed an ArcGIS tool to run the accuracy assessment and tabulate the results in a standard-format error matrix. The pre-programmed 'extract values to points' tool was used to compare the values between the verification points and their spatially-coincident pixels, where values represent system membership. The total number of intersections per possible combination of validation points and raster pixels was output as a table in standard error matrix format where unique values of the reference field comprised the column headers and the unique values of the raster field comprised the row headers.

Various measures of accuracy can be calculated from the error matrix. In addition to estimates of overall accuracy, an error matrix provides insight to the reliability of an individual map class and awareness of where confusion among classes may occur (Foody 2002). Overall accuracy measures the percent of correctly-classified plots relative the total number of verification plots. Producer's accuracy (also known as errors of omission) indicates how well the verification set of plots of the given cover type are classified. Producer's accuracy is calculated as the percent of correctly classified verification points with regard to all verification plots classified as that wetland system. Consumer's accuracy (also known as errors of commission) can be thought of as the likelihood that a pixel claiming to be a system truly represents that system. Consumer's accuracy is calculated as the percentage of correctly classified pixels with regard to all pixels classified as that system in the wetland map (Congalton and Green 2009, Lillesand et al. 2008). Errors of commission as applied to wetland mapping may include: 1) misclassification (e.g., non-wetland areas mapped as wetlands or misidentification of the wetland type), 2) small uplands included within a large wetland mapping unit, and 3) small wetlands of different type included within a larger wetland unit of another type (e.g., a small scrub-shrub wetland within a palustrine forested wetland mapping unit) simply because they are too small to map (below the target mapping unit). The latter two situations are commonly referred to as 'inclusions'. Habitat changes that have occurred between the date of the base imagery and date of field observation/ground-truthing are not considered errors as the wetland was correctly classified on the base imagery (FGDC 2013).

Kappa statistic

It is important to note that even in a randomly attributed set of verification plots, some plots will agree with the classification of the coincident pixel by chance (Turk 1979, Rosenfield and Fitzpatrick-Lins 1986, Congalton 1991, Pontius 2000). For this reason, the kappa statistic, which accounts for such chance agreement is considered a more robust measure of accuracy (Smits et al. 1999). Specifically, the kappa statistic measures the difference in actual agreement between verification plots and a systematically classified image and chance agreement between the same verification plots and a randomly classified image. Kappa statistic values range from 0 to 1 where 1 indicates perfect agreement after the probability of chance agreement has been removed. The calculation can be conceptualized as follows and is detailed by Lillesand and others (2008):

$$k = \frac{observed\ accuracy - chance\ agreement}{1 - chance\ agreement}$$

Data portal development

Both the Alaska Wetlands Map and Alaska Land Cover Map are available through an online, publicly-accessible data portal (www.accs.uaa.alaska.edu). Here, users can explore the distributions of wetland and upland habitats and distributions of mapped rare ecosystems through an intuitive interface or download the raster mosaic for use in a personal GIS. Metadata compliant with Federal Geographic Data Committee (FGDC) standards are embedded within all geospatial downloads. Wetland type color display follows the scheme of the National Wetlands Inventory mapper (USDI 2018).

Results

Wetland types and distribution

Our results confirm that Alaska is a wetland-rich state where 22% of the total terrestrial area is occupied by either freshwater wetland or deepwater habitat (Table 2). The following area summaries do not include Estuarine and Marine Deepwater, as this generalized category was delineated with an arbitrary buffer of 10 km offshore and therefore complicates comparisons with previously-completed wetland maps for terrestrial Alaska. Within terrestrial Alaska, the palustrine system, represented by freshwater forested/shrub, freshwater emergent, and freshwater bryophyte wetlands occupies 17.2 % of the total area and is the dominant wetland type. Collectively, deepwater habitat, represented by lakes, ponds and rivers occupies 4.3% of terrestrial Alaska. The distribution of generalized wetland types is shown in Figure 7.

Table 2. Summary of the Alaska Wetlands Map by areas of generalized wetland types. Note the Estuarine and Marine Deepwater generalized type is excluded from this summary.

Generalized Wetland Types	Area acres	Area hectares	Area percent
Upland	292,061,446	118,193,062	77.9
Freshwater Forested/Shrub Wetland	34,126,723	13,810,593	9.1
Freshwater Emergent Wetland	29,505,383	11,940,404	7.9
Lake	9,639,619	3,901,015	2.6
Riverine	4,679,753	1,893,829	1.2
Estuarine and Marine Wetland	1,915,959	775,361	0.5
Freshwater Pond	1,826,154	739,018	0.5
Freshwater Bryophyte	977,716	395,668	0.3
Total	374,732,753	151,648,949	100

Figure 7. Alaska Wetlands Map depicting eight wetland/deepwater classes and one upland class.

Table 3. Generalized wetland type presented by percent area of ecoregion

Generalized Wetland Type	Pacific Ecoregion	Beringian Ecoregion	Interior Ecoregion	Arctic Ecoregion
Estuarine and Marine Wetland	1.6	1.1	0.1	0.3
Freshwater Bryophyte	<0.1	0.7	0.3	<0.1
Freshwater Emergent Wetland	3.6	12.5	1.4	21.9
Freshwater Forested/Shrub Wetland	8.4	7.0	8.5	12.4
Freshwater Pond	0.3	1.2	0.3	0.5
Lake	1.3	7.7	0.9	3.4
Riverine	0.7	1.7	1.0	1.7
Upland	84.0	68.1	87.5	59.7
Total	100	100	100	100

When parsed by ecoregion the Pacific and Interior ecoregions are dominated by freshwater and forested/shrub wetlands, the Beringian Ecoregion is dominated by freshwater emergent wetlands, and the Arctic Ecoregion is dominated by freshwater emergent wetlands (Table 4).

Accuracy Assessment of Alaska Wetlands map

The overall accuracy of the Alaska Wetlands Map was assessed at 69%. Producer's accuracy ranged from 23-90% by system with the lowest and highest accuracy in the Estuarine and Lacustrine systems, respectively. Errors of commission (Consumer's accuracy) correspond to the non-diagonal row values, where per-class accuracy ranged from 50-93% with the Marine system representing the least reliably mapped system and the Riverine system representing the most reliably mapped system. The low accuracy of the Estuarine and Marine classes, substantially affecting the overall map accuracy. When these two classes are removed from the assessment, overall map accuracy jumps up to 80%. The kappa statistic is calculated as 0.64, which indicates substantial agreement (Landis and Koch 1977).

Table 4. Categories of accuracy in the Alaska Wetlands Map.

		Verification Plots						Consumer's Accuracy
		Estuarine	Lacustrine	Marine	Palustrine	Riverine	Upland	
	Estuarine	7		5				58%
	Lacustrine		27		2	1		90%
	Marine	20		22			2	50%
	Palustrine		1	1	17	2	2	74%
Classified Pixels	Riverine	2				26		93%
	Upland	1	2	2	11	1	26	60%
Producer's Accuracy		23%	90%	73%	57%	87%	87%	**Overall accuracy = 69%**

Wetland reference plots that were classified into the proper wetland system are shown along the major diagonal of the error matrix. All non-diagonal elements of the matrix represent errors of omission or commission. Omission errors corresponds to non-diagonal column elements. For example, three plots (2 + 1 in the second column) that should have been classified as Lacustrine were omitted from that classification. Commission errors correspond to non-diagonal elements row elements. For example, 5 pixels were erroneously classified as Estuarine when they were in fact Marine habitat.

The error matrix highlights two areas of confusion between marine and estuarine habitat, as well as between palustrine and upland habitat. 20 plots of Estuarine habitat were misclassified as Marine habitat and five plots of Marine habitat were misclassified as Estuarine Habitat. Similarly, 11 plots of Palustrine habitat were improperly included in the Upland category. However, Upland habitat was much less frequently misclassified as Marine or Palustrine.

Wetlands of conservation concern

Fifteen wetland ecosystems of conservation concern (S1-S4) were identified and distribution maps were developed for 14 of the 15 rare wetland ecosystems. Due to the paucity of geospatial information, we were not able to generate a distribution map for the *Pohlia wahlenbergii–Philonotis fontana* Seep Plant Association. Cumulatively, the mapped rare wetland ecosystems of conservation concern occupy a total area of 21, 866 km^2, with the *Callitropsis nootkatensis* Wetland and Beringian Tidal Marsh Biophysical Settings representing the largest areas of occupancy. The Mud Volcano and Karst Fen Biophysical Settings representing the smallest areas of occupancy (Table 5).

Table 5. Biophysical settings and plant associations presented in order of decreasing conservation status rank. Conservation Rank S1 = Critically Imperiled, S2 = Imperiled, S3 = Rare, S4 = Apparently Secure but Uncommon.

Rare Wetland Ecosystem	Area (hectares)	Conservation Rank
Karst Fen BpS	20	S2
Arctic Tidal Marsh BpS	115,600	S3
Larix laricina (tamarack) Wetland BpS	3,520	S3
Pacific Uplifted Tidal Marsh BpS	55,440	S3
Picea sitchensis (Sitka spruce) Floodplain Old-growth Forest BpS	46,700	S3
Pohlia wahlenbergii–Philonotis fontana Seep PA	NA	S3S4
Arctic Barrier Island and Spit BpS	19,040	S4
Beringian Barrier Island and Spit BpS	11,860	S4
Beringian Tidal Marsh BpS	389,800	S4
Callitropsis nootkatensis (yellow cedar) Wetland BpS	1,267,600	S4
Geothermal Spring BpS	10,290	S4
Mud Volcano BpS	470	S4
Pacific Barrier Island and Spit BpS	17,820	S4
Pacific Tidal Marsh BpS	300,700	S4
Picea glauca (white spruce) Floodplain Old-growth Forest	35,100	S4

BpS		

The Karst Fen Biophysical Setting was identified as the only imperiled (S2) wetland system in Alaska. This conservation status was down ranked from a calculated value of S1, as we believe this system to be under-surveyed. Four wetland ecosystems are designated as vulnerable (S3) and nine systems are designated as secure (S4). Due to uncertainty regarding the number of occurrences and area of occupancy for the *Pohlia wahlenbergii–Philonotis fontana* Seep Plant Association, a range rank of S3S4 was assigned. Full descriptions of each rare wetland ecosystem are provided as Appendix 1. These descriptions and their accompanying distribution shapefile may also be downloaded from the Alaska Center for Conservation Science.

Data portal development/outreach

The Alaska Wetlands Map and Alaska Land Cover Map are available through an online, publicly-accessible data portal (www.accs.uaa.alaska.edu). Here users can explore the distributions of wetland and upland habitats and distributions of mapped rare ecosystems through an intuitive interface or download the raster mosaic for use in a personal GIS. Metadata compliant with Federal Geographic Data Committee (FGDC) standards are embedded within all geospatial downloads. Wetland type color display follows the scheme of the National Wetlands Inventory mapper (USDI 2018).

Following launch of the data portal, potentially interested parties will be notified and invited to comment on the content and user interface. ACCS presented these results at the Society of Wetland Scientists International conference in Denver, Colorado in 2018 and will circulate information to representatives of federal, state, tribal and local agencies, industry groups and private consulting firms. Consulting firms to be included are those involved in the delineation of jurisdictional wetlands (i.e. 'consultant list' available on the Corps of Engineers Alaska District website), as well as members of the Alaska Chapter of the Society of Wetland Scientists and other relevant organizations.

Discussion

Comparison to previous wetland mapping efforts in Alaska

We estimate that 22% of terrestrial Alaska is either wetland or deepwater habitat and the remaining 78% of the state is upland habitat. These results are highly comparable to Whitcomb et al's. (2009) previous statewide wetland mapping effort of 26%, but substantially less than Hall et al's. 43% (1994). Because land cover classes that could be interpreted as either wetland or upland or represented a mosaic of wetland and upland types were given a default classification of upland, the resulting map is a conservative extent of wetlands in Alaska and contrasts with Hall et al. (1994).

Similar to Hall et al. (1994) and Whitcomb et al. (2009), we found that the majority of terrestrial wetlands are represented by the palustrine emergent type and most of these wetlands occur in the Arctic region. Much of the Arctic ecoregion in Alaska has low topographic relief (i.e., the Arctic Coastal Plain) and is underlain with permafrost, inhibiting drainage and promoting extensive wetland development (Hall et al. 1994). Other notable areas of wetland concentrations occur in the extensive low relief Beringian ecoregion that includes the Yukon-Kuskokwim Delta, the Bristol Bay Lowlands, and fringing Kotzebue Sound. High densities of wetlands are also found in the Tanana-Kuskokwim Lowlands, Yukon Lowlands, Yukon-Old Crow Basin, and Copper River Basin. Freshwater Emergent Wetlands are common in the Alexander Archipelago on flat to moderate slopes. Areas in the state with low occurrence of wetlands correspond with mountain ranges and areas of high topographic complexity as expected. However, small and isolated wetlands are mapped in periglacial mountainous terrains.

Map accuracy

The four measures of accuracy provided for the Alaska Wetlands Map (i.e. overall, kappa statistic, consumers, and producers error) indicate fair accuracy; however, the use of the error matrix in accuracy assessment applications is based on a number of important assumptions. It is assumed that each pixel can be allocated to a single class in both the ground and map data sets, and that these two data sets have the same spatial resolution and are perfectly registered (Stralher et al 2006). All of these assumptions are often not satisfied in remote sensed data. In some instances, deviation from the assumed condition is relatively unimportant (e.g., if testing pixels are drawn from very large homogenous regions of the classes then the impact of mis-registration of the data sets is unlikely to have a major impact on accuracy assessment), but in other situations deviation from the assumed condition may lead to significant error and misinterpretation (e.g., if the land cover mosaic is very fragmented and mixed pixels are common). For these reasons we expect accuracy to be reduced in areas of the map that attempt to capture features less than 30 m in maximum dimension such as small ponds, narrow streams, ribbons of upland, and upland-wetland complexes. Producer's (omission) errors are wetlands that are not identified on the map, i.e., points that should have been classified as a certain wetland system but were omitted from that system. Omission of wetland pixels may be due to several factors inhibiting their identification or correct delineation. The scale and emulsion of imagery, mapping scale or base map scale, quality of imagery, environmental conditions when imagery was captured, and difficulty of identifying particular types of wetlands may all contribute to omission errors (FGDC 2013).

Having more NWI validation points would add to the validity of the error matrix, as a minimum of 50 validation points has been suggested as an alternative minimum (Lillesand et al. 2008). Higher numbers of validation points would have been possible for some NWI systems but not others due to lack of mapping for specific wetland types (Marine, Riverine), so to keep our reference data set consistent we sampled 30 points from each ecoregion. Another recognized issue with our accuracy assessment is confusion between the Marine and Estuarine systems within the validation points. In accordance with NWI guidance, the boundary between wetland and deepwater habitat in the Marine and Estuarine systems coincides with the elevation of the extreme low water of spring tide; with the boundary between Marine and Estuarine systems based on a salinity level of 30%. As these criteria are temporal and chemical they are difficult to delineate on remotely sensed imagery. It is likely that both the Status and Trend data and our mapping failed to accurately locate the boundary between coastal wetland and deepwater as well as marine and estuarine habitat. Based on the errors of commission for the Estuarine plots, we clearly misapplied 'Marine' to reference plots located in estuarine habitat. This misattribution is the main source of inaccuracy within the map. When Marine and Estuarine systems are excluded from the assessment, accuracy increases to 80%.

Potential Map Errors and Future Sampling

Future assessments of accuracy could weigh the number of validation plots in accordance to the relative areas of wetland types. Most of the terrestrial wetlands are mapped as Palustrine; therefore more Palustrine reference points should be ground-truthed and part of the reference data set. Also, sampling could be divided up with respect to the variability within each category, for example more sampling in Palustrine and less in Riverine habitats. Additional problem areas for field verification include: 1.) coastline areas not mapped by NWI, 2.) known areas of edge conflicts on existing land cover mapping, 3.) small wetland and deepwater features, and 4.) known mapping errors in the source maps.

Map use and limitations

The wetland map presented here uses the best available land cover data as a proxy for wetland habitat. All work was conducted in a GIS environment and the habitat types and distributions have not been field checked, ground-truthed for accuracy, or post-processed. As such, this map is best used for the coarse-level analysis of habitat and identification of data gaps at the landscape scale (Figure 9).

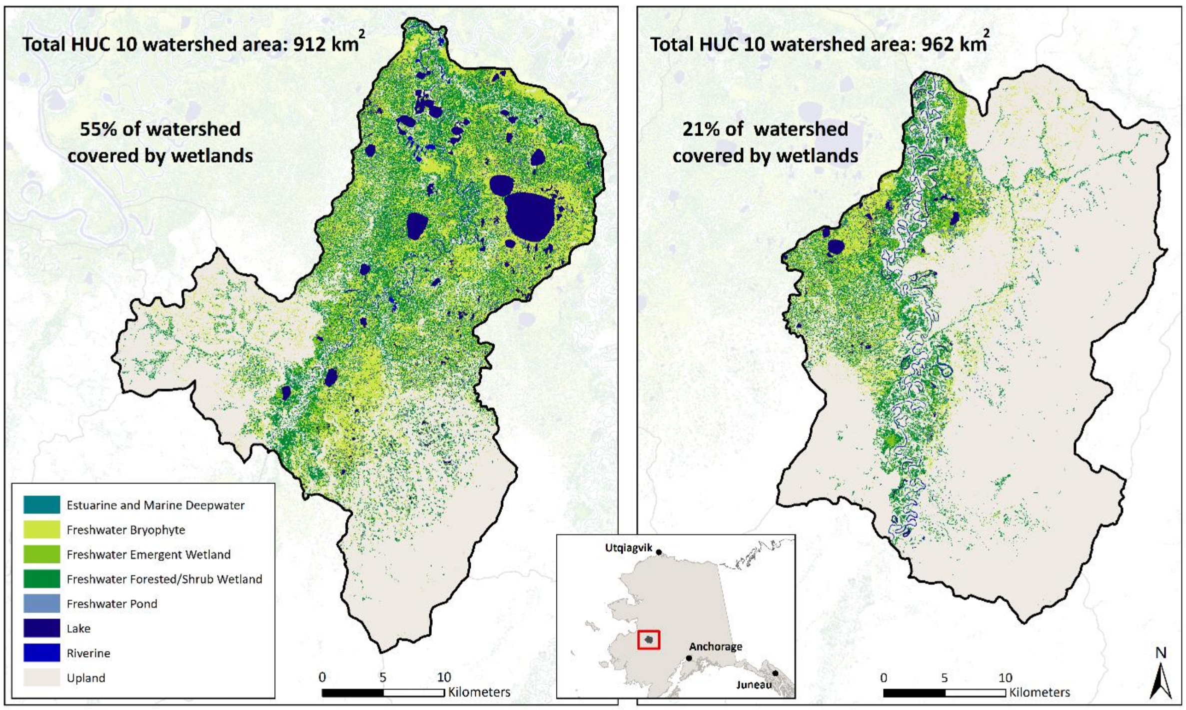

Figure 8. Example of two adjacent watersheds (Yentna and Iditarod rivers, left and right panels, respectively) illustrating an appropriate scale for use of the Alaska wetland map.

While wetland codes follow the National Wetland Classification scheme (Cowardin et al. 1979, Dahl et al. 2009) they do not meet the minimum national standards established for the National Wetlands data layer (FGDC 2013). Where available, NWI coverage should take precedence (Figure 9). While the scale of the Alaska Wetlands Map provides greater resolution than previous statewide efforts (Whitcomb et al. 2009), it fails to detect features less than 30 m in dimension such as small ponds, streams, and upland inclusions (Figure 10).

Layers recommended for use with the Alaska Wetlands Map are 1.) the land resource regions developed by the Natural Resource Conservation Service (NRCS), which are analogous to ecoregions and nest within the Major Land Resource Regions for Alaska that are proposed for stratification of accuracy assessment plots (USDA 2006); 2.) Permafrost Characteristics of Alaska (Jorgenson et al. 2008); and 3.) The Alaska Landscape Condition Model recently developed by ACCS for the Crucial Habitat Assessment Tool (CHAT). These layers represent the best available data for the landscape character mapped.

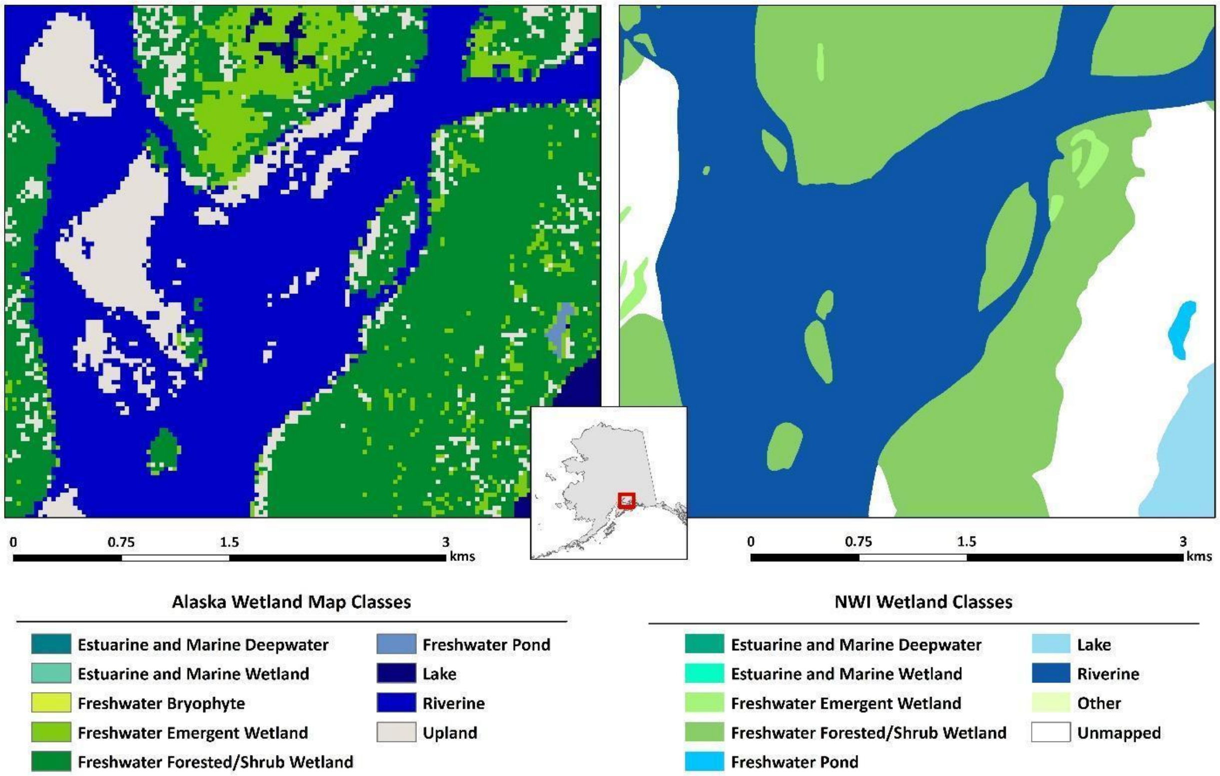

Figure 9. Alaska Wetlands Map classification (left) compared to National Wetlands Inventory (right).

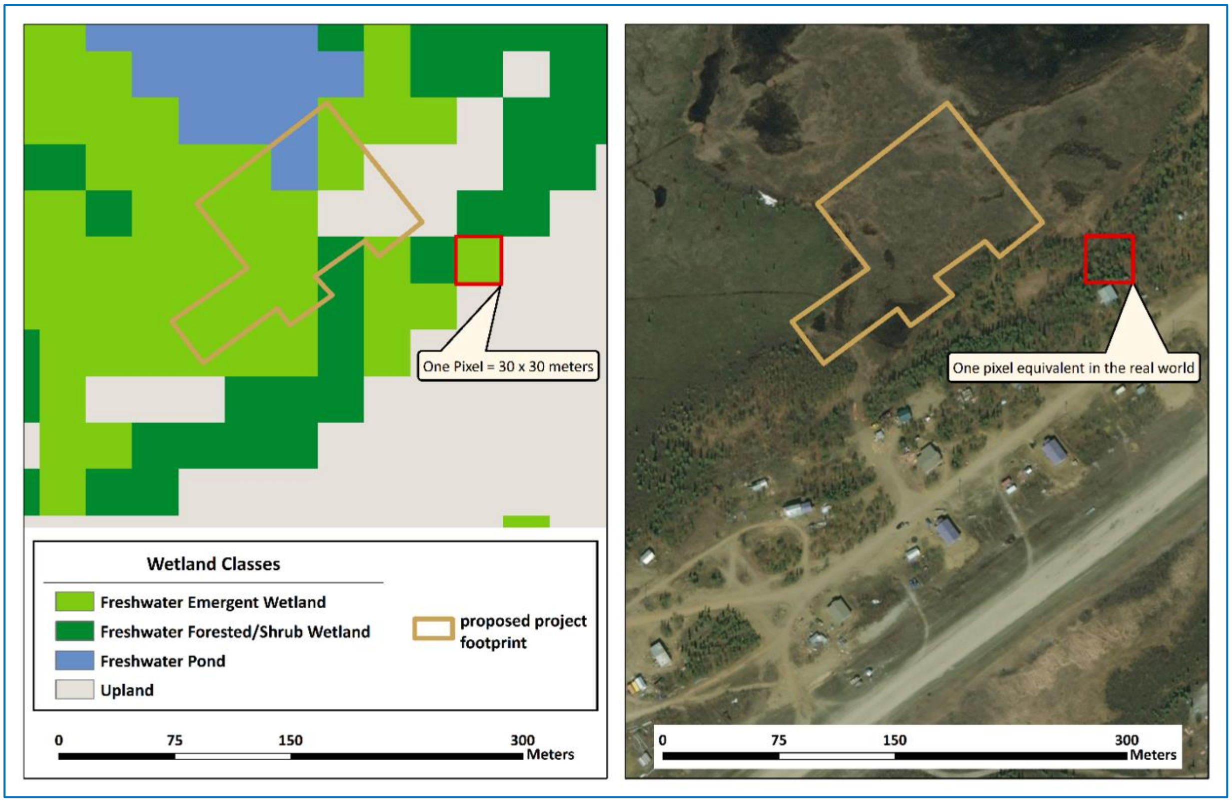

Figure 10. Figure illustrating an inappropriate scale for use of the Alaska wetland map. The 30 meter pixel size of the Alaska Wetlands Map does not work well for fine-scale work, note coarse pixilation of wetland boundaries on left side of figure.

Status of wetlands of conservation concern

Rare wetland types in Alaska are overwhelmingly represented by nutrient-rich systems that are infused by tidal or mineral-enriched ground-water. Examples of these wetlands in Alaska are tidal marshes and karst fens. Mineral rich groundwater supply is an important indicator of plant diversity in other wetland complexes across the U.S. Fens are among the most floristically diverse of all wetland types, supporting a large number of uncommon bryophytes and vascular plant species (Bedford and Godwin 2003), including areas of the glaciated Midwest and Northeast U.S. and portions of the Appalachian Mountains and mountainous West.

The disproportionately low number of truly rare or threatened systems is likely owed to the state's small anthropogenic footprint (see Trammell et al. 2014). For these reasons, many of the state's rare ecosystems are not under direct threats from development or other activities. However, in the context of a rapidly changing climate, which is particularly acute at high latitudes (ACIA 2004, USGCRP 2018), a number of systems described here may be at heightened risk. Coastal sea level rise will affect Arctic tidal marshes, changing the composition of inland flora as salt-tolerant species migrate up gradient. Unfortunately, current international mandates for biological diversity are insufficient in scope and future agreements are slow to form (Noss et al. 2012).

Recommendations for field study

During our literature review the following systems (Table 6) were identified as candidate wetlands of conservation concern. Due to a paucity of literature and/or geospatial information we were unable to determine their conservation status. Thus, further research and field visits to know sites are recommended.

Table 6. Candidate wetland ecosystems of conservation concern.

Ecosystem	Region
Arsenic springs	Statewide
Calcareous fens	Boreal
Carex kelloggii-Sphagnum species plant association in sedge-moss bogs	Beringian, Arctic
Domed bogs	Southern
Eelgrass communities	Statewide
Plant associations dominated or co-dominated by *Carex limosa*	Statewide
Sloped fens in Prince William Sound	Pacific

Summary

The map presented here is the first to map wetlands in accordance with the national wetland classification system at a medium-scale resolution for all of Alaska. Similarly, the description, ranking, and mapping of wetlands of conservation concern represents the first comprehensive treatment of rare wetland systems in Alaska. These complementary products are expected to promote the understanding of wetland type and distribution, facilitate coordination among organizations and agencies involved with wetland issues, and provide a basis for wetland research and modeling. An integrated mapping approach was used to create the Circumarctic Vegetation Mapping (CAVM) project (Walker 1999) using multiple source maps to inform a new vegetation map; the Alaska Wetlands Map could be a source map, used for comprehensive mapping efforts such as the CAVM, it could also be used for predictive modeling as a presence or absence of wetlands layer. Specifically, the mapping provided here gives a uniform and comprehensive inventory of both common and rare types, from which reference condition may be assessed, future condition may be modeled, and status and trend may be monitored.

Additionally, we envision this statewide map facilitating coordination among organizations and agencies involved with wetland conservation. Greater knowledge of the wetland systems of Alaska should streamline monitoring and assessment of a critical Alaska natural resource, allowing more efficient collaboration among organizations and agencies involved with wetland management. The Environmental Protection Agency recently approved the Alaska Wetland Program Plan (DEC 2015) and the State of Alaska intends to implement this plan to meet the broader goal of wetland protection and restoration work being addressed in a more strategic way. Broadly, the wetland map will provide science-based information that can serve as baseline environmental data for the Wetlands Protection Plan. The map also provides criteria for assessing wetland condition and ranking. Identification of those wetland systems that are of conservation concern is instrumental in further prioritization of areas where wetland monitoring and assessment would be implemented as part of the Wetlands Protection Plan.

The Alaska Wetlands Map increases capacity for spatial assessments of direct and indirect impacts of climate change and anthropogenic disturbance on wetlands. This product allows natural resource managers to identify wetlands susceptible to anthropogenic and natural impacts, to prioritize wetlands for conservation, as well as to track wetland gains and losses at the landscape scale.

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Appendix 1: Wetland Type Descriptions

Estuarine and Marine Deepwater

In concept the estuarine and marine deepwater generalized type includes all lands permanently flooded by tidal water, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are rooted in, or attached to, the substrate (Figure 11). The estuarine deepwater type consists of tidal habitats that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. The salinity may be periodically increased above that of the open ocean by evaporation. Along some low-energy coastlines there is appreciable dilution of sea water. This habitat is exposed to the waves and currents of the open ocean and water regimes are determined primarily by the ebb and flow of oceanic tides. Salinities exceed 30 ppt, with little or no dilution except outside the mouths of estuaries. Shallow coastal indentations or bays without appreciable freshwater inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the marine system because they generally support typical marine biota.

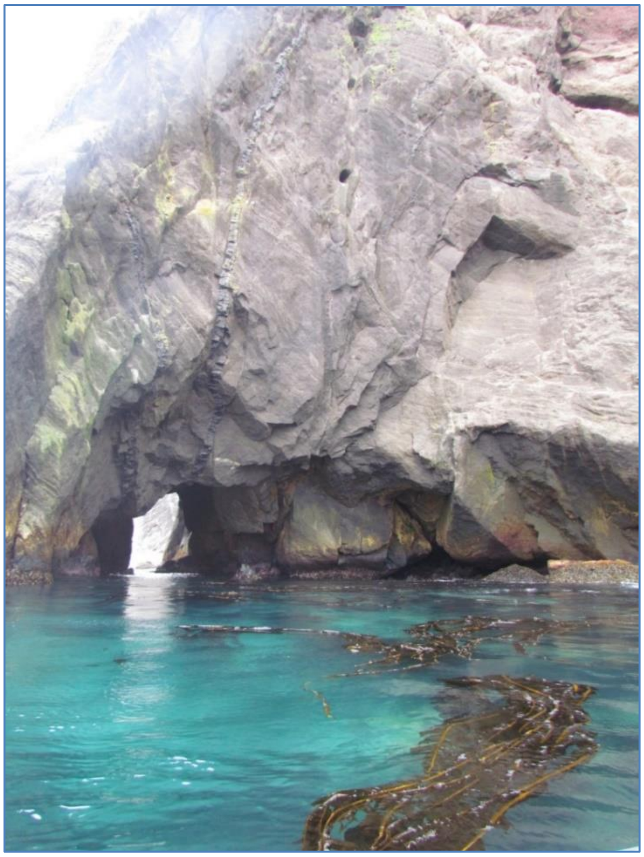

Figure 11. Floating kelp forest in the Aleutian Islands (photo by Angela Dorhoff).

Marine deepwater (M1) habitat consists of the open ocean overlying the continental shelf specifically marine subtidal areas continuously covered with saltwater, i.e. located below extreme low water. Salinities exceed 30 parts per thousand (ppt). The only water regime this designation includes is Subtidal.

Estuarine deepwater habitat (E1) are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, with ocean-derived water being diluted by freshwater from the land. The seaward limit of estuarine subtidal is defined by (1) an imaginary line closing the mouth of a river, bay or sound. Subtidal estuarine habitat includes offshore areas of continuously diluted sea water. The only water regime this designation includes is Subtidal. For more information, please consult our wetlands map user guide: https://alaskaconservationscience.org/vegetation/.

Note: The spatial distribution of wetland and deepwater habitat produced by ACCS are objective extrapolations of credible data. These distributions are intended to inform users of wetland types at a landscape scale, to guide future surveys, and to test hypotheses regarding habitat quality and abundance. These products are not intended to substitute for field-collected data, nor are they intended to be the sole basis for natural resource management decisions. Wetland mapping presented in this portal does not constitute a jurisdictional determination of wetland boundary, a more accurate wetland boundary must be determined by on the ground field survey. This note applies to all wetland and deepwater types shown in the Alaska Wetlands Map. For more information, please consult our wetlands map user guide: https://alaskaconservationscience.org/vegetation/.

Estuarine and Marine Wetland

In concept the estuarine and marine generalized wetland types are flooded and exposed by tides; both types include the associated splash zone. The boundary between wetlands and deepwater habitats in the Marine and Estuarine Systems coincides with the elevation of the extreme low water of spring tide. Those areas above the extreme low water of a spring tide are considered either marine or estuarine wetlands. Estuarine wetlands consist of tidal wetlands (Figure 12) that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land.

Figure 12. Tidal mudflats at Hartney Bay near Cordova, Alaska, an example of an estuarine wetland.

The salinity may be periodically increased above that of the open ocean by evaporation. Along some low-energy coastlines there is appreciable dilution of sea water. Different from estuarine wetlands, marine wetlands are found along the high-energy ocean coastline (). These habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinities exceed 30 ppt, with little or no dilution except outside the mouths of estuaries. Shallow coastal indentations or bays without appreciable freshwater inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the marine system because they generally support typical marine biota. Water regimes include Subtidal. For more information, please consult our wetlands map user guide: https://alaskaconservationscience.org/vegetation/.

Figure 13. Marine wetland area at low tide near Sitka, Alaska.

Freshwater Bryophyte

In concept this type includes freshwater wetlands dominated by moss or lichen (Figure 14). These wetlands are further defined as areas where mosses or lichens cover at least 30 percent of substrates other than rock and where emergents, shrubs, or trees alone or in combination cover less than 30 percent. Water regimes include Seasonally Flooded, Seasonally Flooded-Saturated, Continuously Saturated and Seasonally Saturated. For more information, please consult our wetlands map user guide: https://alaskaconservationscience.org/vegetation/.

Figure 14. Sphagnum-dominated peatland in Southeast Alaska.

Freshwater Emergent

In concept this type includes all freshwater wetlands dominated by persistent emergent plants as well as all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. Here, vegetation is usually dominated by perennial, emergent plants (i.e. erect, rooted, herbaceous hydrophytes) are the tallest life form with at least 30 percent areal coverage (Figure 15). This vegetation is present for most of the growing season in most years. All water regimes are included except Subtidal and Irregularly Exposed.

Figure 15. Freshwater emergent wetland in the Cook Inlet Basin, Southcentral Alaska.

Freshwater Forested/Shrub Wetland

In concept this generalized type includes all freshwater wetlands dominated by trees or shrubs as well as all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt. In shrub wetlands, woody plants less than 6 m (20 ft) tall are the dominant life form (i.e. the tallest life form with at least 30 percent areal coverage). The 'shrub' life form includes true shrubs, young specimens of tree species that have not yet reached 6 m in height, and woody plants (including tree species) that are stunted because of adverse environmental conditions. All water regimes except Subtidal and Regularly Flooded-Tidal Fresh are included. Not all Water Regimes apply to all subclasses. In forested wetlands, trees are the dominant life form (i.e. the tallest life form with at least 30 percent areal coverage) (Figure 16). The 'tree' life form is defined as woody plants at least 6 m (20 ft) in height. All water regimes except Subtidal and Regularly Flooded-Tidal Fresh are included. For more information, please consult our wetlands map user guide: https://alaskaconservationscience.org/vegetation/.

Figure 16. Mixed conifer forested wetland including *Callitropsis nootkatensis* and with *Lysichiton americanus* in the understory in Glacier Bay National Park and Preserve, Alaska.

Freshwater Pond

In concept this generalized type includes small, shallow, permanent, or intermittent freshwater bodies, which occupy less than 8 ha (20 ac) and where salinity due to ocean-derived salts is below 0.5 ppt (Figure 17). Substrates may be rock or unconsolidated bottom, aquatic bed or unconsolidated shore. For the purposes of mapping, the Freshwater Pond type was delineated in accordance with the current National Hydrologic Dataset data. For more details see the final report at https://alaskaconservationscience.org/vegetation/.

Figure 17. Pond lily (*Nuphar lutea*) dominated pond in Kenai Fjords, Alaska.

Lake

In concept this generalized type includes wetlands and deepwater habitats satisfying all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with 30 percent or greater areal coverage; and (3) total area of at least 8 ha (20 ac) (Figure 18). For the purposes of mapping, the Lake type was delineated in accordance with the current National Hydrologic Dataset data. For more details see the final report at https://alaskaconservationscience.org/vegetation/.

Figure 18. Lake habitat in Southcentral, Alaska (Stormy Lake – photo source ACCS).

Note: The spatial distribution of wetland and deepwater habitat produced by ACCS are objective extrapolations of credible data. These distributions are intended to inform users of wetland types at a landscape scale, to guide future surveys, and to test hypotheses regarding habitat quality and abundance. These products are not intended to substitute for field-collected data, nor are they intended to be the sole basis for natural resource management decisions. Wetland mapping presented in this portal does not constitute a jurisdictional determination of wetland boundary, a more accurate wetland boundary must be determined by on the ground field survey.

Riverine

In concept this generalized type includes all wetlands and deepwater habitats contained within a channel (**Error! Reference source not found.**with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts of 0.5 ppt or greater. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water". For the purposes of mapping, the Riverine type was delineated in accordance with the current National Hydrologic Dataset data. For more details see the final report at https://alaskaconservationscience.org/vegetation/.

Figure 19. Small patches of white spruce (*Picea glauca*) forests on floodplains of the Yukon River in Yukon-Charley Rivers National Preserve, Alaska.

Upland

This is a default classification for regions of the map that are not classified as wetlands or other aquatic habitats. As such, the designation "Upland" represents generalized terrestrial areas which have not been further subdivided or categorized by type. While "Upland" primarily includes terrestrial (non-wetland) areas (Figure 20) and former wetlands that are effectively drained or filled, it may include unclassified

Figure 20. Paper birch-quaking aspen forest found in the Interior region of Alaska.

wetlands such as human-modified areas (e.g., farmed wetlands), wetlands that are too small to be differentiated, wetlands that couldn't be detected on the type of imagery used (e.g., small wetlands under forest cover), and other unintentional wetland omissions (errors). This designation is given to any pixel that does not meet the criteria of a wetland or deepwater habitat.

The upland limit of wetland is designated as (1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; (2) the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or (3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not. For more information, please consult our wetlands map user guide: https://alaskaconservationscience.org/vegetation/.

Note: The spatial distribution of wetland and deepwater habitat produced by ACCS are objective extrapolations of credible data. These distributions are intended to inform users of wetland types at a landscape scale, to guide future surveys, and to test hypotheses regarding habitat quality and abundance. These products are not intended to substitute for field-collected data, nor are they intended to be the sole basis for natural resource management decisions. Wetland mapping presented in this portal does not constitute a jurisdictional determination of wetland boundary, a more accurate wetland boundary must be determined by on the ground field survey.

Appendix 2: Coarse Land Cover Types for each Alaska Wetland Map System Classification

System Classification	Coarse Land Cover Types for each System that comprise at least 5% of the system
Estuarine and Marine Deepwater	Freshwater or Saltwater; Saltwater
Estuarine and Marine Wetland	Bareground; Freshwater or Saltwater; Herbaceous (Wet-Marsh) (Tidal)
Freshwater Bryophyte	Herbaceous (Wet) (Interior Alaska, Cook Inlet Basin); Herbaceous (Wet) (Northern and Western Alaska); Moss
Freshwater Emergent Wetland	Herbaceous (Marsh) (Northern and Western Alaska); Herbaceous (Wet) (Interior Alaska, Cook Inlet Basin); Herbaceous (Wet) (Northern and Western Alaska); Tussock Tundra (Low shrub or Herbaceous)
Freshwater Forested/Shrub Wetland	Low Shrub; Tussock Tundra (Low shrub or Herbaceous); Needleleaf Forest (Woodland-Open) (Peatland) (Southern Alaska)
Freshwater Pond	Freshwater or Saltwater
Lake	Freshwater or Saltwater
Riverine	Bareground; Freshwater or Saltwater; Sparse Vegetation (Northern and Western Alaska)

Upland	Algal Bed (Tidal-Subtidal) (Southern Alaska) Bareground Bareground (Beach or Tide Flat) (Southern Alaska) Deciduous Forest (Open-Closed) Deciduous Forest (Open-Closed) (Seasonally Flooded) (Southern Alaska) Deciduous Forest (Woodland-Closed) (Southern Alaska) Dwarf Shrub Dwarf Shrub-Lichen Dwarf Shrub (Southern Alaska) Dwarf Shrub or Dwarf Shrub-Lichen Dwarf Shrub, or Herbaceous (Mesic) (Southern Alaska) Fire Scar Freshwater or Saltwater Hemlock-Sitka Spruce (Woodland-Closed) Hemlock (Woodland-Closed) Herbaceous (Aquatic) Herbaceous (Aquatic) (Southern Alaska) Herbaceous (Marsh) (Interior Alaska, Cook Inlet Basin) Herbaceous (Marsh) (Northern and Western Alaska) Herbaceous (Mesic) Herbaceous (Mesic) (Interior Alaska, Cook Inlet Basin) Herbaceous (Mesic) (Northern and Western Alaska) Herbaceous (Mesic) (Northern and Western Alaska) or Tussock Tundr (Herbaceous) Herbaceous (Mesic) (Southern Alaska) Herbaceous (Peatland) (Southern Alaska) Herbaceous (Tidal) (Southern Alaska) Herbaceous (Wet-Marsh) (Southern Alaska) Herbaceous (Wet-Marsh) (Tidal)
Upland	

Upland	Herbaceous (Wet) (Interior Alaska, Cook Inlet Basin) Herbaceous (Wet) (Northern and Western Alaska) Ice-Snow Lichen Low-Tall Shrub (Southern Alaska) Low Shrub Low Shrub (Peatland) (Southern Alaska) Low Shrub (Tidal) (Southern Alaska) Low Shrub or Tall Shrub (Open-Closed) Low Shrub/Lichen Moss Moss (Peatland) (Southern Alaska) Moss (Southern Alaska) Needleleaf Forest (Open-Closed) (Seasonally Flooded) (Southern Alaska) Needleleaf Forest (Woodland-Closed) (Southern Alaska) Needleleaf Forest (Woodland-Open) (Peatland) (Southern Alaska) Saltwater Sitka Spruce (Woodland-Closed) Sparse Vegetation (Interior Alaska, Cook Inlet Basin) Sparse Vegetation (Northern and Western Alaska) Tall Shrub (Open-Closed) Tussock Tundra (Low shrub or Herbaceous) Urban, Agriculture, Road White Spruce or Black Spruce-Deciduous (Open-Closed) White Spruce or Black Spruce (Open-Closed) White Spruce or Black Spruce (Woodland) White Spruce or Black Spruce/Lichen (Woodland-Open)

Appendix 3: Descriptions for Wetlands of Conservation Concern in Alaska

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 21; 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.

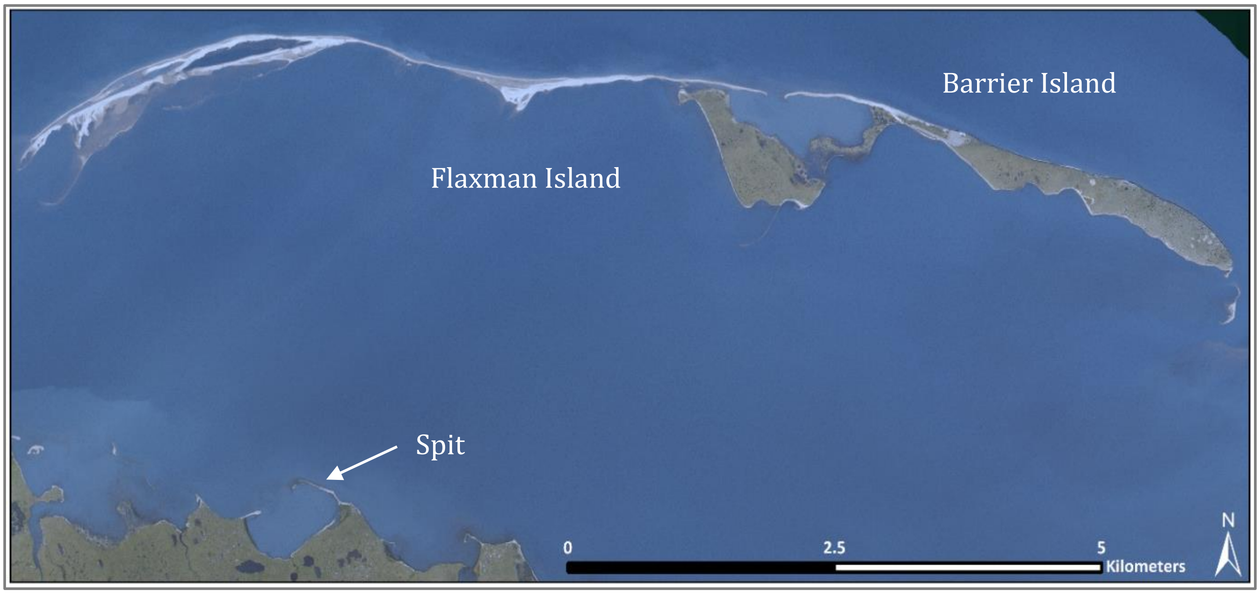

Figure 21. Aerial view of a barrier island (Flaxman Island), and inset of a spit along the Arctic Ocean.

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 under mapped, 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 22).

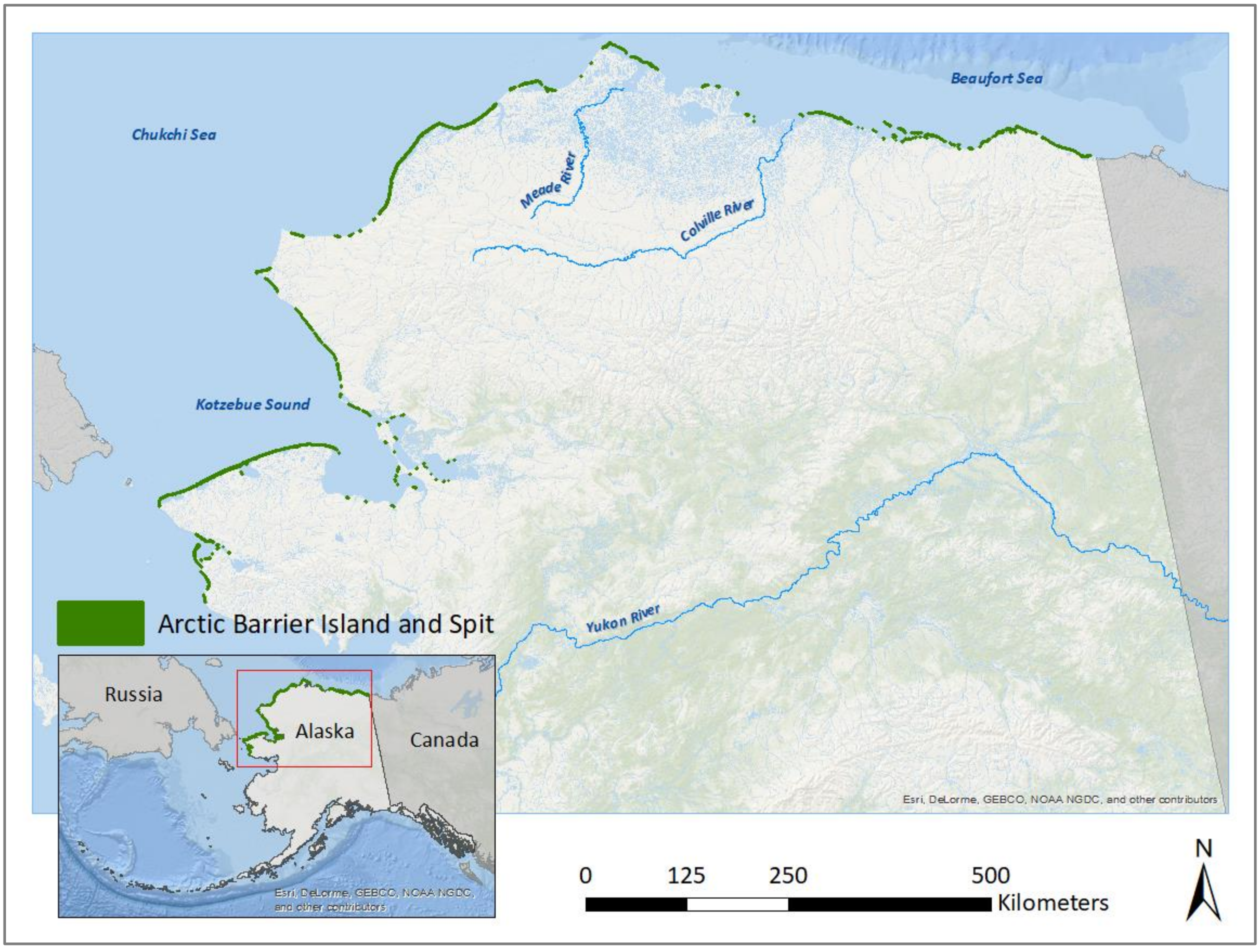

Figure 22. Distribution of the Arctic Barrier Island and Spit Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

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 23). Others, such as Sheshalik Spit near Kotzebue, extend far into the ocean with wide tidal inlets (Figure 24).

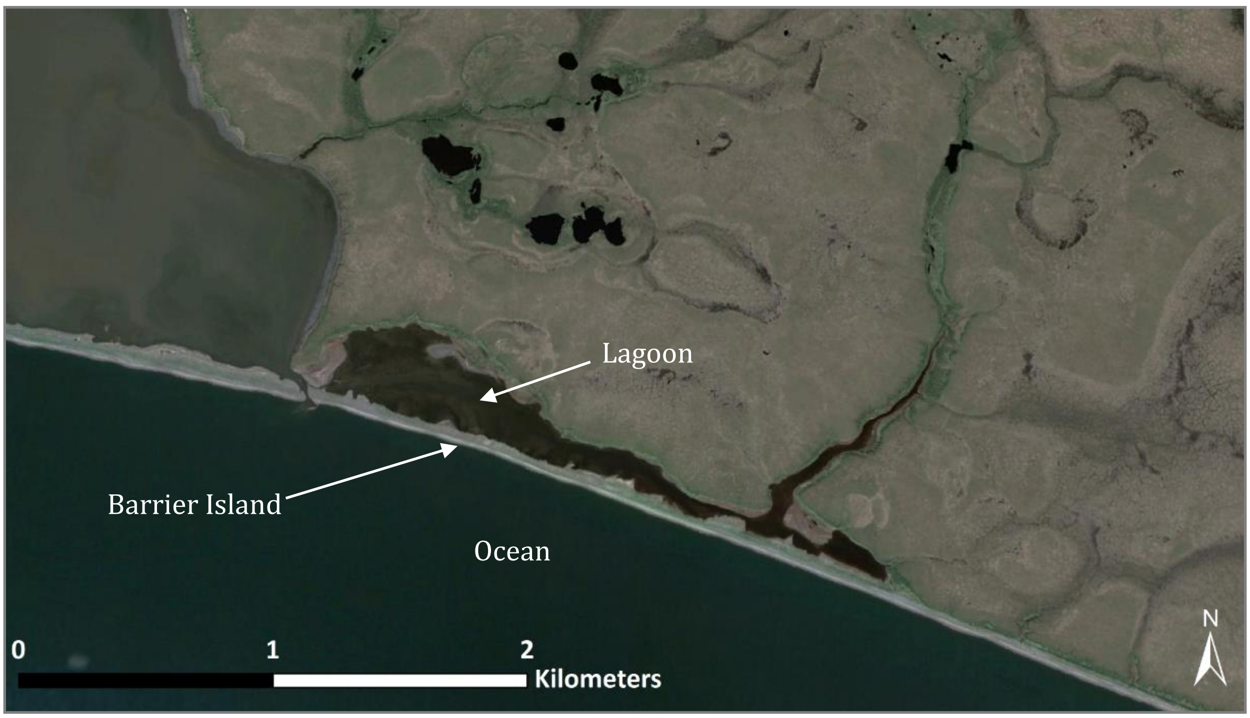

Figure 23. Aerial view of a barrier island northwest of Kotzebue (source: Google Earth, accessed September 2, 2015).

Figure 24. 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 25; Hopkins and Hartz 1978, Martin et al. 2009).

Figure 25. Ice-push and sediment deposition on a spit near Wainwright on the Chukchi Sea.

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 26), with the succulent, halophytic forb, *Honckenya peploides* occurring on

Figure 26. *Leymus mollis* stabilizing a dune near Wainwright, Alaska.

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).

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 7, Table 8). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 7. 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.
Polar bear	*Ursus maritimus*	G3G4	S2	Known to use coastal areas for feeding and denning.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.
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 8. 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.
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 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 27). 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 27. 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 28). The distribution of tidal marshes in Northern Alaska was developed from estuarine and marine intertidal subsystems of the National Wetland Inventory (USFWS 2015).

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).

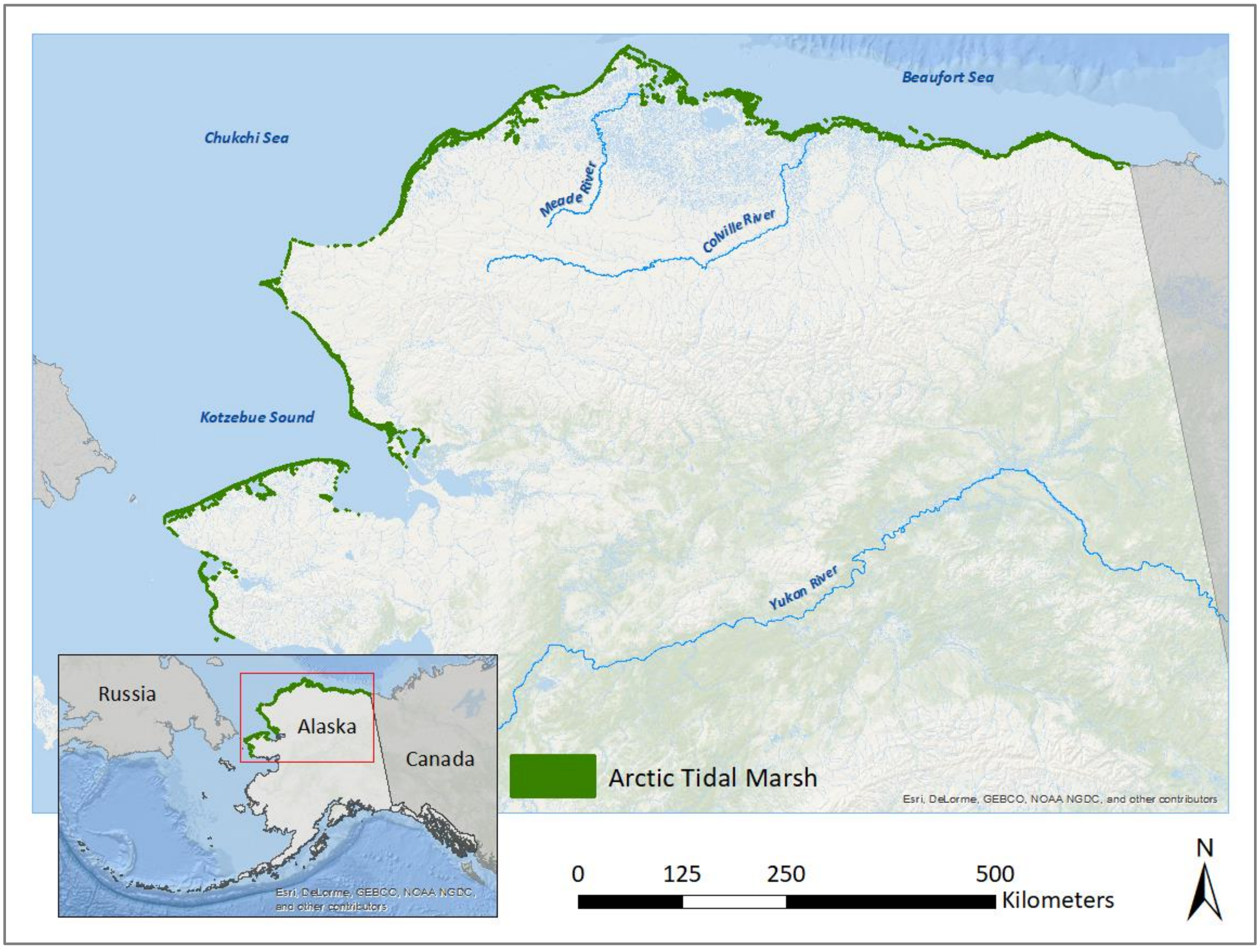

Figure 28. Distribution of the Arctic Tidal Marsh Biophysical Setting. Note that areas of occupancy in this map are buffered for greater visibility.

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

Figure 29. The alkai grass, *Puccinellia phryganodes* on subsiding tundra near Deadhorse, Alaska.

along the coast allows inundation of nearshore basins, polygonal ground and tussock tundra (Figure 30; 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 30. 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* (**Error! Reference source not found.** (Jorgenson et al. 1997, Flint et al. 2008).

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.

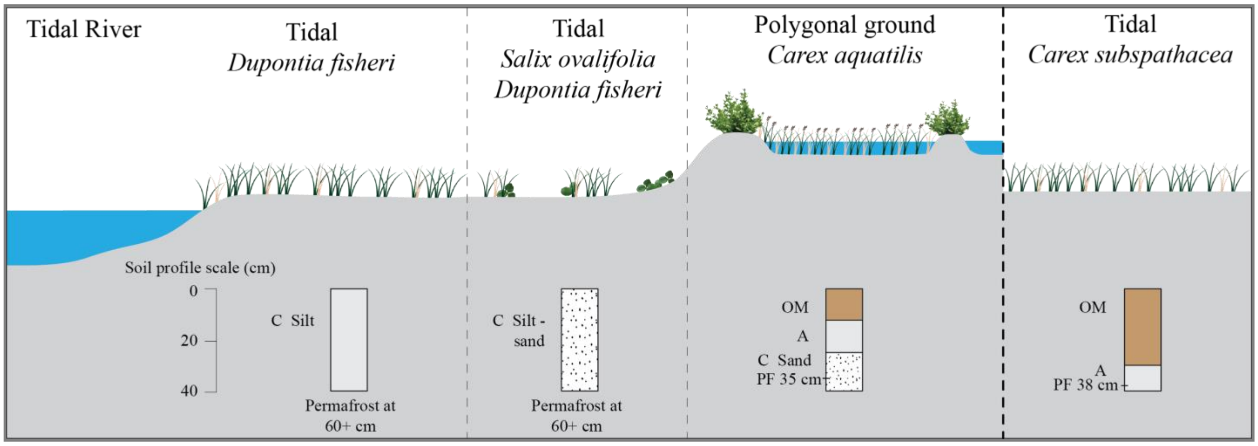

Figure 31. Schematic physiography and vegetation profile along a tidal river in Arctic Alaska.

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 32). 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.* In coastal lagoons the *Puccinellia phryganodes* association typically occurs in the lower tidal zone (Figure 33). 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*.

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).

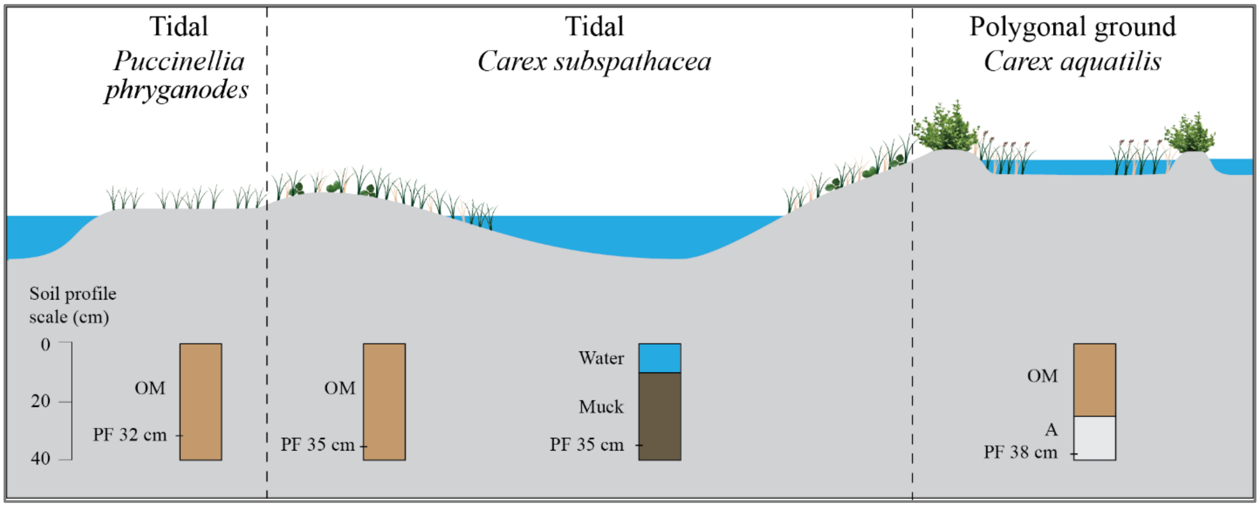

Figure 32. Schematic physiography and vegetation profile of tidal vegetation along a coastal lagoon in Arctic Alaska.

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 9, Table 10). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 9. 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 during migration and as winter habitat along Southern coastal Alaska.

Table 10. 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 11).

Table 11. 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 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 33). 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).

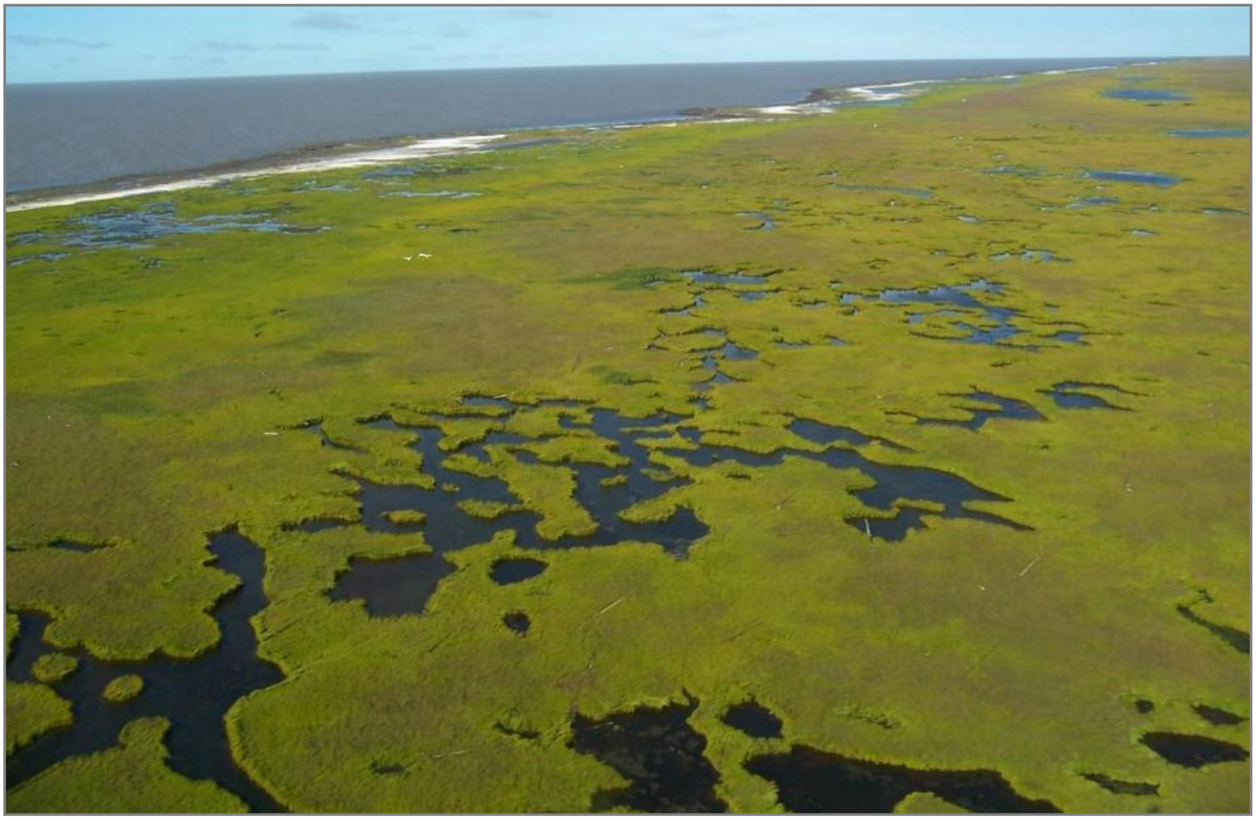

Figure 33. Tidal marsh on the outer coast of the Yukon-Kuskokwim Delta, Alaska (photo by T. Boucher).

Distribution

Tidal marshes occur as a narrow band along the Bering Sea coastline (Figure 34). The Beringian Tidal Marsh distribution map was developed from select tidal marsh landcover classes of the Alaska Vegetation Map (Boggs et al. 2015).

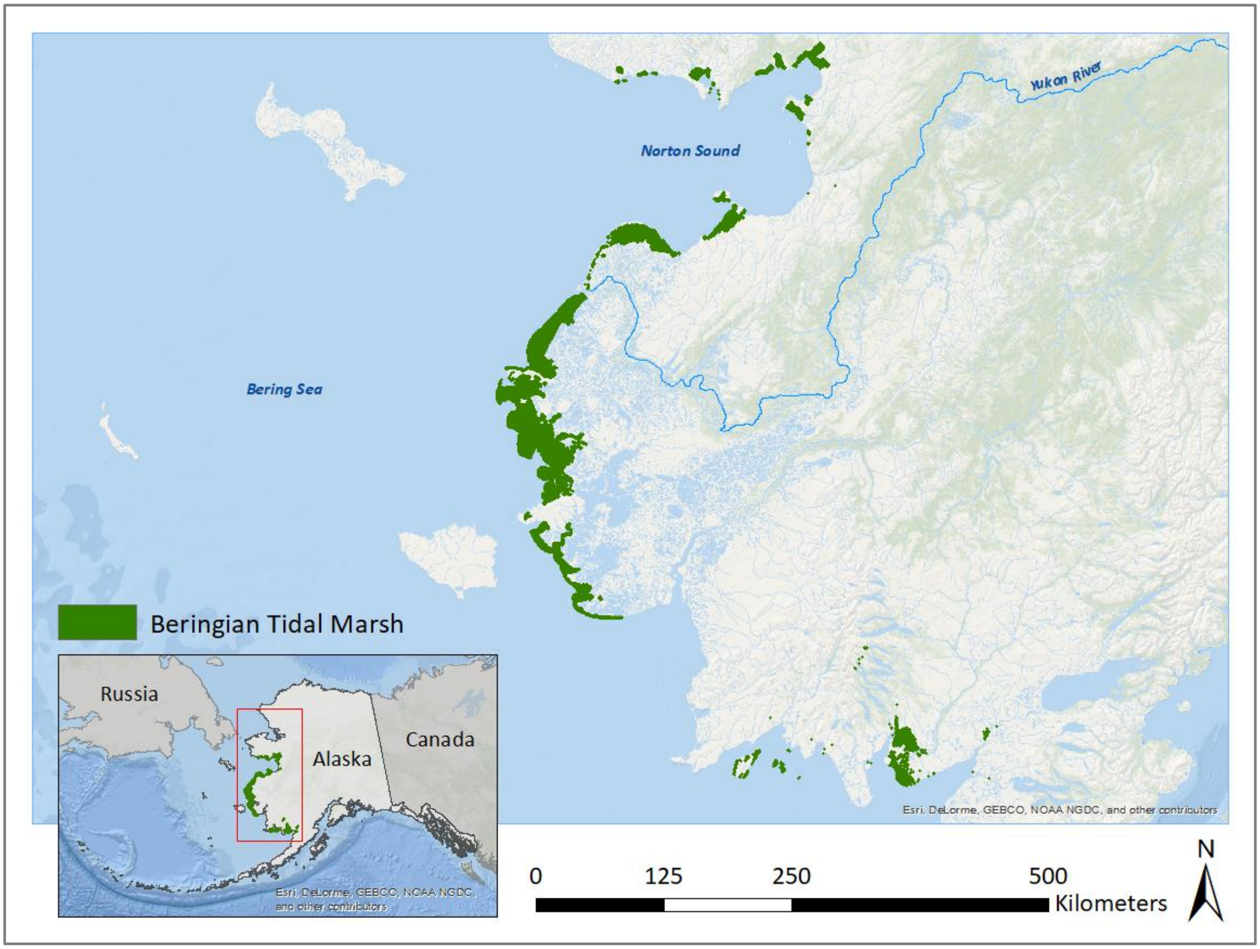

Figure 34. Distribution of the Beringian Tidal Marsh Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

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 35).

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).

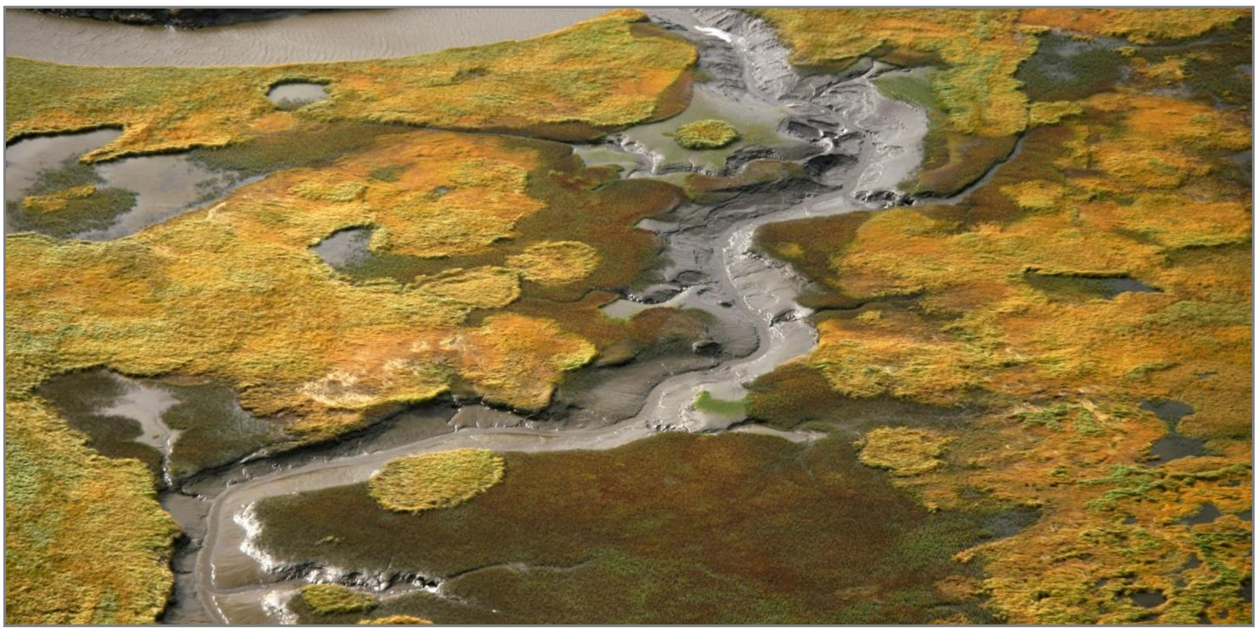

Figure 35. Inland tidal mudflats and meadows dominated by Puccinellia and Carex species on the Yukon-Kuskokwim Delta, Western Alaska (photo by T. Boucher).

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 along the Yukon-Kuskokwim Delta (Figure 33 and Figure 35; 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). 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 36). 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 36. 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 12Please visit the Alaska Center for Conservation Science website for species descriptions (accs.uaa.alaska.edu).

Table 12. 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.
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.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.
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

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
				areas.

Table 13. 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 14. Plant associations of conservation concern within the Beringian Tidal Marsh Biophysical Setting.

Table 14. 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

Name	Global Rank	State Rank	Concept Source
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
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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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 37). 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).

Distribution

Callitropsis nootkatensis occurs in coastal mountain ranges from southern Alaska to the Siskiyou mountains in northern California (Figure 37). 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 39) 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 37. Mixed conifer association including Callitropsis nootkatensis and with Lysichiton americanus in the understory in Glacier Bay National Park and Preserve.

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.

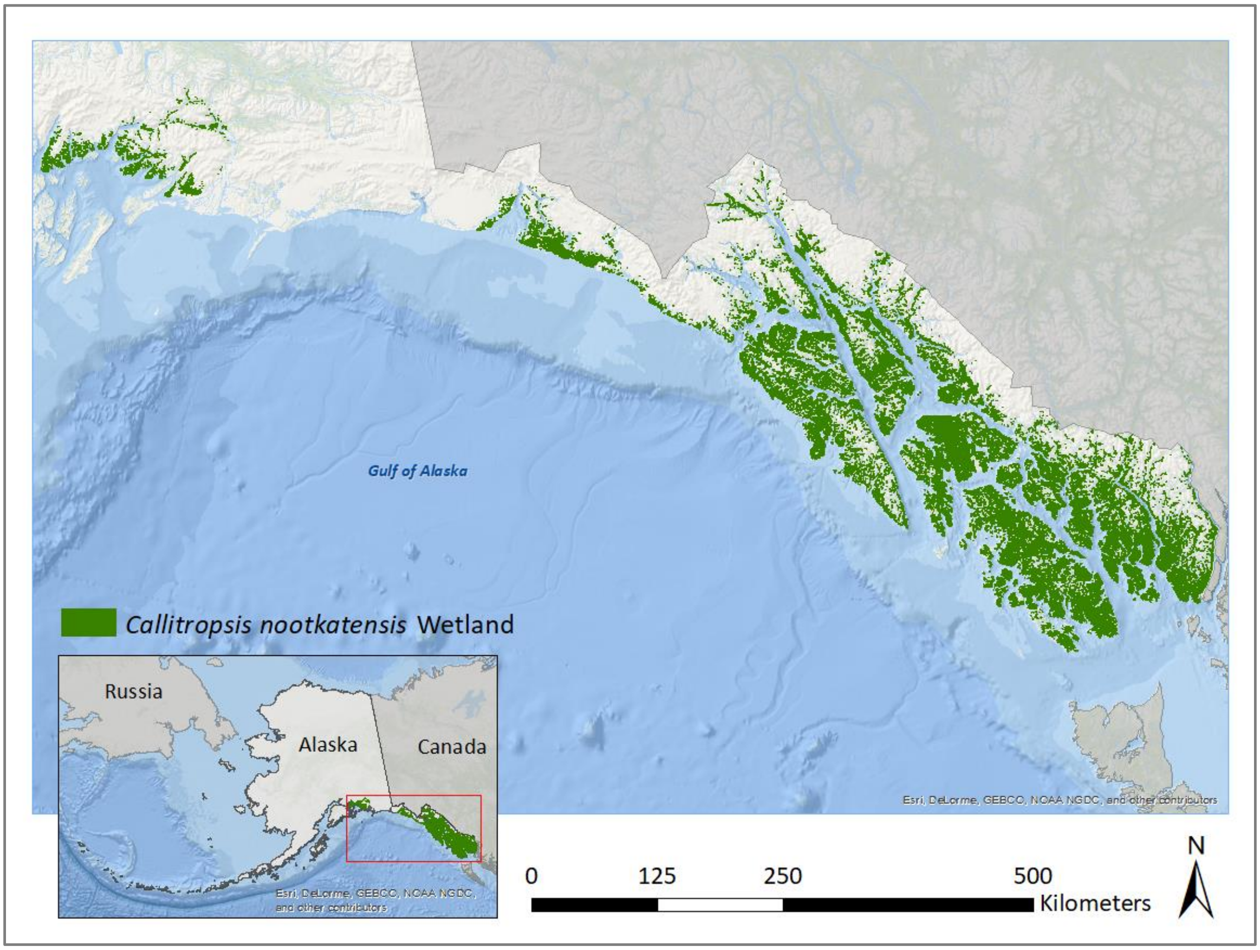

Figure 38. Distribution of the Callitropsis nootkatensis Wetland Biophysical Setting in southeast Alaska (Hennon et al. 2016). Note that the areas of occupancy in this map are buffered for greater visibility.

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 40). 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 39. *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 15. Amphibian, mammal and bird species within the Callitropsis nootkatensis Wetland Biophysical Setting.). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 15. 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				

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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 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 16. 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 17).

Table 17. 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

Name	Global Rank	State Rank	Concept Source
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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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 40). 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.

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 (; 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 41) 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 40. Granite Hotspring, Alaska (photo by M. Duffy).

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 (; Davis 1980).

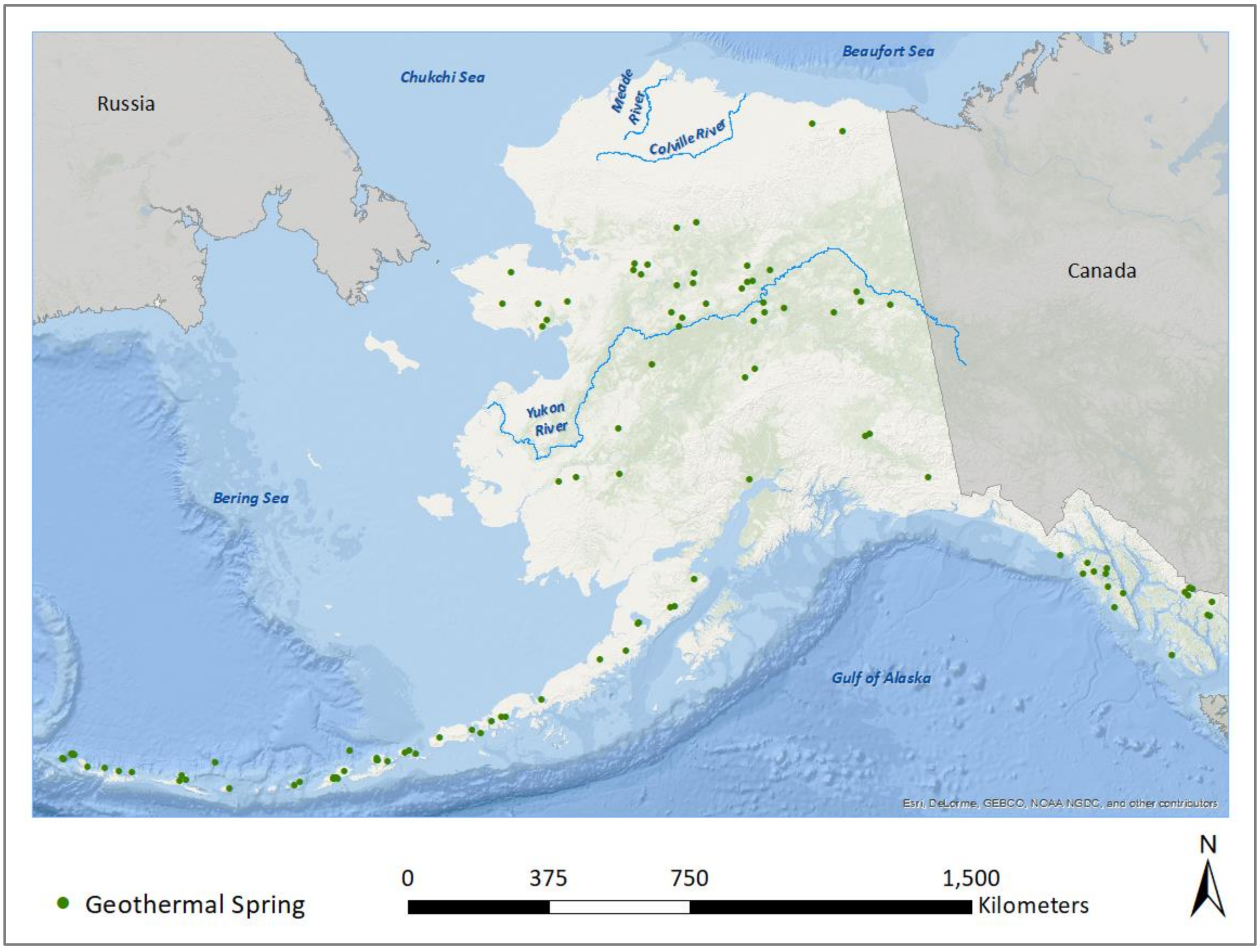

Figure 41. Distribution of the Geothermal Spring Biophysical Setting in Alaska. Note that point occurrences in this map are buffered for greater visibility.

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).

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).

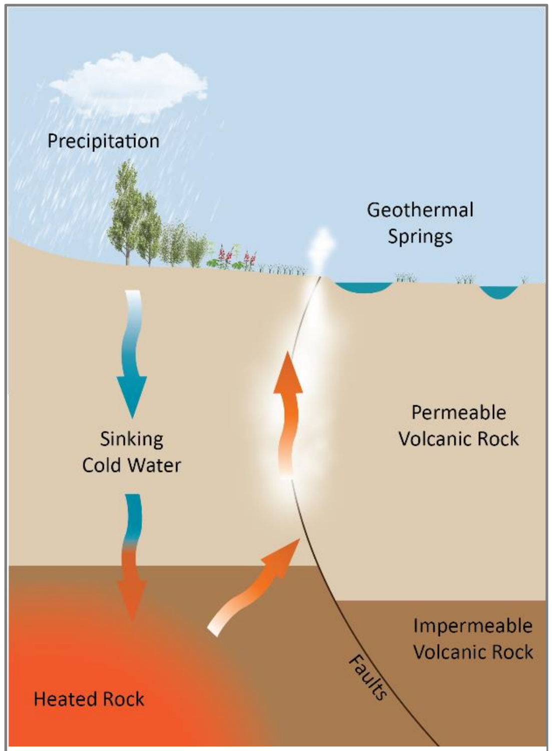

Figure 42. Geothermal springs water flow diagram.

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).


Figure 43. Makushin Volcano Hotspring, Alaska (photo by T. Nawrocki).

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 44). 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 44. 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. 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 18 and Table 19). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 18. 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 19. Plant species of conservation concern within the Geothermal Springs Biophysical Setting.

Scientific Name	Global Rank	State Rank	Habitat Description
Botrychium pendunculosum	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.
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.

Scientific Name	Global Rank	State Rank	Habitat Description
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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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 45). *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.

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 46) 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 45. *Larix laricina* Wetland Biophysical Setting at Denali National Park, Alaska.

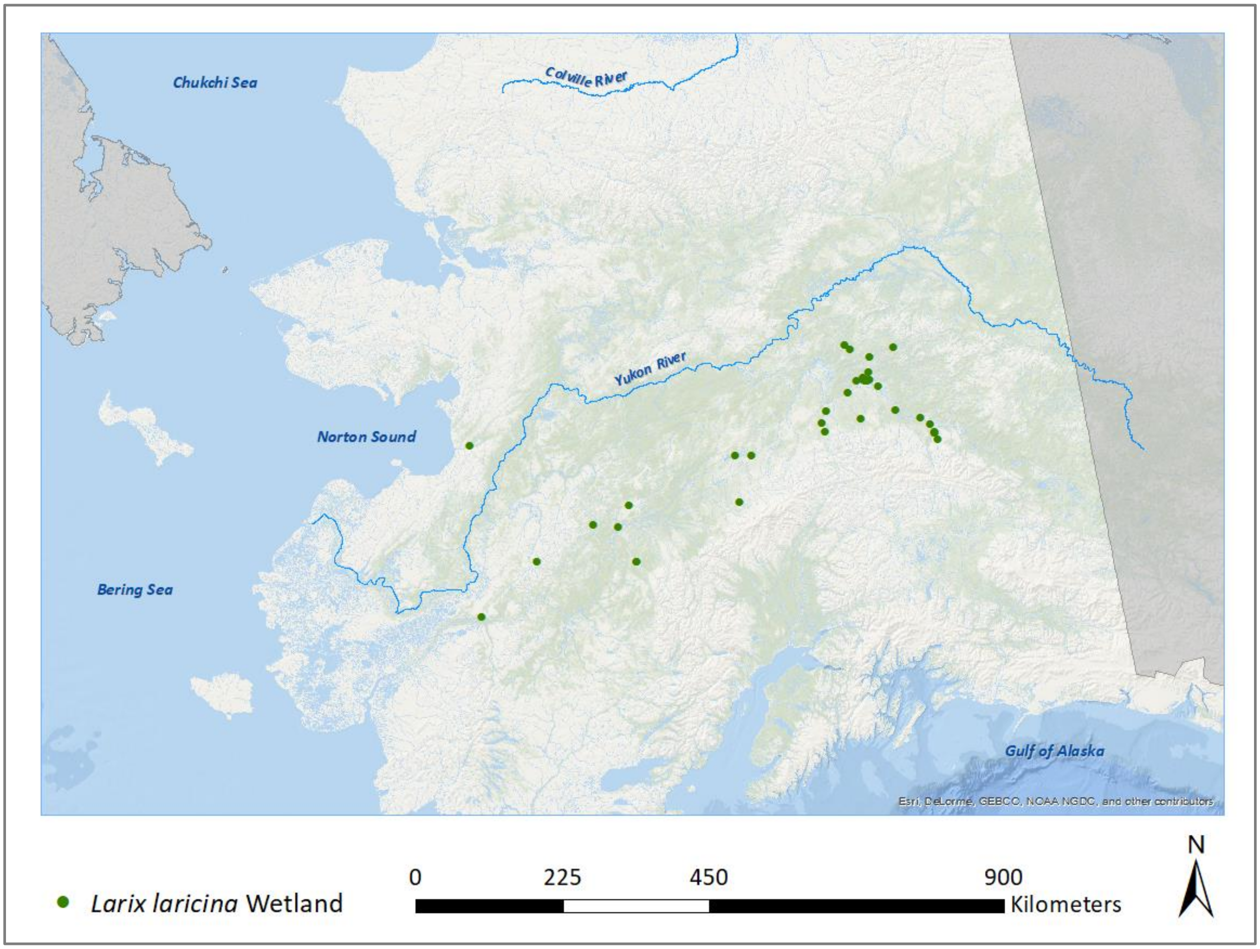

Figure 46. Distribution of the *Larix laricina* Wetland Biophysical Setting. Note only small patches of mature *Larix laricina* forest occur within its range and point occurrences shown in the map are buffered for greater visibility.

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 ^{o}C 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 47; 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 overstory is dominated by *Larix laricina*, with *Picea mariana* and *Betula neoalaskana* present as

Figure 47. Stand of *Larix laricina* near Fairbanks, Alaska.

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 46). *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 48); 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 48. *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 20, Table 21). 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.

Table 20. 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 21. 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 22).

Table 22. 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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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 (**Error! Reference source not found.**). Here, successive exudations of fluid-rich, fine-grained sediments build domes up to 100 m tall and 2,500 m diameter (Figure 50). These biophysical settings represent sensitive habitats supporting disjunct populations of halophytic and salt-tolerant plants and thermophilic microbial organisms.

Distribution

Mud volcanism is known from 44 provinces worldwide, with approximately 50% (900) of mud volcanos occurring occurring onshore (Kopf 2002, Dimitrov 2002). In Alaska, terrestrial mud volcanoes are known exclusively from the exclusively from the Copper River Basin. Offshore, mud volcanoes are expected to occur but have not been been documented from the Aleutian Trench (Kopf 2002); marine occurrences are not considered here. The Copper The Copper River Basin volcanoes occur as two complexes; the Tolsona and Klawasi groups. Volcano morphology morphology ranges from large domes (>5º slope) capped by a main, water-filled crater (Klawasi group) to low-relief low-relief (<5º slope) pies with numerous vents at their summit (Tolsona group). Mud Volcano biophysical setting biophysical setting occurrences were digitized from locations documented by Nichols and Yehle (1961). An average An average diameter of 542 m was determined from the maximum diameters provided by Pewe & Reger (1983) for (1983) for the mapped mud volcanos (

).

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 ºC and freezing temperatures may occur in any month in most of the region.

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).

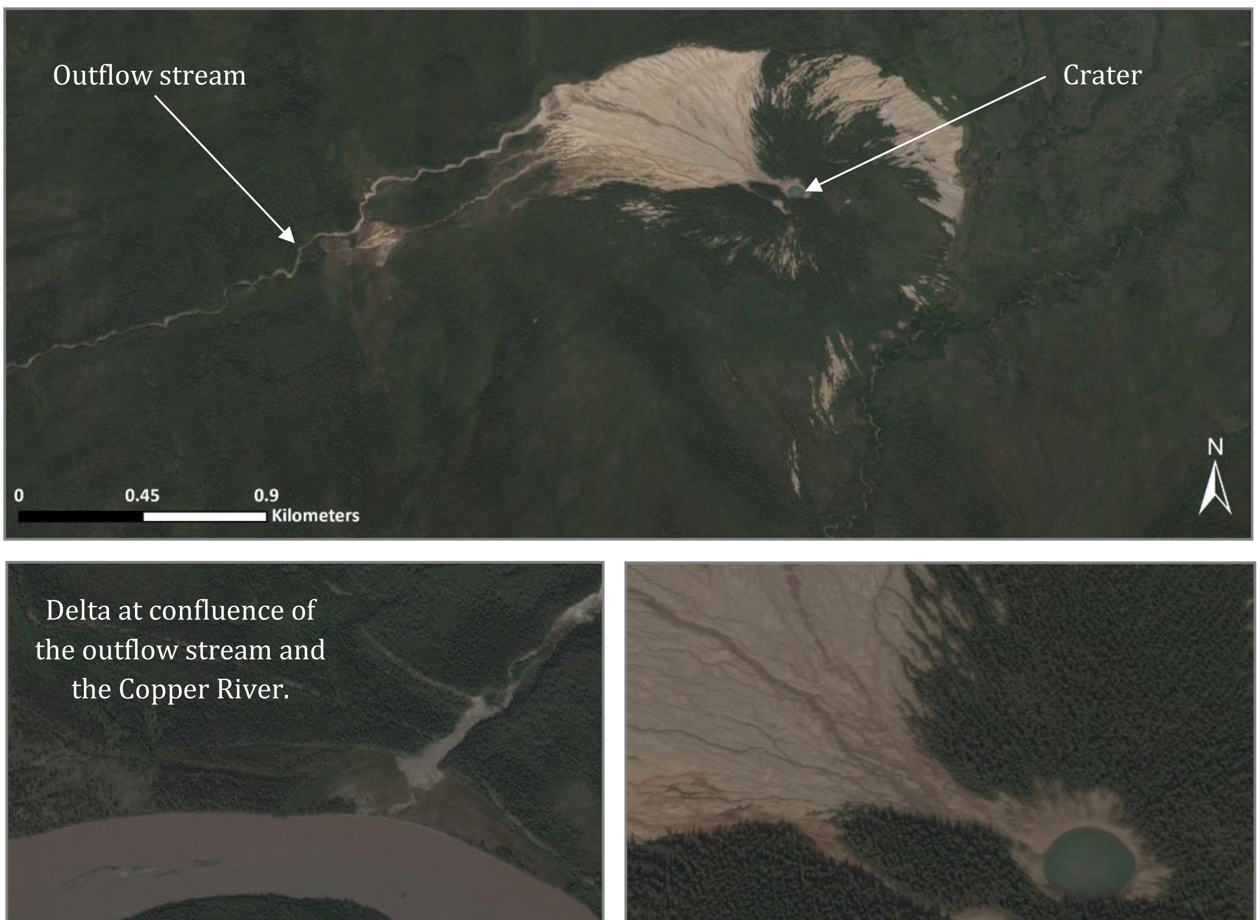

Figure 49. Aerial views of Lower Klawasi mud volcano showing the dome, crater and the delta formed by mud flow deposits (source: Google Earth, accessed September 2, 2015).

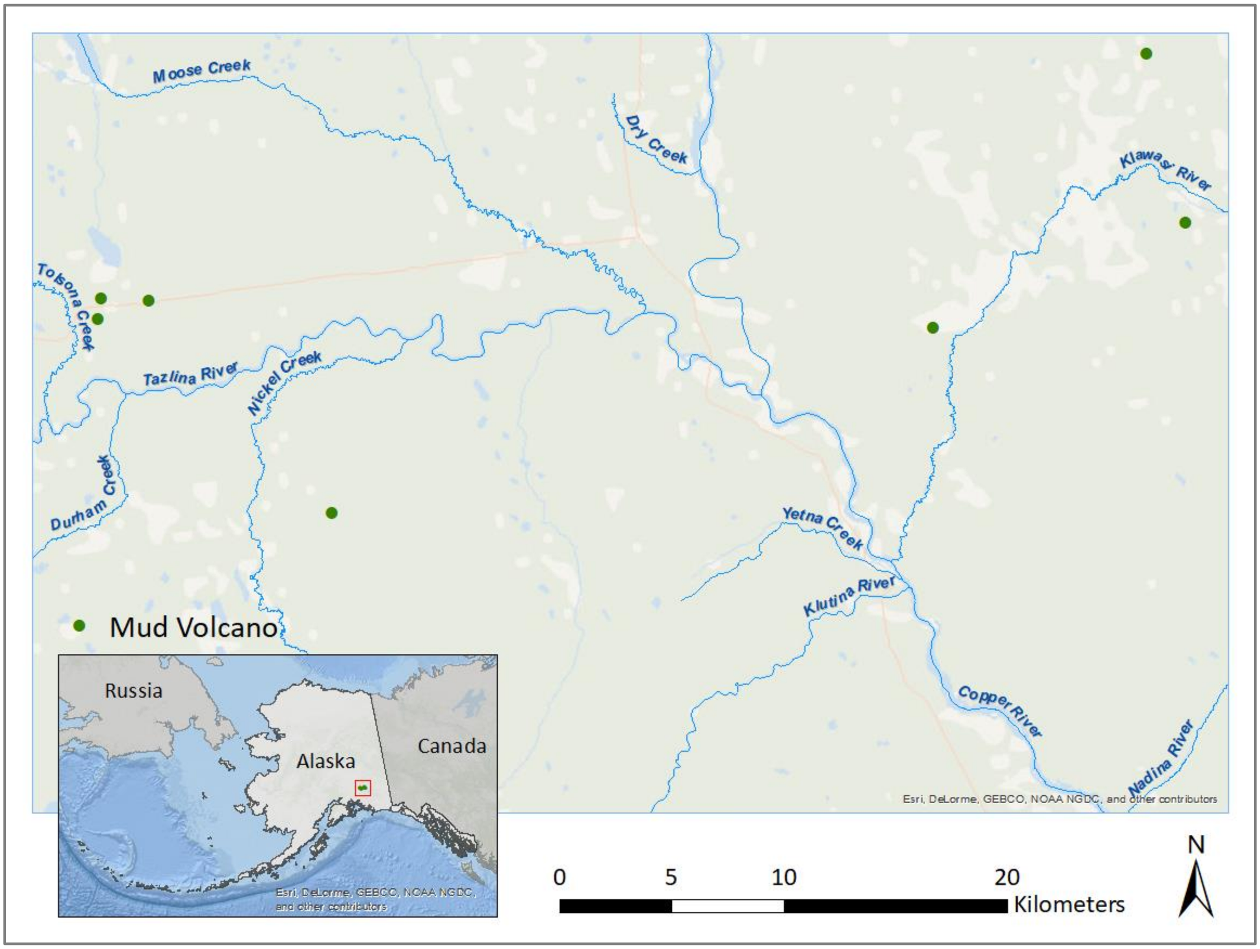

Figure 50. Distribution of the Mud Volcano Biophysical Setting. Note that point occurrences in this map are buffered for greater visibility.

Figure 51. A recent mudflow at the summit of the Lower Klawasi mud volcano, Alaska.

The Tolsona group is comprised of the Nickel Creek, Shepard (inactive), and Tolsona mud volcanoes 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 (**Error! Reference source not found.**), 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).

Figure 52. Lower Klawasi crater showing the *Picea glauca/Shepherdia canadensis*/moss Plant Association near the rim.

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 (**Error! Reference source not found.**). Open *Picea glauca*/*Shepherdia canaden*sis/*Pleurozium schreberi* forests are common, extending from top to bottom of the dome sideslopes (Figure 52). 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 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. Biological crusts are uncommon, occurring on the Lower Klawasi caldera rim, and as small patches on barren mud flows.

Beyond the dome, mudflow sediments dominated the floodplain and delta of the outflow stream to the Copper River

Figure 53. *Juncus arcticus* ssp. *ater* Plant Association on the lower flanks of the Lower Klawasi mud volcano.

Copper River (

). 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 23).

Table 23. 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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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 54). 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 54. 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 55, 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.

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 to 13 km in length, 2 km in width and typically rise less than 10 m above sea level (Thilenius 1990).

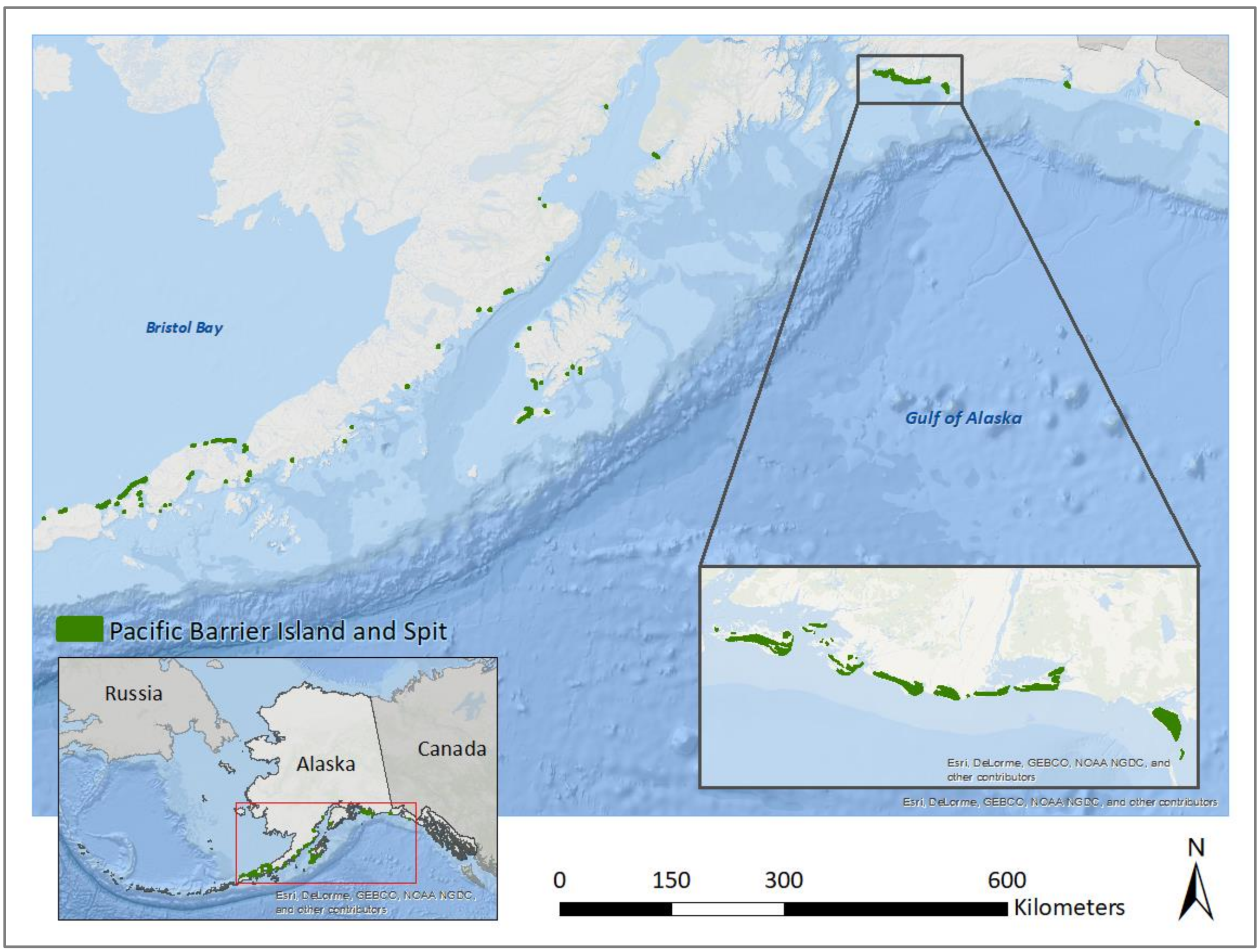

Figure 55. Distribution of the Pacific Barrier Island and Spit Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

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 56). 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.

The barren or sparsely-vegetated dunes located toward the ocean receive significant windblown sand.

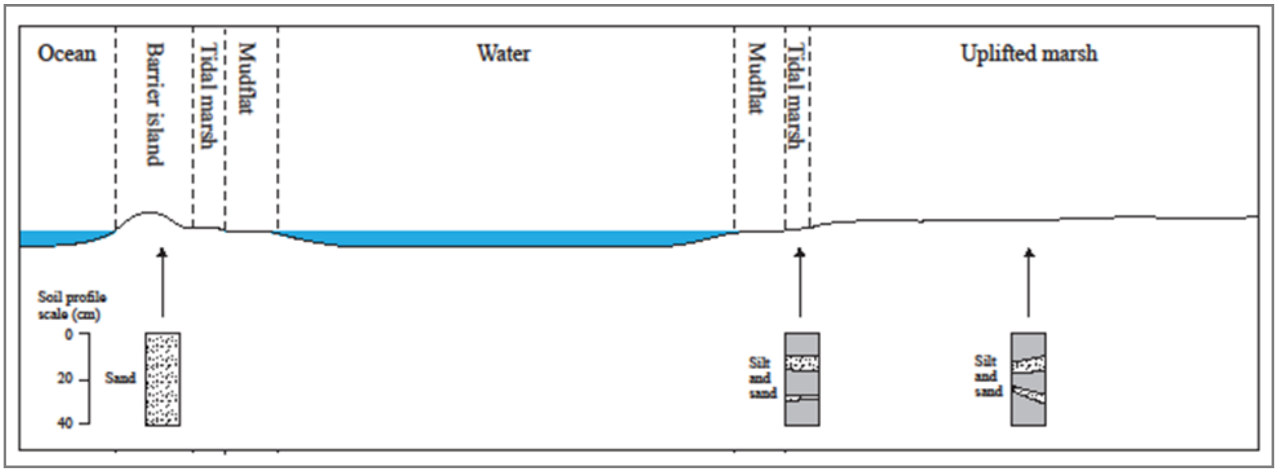

Figure 56. Schematic physiography and vegetation profile of a barrier island on the Copper River Delta, Alaska.

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.

Species of Conservation Concern

Barrier islands, spits and their associated dunes, swales, lagoons, estuaries and bays provide a wide wide variety of habitats that, where separated from the from the mainland, reduces access by predators (Boggs (Boggs 2000). The mammal, bird, and plant species species listed below are designated critically imperiled imperiled or vulnerable either globally (G1-G3) or or within Alaska (S1-S3) and are known or suspected suspected to occur in this biophysical setting (Table 24,

Figure 57. Semipalmated plover (*Charadrius semipalmatus*) (photo by T. Bowman).

Table 25). 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 57). 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 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).

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.
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

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
				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.
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 25. 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 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 (**Error! Reference source not found.**; 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 58. Tidal marsh in Kenai Fjords, Alaska.

Distribution

Tidal marshes are widely distributed along the coastline of Southern Alaska and the Aleutian Islands. Here, numerous small tidal marshes are maintained in protected pockets 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.

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 18ºC; average winter temperatures are between -3 and 3ºC. 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 15ºC; average winter temperatures are between -11 and -6ºC.

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

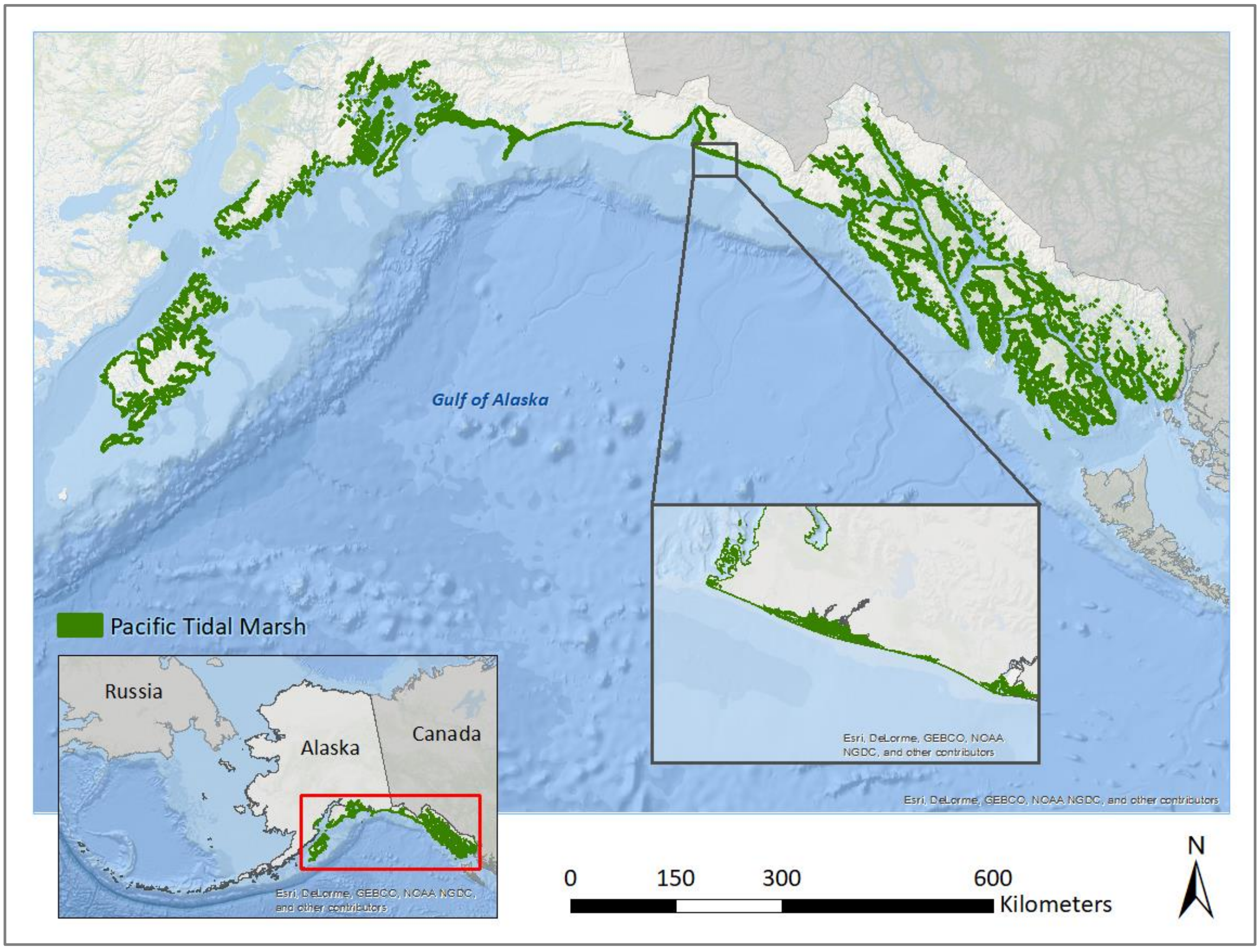

Figure 59. Distribution of the Pacific Tidal Marsh Biophysical Setting. Tidal marshes have not been mapped in the Aleutian Islands. Note that the areas of occupancy in this map are buffered for greater visibility.

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).

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 61). 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 (Figure 61). Relationships between tidal levels and vegetation 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).

Figure 60. Tidal marsh in Kenai Fjords, Alaska.

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).

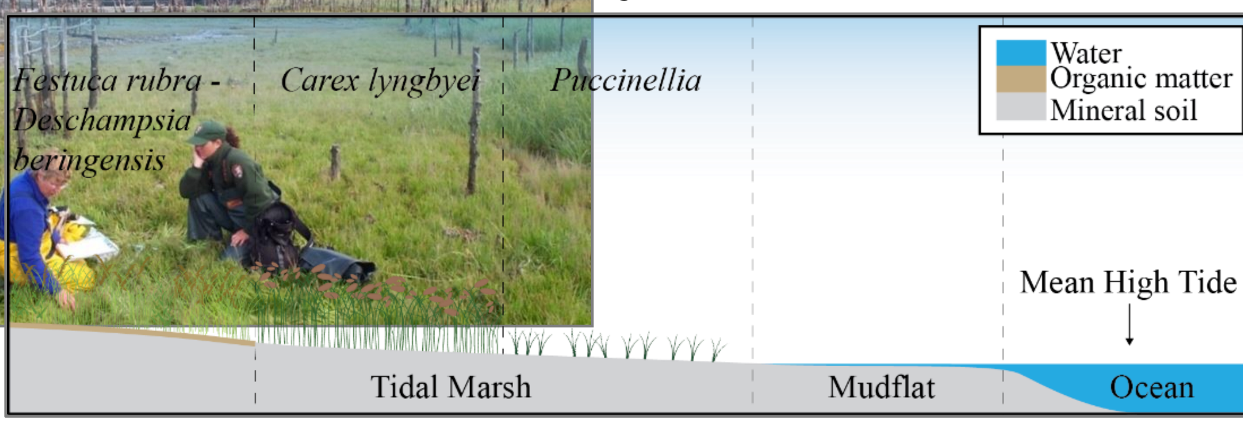

Figure 61. Schematic physiography and vegetation profile of a tidal marsh on a young tidal surface, Copper River Delta, Alaska.

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 62. Marbled Godwit (photo by T. Bowman).

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.

Figure 63. Tidal marshes and mudflats at Hartney Bay near Cordova, Alaska.

Species of Conservation Concern

Tidal marshes provide a staging area for millions of migrating shorebirds and waterfowl (Figure 62), and 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 26, Table 27). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 26. 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.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.
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).

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.
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.

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
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.
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 27. 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 28).

Table 28. 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
Cochlearia sessilifolia	G1G2	S1S2	Boggs et al. 2008
Deschampsia caespitosa	G4	S3	DeVelice et al. 1999
Puccinellia glabra-Plantago maritima	G3	S3	Hanson 1951

Name	Global Rank	State Rank	Concept Source
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 64). 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 68; *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 64. 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 (). 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.

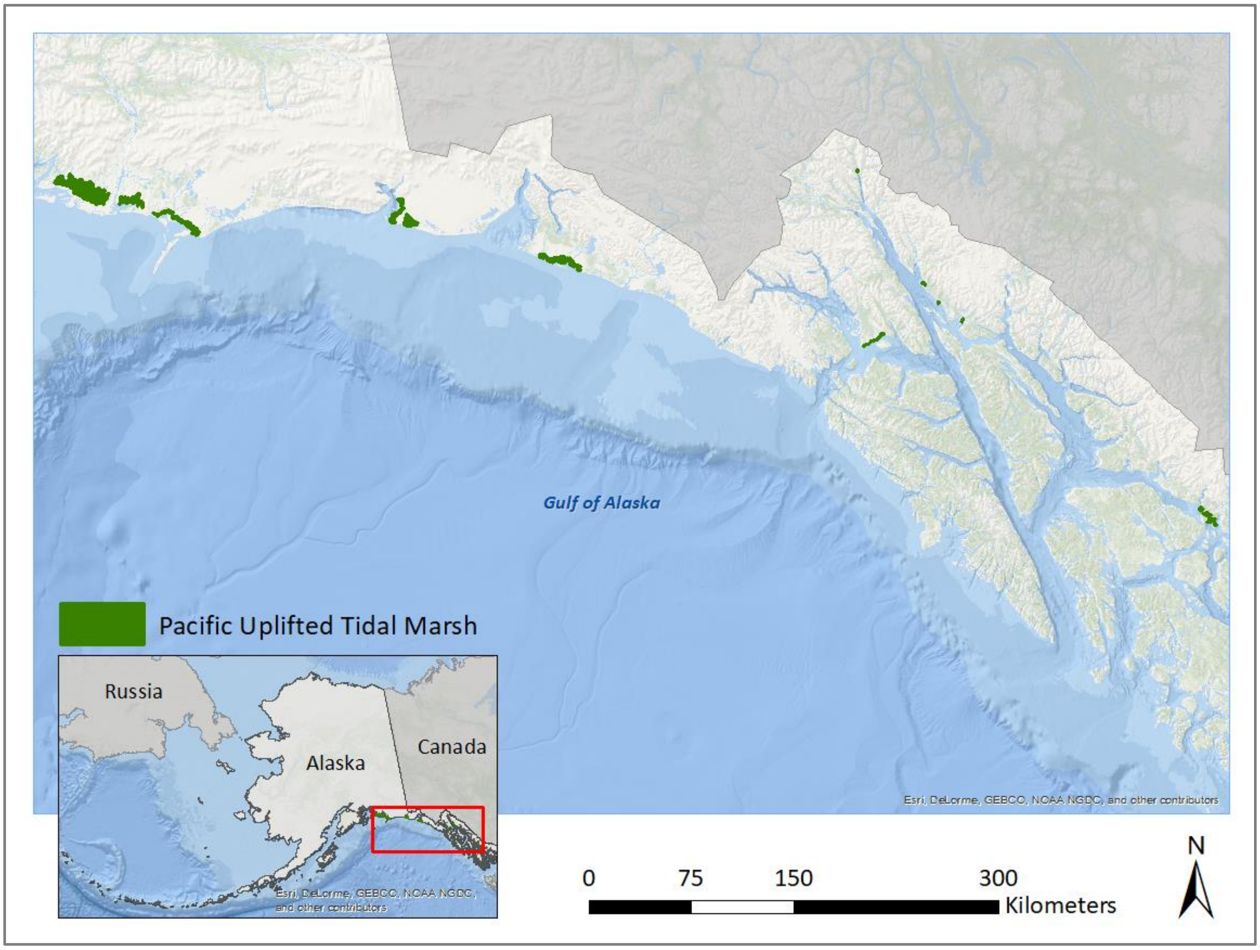

Figure 65. Distribution of the Pacific Uplifted Tidal Marsh Biophysical Setting. Note that the areas of occupancy in this map are buffered for greater visibility.

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 66; 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 67). 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.

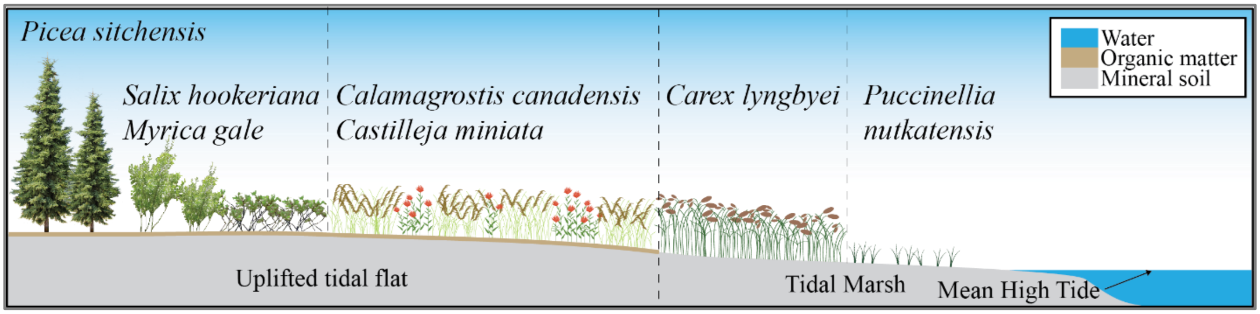

Figure 66. Schematic physiography and vegetation profile of a young tidal marsh uplifted above the tidal zone.

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.

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).

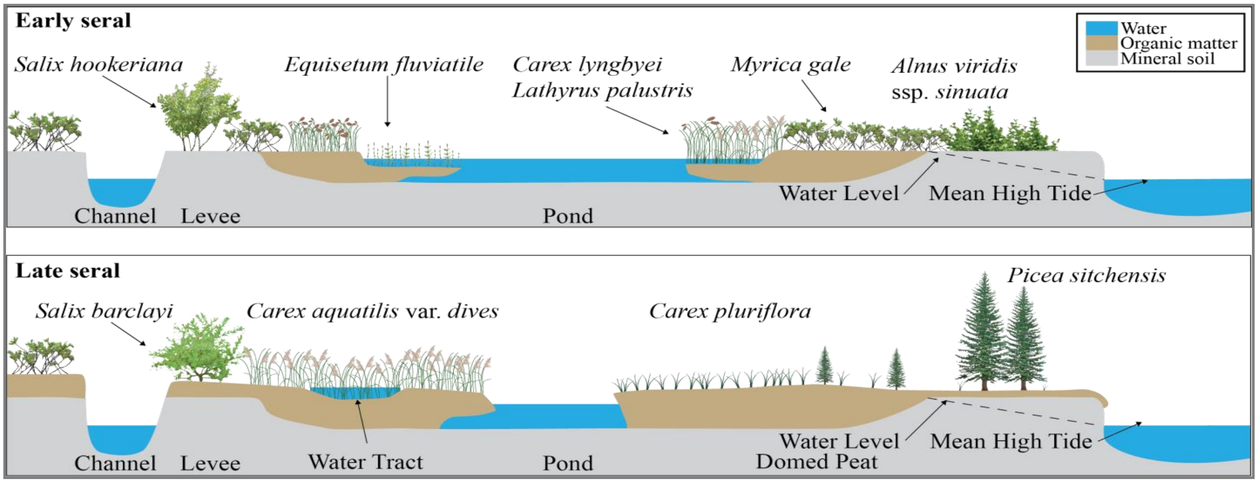

Figure 67. Schematic physiography and vegetation profile of a mature tidal marsh lifted above tidal zone influence depicting two stages of succession; early-seral at 28 years after uplift and late-seral at 200+ years after uplift (Boggs and Shephard 1999).

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).


Figure 68. Dusky Canada Geese (*Branta canadensis occidentalis)* on an uplifted tidal marsh pond of the Copper River Delta (photo by T. Bowman).

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 (G1-G3) or within Alaska (S1-S3) and are known or suspected to occur in this biophysical setting (Table 29,

Table 30). Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 29. 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 30. 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.

Scientific Name	Global Rank	State Rank	Habitat Description
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 31).

Table 31. 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 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 71). 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

Figure 69. Small patches of *Picea glauca* forests on floodplains of the Yukon River in Yukon-Charley Rivers National Preserve, Alaska.

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).

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 70).

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 ^{o}C in the east to -4 ^{o}C in the west. The average frost-free period ranges from 70 to 120

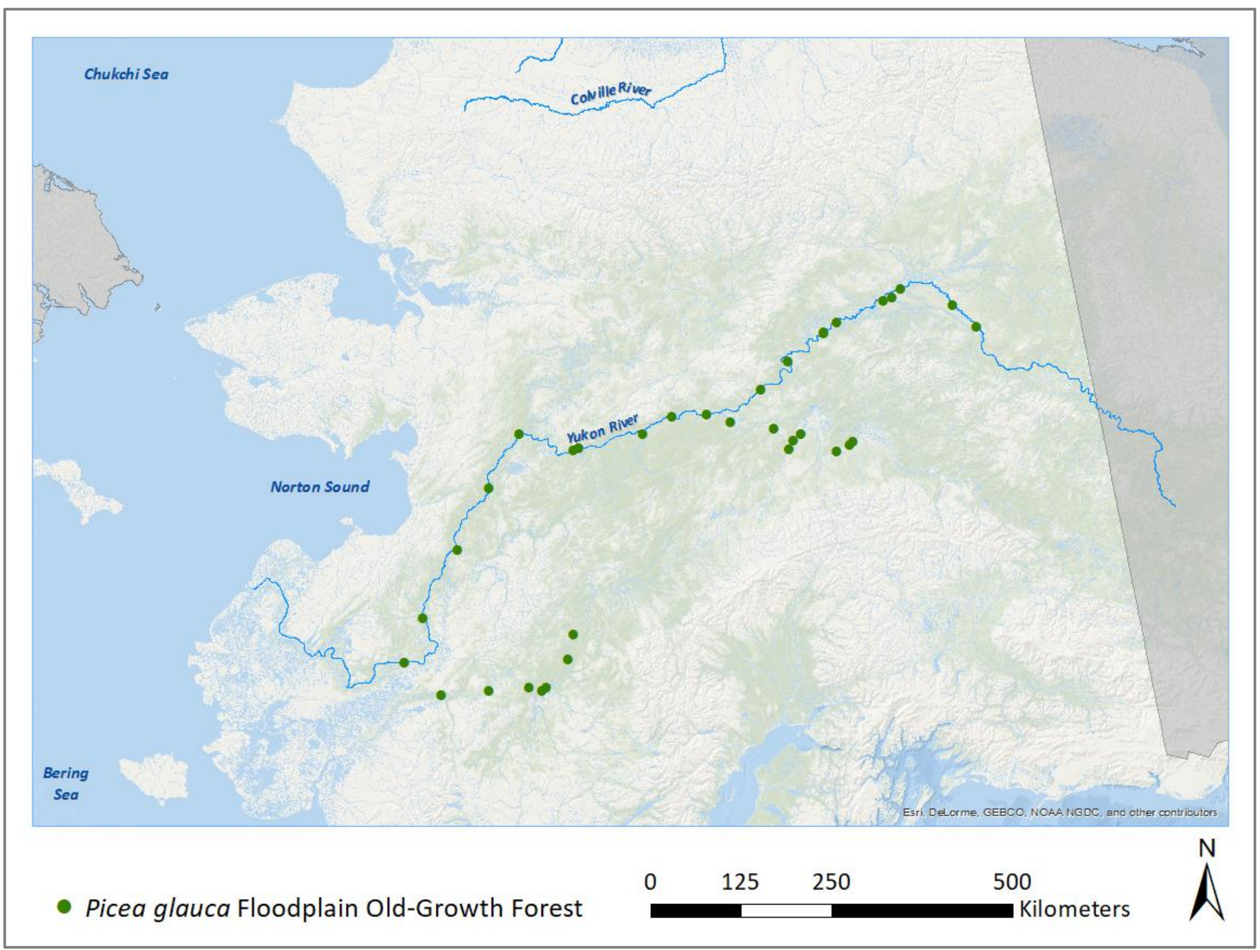

Figure 70. Distribution of the *Picea glauca* Floodplain Old-growth Forests Biophysical Setting. Note point occurrences in this map are buffered for better visibility.

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 71. 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 71). 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 72). *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 72. 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 (**Error! Reference source not found.** 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 32. 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 33. 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 (**Error! Reference source not found.**

Table 34. 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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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 73; 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 73. 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 (Figure 74; Franklin and Dyrness 1973, Hemstrom and 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).

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.

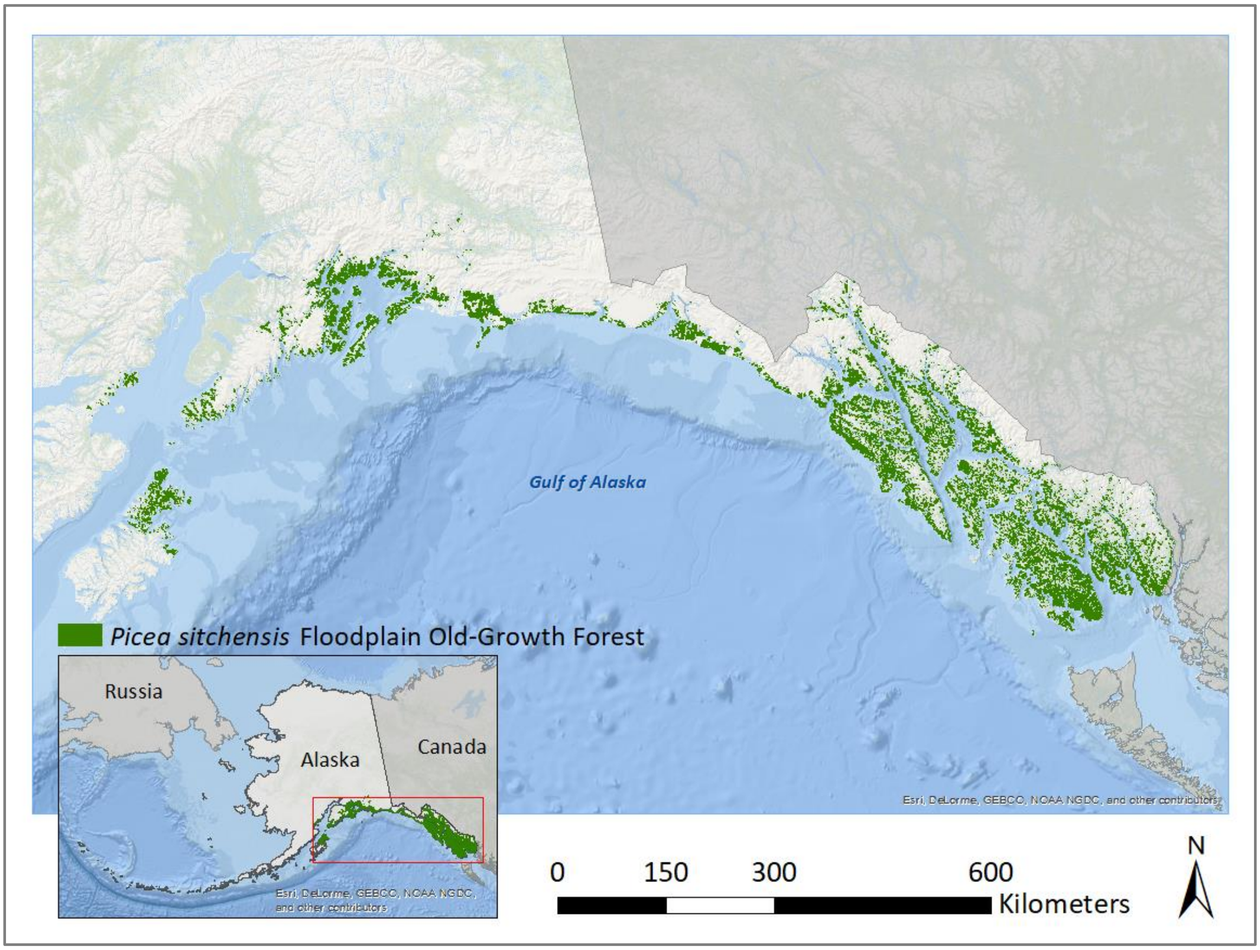

Figure 74. Distribution of the *Picea sitchensis* Floodplain Old-growth Forest Biophysical Setting in Southern Alaska. Note that the areas of occupancy shown in this map are buffered for greater visibility.

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.

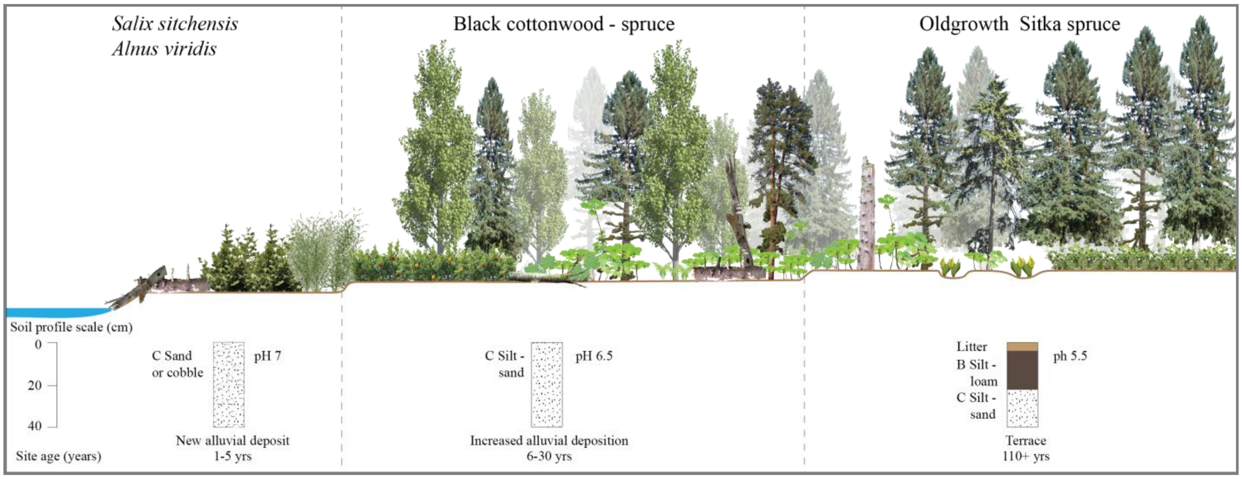

Figure 75. Schematic physiography and vegetation profile of a *Picea sitchensis* Floodplain Old-growth Forest Biophysical Setting.

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 75). 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.

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*.

Figure 76. Old-growth *Picea sitchensis* floodplain forests along the Stikine River, Alaska.

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 (**Error! Reference source not found.** Please visit the Alaska Center for Conservation Science website for species descriptions (ACCS 2016).

Table 35. 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.
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

Common Name	Scientific Name	Global Rank	State Rank	Habitat Description
				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 36. 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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