The Alaska Yukon Region of the Circumboreal Vegetation map (CBVM).

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Jorgensen, T.; Meidlinger, D.

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Design and layout: Courtney Price

For more information please contact:
CAFF International Secretariat
Borgir, Nordurslod
600 Akureyri, Iceland
Phone: +354 462-3350
Fax: +354 462-3390
Email: caff@caff.is
Internet: www.caff.is
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Introduction

The circumboreal vegetation mapping (CBVM) project is an international collaboration among vegetation scientists to create a new vegetation map of the boreal region at a 1:7.5 million scale with a common legend and mapping protocol (Talbot and Meades 2011). The map is intended to portray potential natural vegetation, or the vegetation that would exist in the absence of human or natural disturbance, rather than existing vegetation that is commonly generated at larger scales. This report and map contributes to the CBVM effort by developing maps of bioclimatic zones, geographic sectors with similar floristic variability, and vegetation in boreal Alaska, Yukon, northwestern British Columbia, and a mountainous portion of southwest Northwest Territories—termed the Alaska-Yukon region. It further develops the mapping from the initial classification and proto-type mapping efforts for southwestern Alaska (Jorgenson 2012) and western Canada (Meidinger and MacKenzie 2012) to this broader area.

Bioclimatic zonation provides a strong basis for determining the distribution of zonal ecosystems (Pojar et al. 1987, Meidinger and Pojar 1991). The CBVM project utilizes the approach of Sánchez-Mata and Rivas-Martínez (2011) that differentiates zones based on temperature and precipitation indices. Based on computerized mapping of world-wide climate data, they divided boreal northwestern North America into four bioclimatic zones: xeric (Yukon Flats region), continental (central Alaska and Yukon), subcontinental (southwestern Alaska), and oceanic (southwestern Alaska, Aleutians, and portion of southeast Alaska panhandle). In our effort, bioclimatic mapping was based on the higher-resolution regional gridded climatic data of Parameter Regression of Independent Slopes Model (Prism Climate Group 2008, Hamann et al. 2013) and, thus, differs somewhat from the maps by Sánchez-Mata and Rivas-Martínez (2010).

Floristic and biogeographic regions within our map area have been differentiated through numerous approaches. Uvandy (1975) divided the region into five biogeographical provinces: Alaskan Tundra (northern and western Alaska), Yukon Taiga (Interior Alaska and Yukon), Aleutian Islands (southwestern Alaska and Aleutians), Sitkan (southeastern Alaska), and Rocky Mountain (northern BC). Bailey (1996) divided the AY region into four zones: Subarctic Division and Subarctic Regime Mountains (interior and western Alaska), Marine Division and Marine Regime Mountains (Alaska Range, southwestern Alaska, southeast Alaska panhandle). From a broader global perspective, Takhtajan (1986) differentiated only three provinces, Arctic (northern Alaska and Canada, and Aleutians), Canadian (boreal), and Vancouverian (coastal rainforests). These approaches differ in how they deal with the major climatic and physiographic transition zones across the region.

Vegetation classification and mapping efforts for the Alaska-Yukon region have used numerous approaches based on plant structure and species composition. For Alaska, the Alaska Vegetation Classification (Viereck et al. 1992) is the main statewide system and uses a five-level hierarchical approach that partitions both vegetation structure and composition. The floristic classification of boreal vegetation of North America by Rivas-Martinez and Sánchez-Mata (2011) provides a good framework for a comprehensive classification, yet lacks sufficient Alaskan plots to provide a comprehensive classification for Alaska. There have been numerous statewide efforts to map vegetation across Alaska, but they have primarily been oriented toward vegetation structure and composition. For example, Bailey (1996) divided the AY region into four zones: Subarctic Division and Subarctic Regime Mountains (interior and western Alaska), Marine Division and Marine Regime Mountains (Alaska Range, southwestern Alaska, southeast Alaska panhandle). From a broader global perspective, Takhtajan (1986) differentiated only three provinces, Arctic (northern Alaska and Canada, and Aleutians), Canadian (boreal), and Vancouverian (coastal rainforests). These approaches differ in how they deal with the major climatic and physiographic transition zones across the region.

Vegetation and biogeographic mapping has been developed at various scales in Canada. At the federal level, the Ecosystem Land Classification (ELC) or the National Ecological Framework (NEF) (Ecological Stratification Working Group 1995), provided a framework for dividing the country into a hierarchy of physiographic and climatic areas, while Ecoclimatic Regions of Canada (Ecoregions Working Group 1989) provided broad-scale mapping following a zonal ecosystem
approach. For northwestern Canada, Oswald and Senyk (1977) completed the first map of the Ecoregions of the Yukon. Subsequent ecoregion mapping (Smith et al. 2004) contributed to the 1995 NEF. Recent mapping in Yukon has updated the ecoregion mapping of 1995 (Ecological and Landscape Classification Technical Working Group 2014). In addition, a map of bioclimate zones has been completed for Yukon (Ecological and Landscape Classification Technical Working Group 2015) following the mapping principles of Flynn and Francis (2012) (see also Environment Yukon 2015b). The Northwest Territories conducted further ecoregion mapping following from the NEF (Downing et al. 2006) that led to the mapping of ecoregions within the framework of Ecological Regions of North America (Commission for Environmental Cooperation 1997). The map of the cordilleran region (Ecosystem Classification Group 2010) of this territory is included in the Alaska-Yukon CBVM. For British Columbia, there is both an ecoregion map (Demarchi et al. 1990, Demarchi 2011) and biogeoclimatic map (Version 9, https://www.for.gov.bc.ca/hre/becweb/resources/maps/CartographicProducts.html) based on a zonal ecosystem approach (Meidinger and Pojar 1991). These mapping approaches differ in that ecoregions are broad areas of uniform physiography and climate (elevational vegetation zones are not formally mapped), while biogeoclimatic zones differentiate vegetation-ecological zones using the concept of zonal ecosystem.

This study was initially supported by the U.S. Fish and Wildlife Service (FWS) to cover boreal Alaska and was subsequently expanded to cover the area encompassed by the Northwest Boreal Landscape Conservation Cooperative through FWS funds to the Conservation of Arctic Flora and Fauna program. Specific objectives of the study were to:

1. compile localized vegetation classifications and maps to aid in development of a region-wide classification;
2. compile existing ancillary thematic and remote sensing products to form the inputs for mapping;
3. develop bioclimatic zones and geographic sectors to better partition the variability in floristic characteristics;
4. produce a vegetation map consistent with the CBVM protocols, and
5. modify the map to complete the area within the Northwest Boreal LCC. The mapping approach is similar to that used for the map of the natural vegetation of Europe (Bohn et al. 2000).
Methods

Data Compilation


To support the integrated-terrain-unit mapping approach for the CBVM project we compiled satellite images and map data on climate, topography, geology, and fire history (Table 1). The basis of the mapping was mosaicked MODIS images that were projected for our regional mapping. Numerous climatic indices based on the PRISM climate data were already developed by Hamann et al. (2013).

Table 1. List of data inputs used in mapping.

<table>
<thead>
<tr>
<th>Map Product</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Cover</td>
<td>Alaska statewide Landcover (Selkowitz and Stehman 2011) and Canada land cover map (CCRS 1999).</td>
</tr>
<tr>
<td>Surficial Geology</td>
<td>Surficial geology of Alaska (Karlstrom 1964). Surficial geology of Canada (Fulton 1995)</td>
</tr>
<tr>
<td>Glaciation Limits</td>
<td>Alaska Paleoglaciers Atlas: <a href="http://instaar.colorado.edu/groups/QGIL/ak_paleoglaciers_atlas/">http://instaar.colorado.edu/groups/QGIL/ak_paleoglaciers_atlas/</a></td>
</tr>
<tr>
<td>Mean Annual Precip.</td>
<td>See above.</td>
</tr>
<tr>
<td>Growing Deg. Days</td>
<td>See above.</td>
</tr>
<tr>
<td>Continentality</td>
<td>Derived from continentality and growing degree days.</td>
</tr>
<tr>
<td>Bioclimate</td>
<td>See above.</td>
</tr>
<tr>
<td>Fire History</td>
<td>Alaska Interagency Coordination Center (<a href="http://afsmaps.blm.gov/imf/imf.jsp?site=firehistory">http://afsmaps.blm.gov/imf/imf.jsp?site=firehistory</a>), and Canadian Wildland Fire Information System (<a href="http://cwfis.cfs.nrcan.gc.ca/datamart">http://cwfis.cfs.nrcan.gc.ca/datamart</a>)</td>
</tr>
<tr>
<td>Treeline</td>
<td>Manually interpreted from Landsat Geocover</td>
</tr>
<tr>
<td>Physiography</td>
<td>Manually interpreted from MODIS imagery and Landsat Geocover</td>
</tr>
</tbody>
</table>

A new treeline map was developed to better define the northern limits of boreal vegetation. While there was an existing circumpolar treeline (Walker et al. 2002) it was inconsistent with modern imagery and needed improvement. For our purposes, we used the physiognomic (biologic) forest line definition of Tuhkanen (1993) for the limit of continuous forest. For the new treeline, we used the Landsat Geocover mosaic (Table 1) to manually interpret the boundaries of nearly contiguous forest patches along the margins of the boreal zone. As implemented, this is more appropriately a forest boundary evident on moderate-resolution imagery, rather than the traditional concept of treeline that includes lower density individual trees at the limits of tree reproduction. After manual image interpretation of the Geocover Landsat mosaic, it was compared to the distribution of broadleaf and coniferous forest classes on the statewide NLCD land cover map (Selkowitz and Stehman 2011) and revised where needed.
Bioclimates

Bioclimatic zonation of Alaska followed the approach of Rivas-Martinez and Sánchez-Mata (2011) based on temperature and precipitation indices. We used indices, primarily mean annual temperature (MAT), mean annual precipitation (MAP), growing degree days (GDD, base 5 °C), and continentality, calculated from higher-resolution regional gridded PRISM climatic data (Hamann et al. 2013) and available online (Table 1). In addition, we included fire history as an indicator of climate-induced disturbance. While the classification was based on the system by Rivas-Martinez and Sánchez-Mata (2011), cutpoints were adapted to the available PRISM-based indices, and to better differentiate ecological zonation in transitional areas. We used growing degree days, instead of the ‘It’ warmth index, because it was available and is widely used in forest ecology. We also modified the terminology for thermotypes (based on growing degree days) to use terminology more readily understandable to a broader audience (e.g., warm vs thermo, cold vs supra) and to avoid terms related to topography (e.g., oroboreal).

Table 2. Continentality (Ic) and thermotype (based on growing degree days, GDD) classes.

<table>
<thead>
<tr>
<th>Continentality</th>
<th>Ic</th>
<th>Thermotype</th>
<th>GDD (base 5 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperoceanic (H)</td>
<td>&lt;11</td>
<td>Cryic</td>
<td>100-300</td>
</tr>
<tr>
<td>Oceanic (O)</td>
<td>11-21</td>
<td>Frigid</td>
<td>300-700</td>
</tr>
<tr>
<td>Subcontinental (S)</td>
<td>21-28</td>
<td>Cold</td>
<td>700-920</td>
</tr>
<tr>
<td>Continental (C)</td>
<td>28-46</td>
<td>Cool</td>
<td>920-1200</td>
</tr>
<tr>
<td>Hypercontinental (Y)</td>
<td>&gt;46</td>
<td>Warm</td>
<td>&gt;1200</td>
</tr>
</tbody>
</table>

The bioclimate indices were used at several stages. First, they were used to help identify the boundaries of the provinces and sectors. Second, during mapping the bioclimate maps were frequently used to review polygon boundaries, especially in mountainous areas. Third, after the initial map was completed, the mean values of selected bioclimate indices (Continentality, GDD, MAT) were calculated and assigned to each polygon. These values were then referred to when assigning the vegetation codes to each polygon.

Provinces and Geographic Sectors

To establish the boundaries of the Alaska-Yukon and Aleutian provinces that formed our mapping domain, we: (1) developed a new treeline to define the western and northern boundaries of the province (described above); (2) compiled existing studies of floristic and biogeographic zonation; (3) compiled data on the distribution of abundant and endemic plant species that helped identify the species characteristic of the region; and (4) used the bioclimate indices to help resolve boundaries. Compilation of existing biogeographic zonation included: biogeographical provinces from Udvardy (1975), biotic provinces of North America (Dice 1943), forest regions of Canada (Rowe 1972), floristic regions of the world (Takhtajan 1986), floristic regions of Alaska (Murray and Lipkin 1987), ecoregions of Canada (Wiken et al. 1993), ecoregions of the world (Bailey 1996), biotic communities of North America (Brown 1998), terrestrial ecoregions of North America (Ricketts 1997), floristic plant geography of North America (McLaughlin 2007), and Alaska biomes (Simpson et al. 2007).

Geographic sectors were differentiated by both bioclimatic zonation and regional distribution of characteristic species. The geographic sectors primarily reflect the bioclimates of low elevations. For plant distributions, we relied on distribution maps in Hulten (1968), Cody (1996), E-Flora BC (http://ibis.geog.ubc.ca/biodiversity/eflora/) and digital range maps of North American trees (Little 1971).

Vegetation Classification and Mapping

Vegetation was classified and mapped at two hierarchical levels: (1) formations that differentiated zonal, extrazonal, and azonal systems; and (2) geographic sectors (variants) based on dominant species that reflect broad longitudinal zonation. Bioclimatic data were included as mapping attributes and were used at both the formation (elevational zonation, e.g., alpine) and geographic variants (regional zonation, e.g., northern). The CBVM hierarchical system includes a Level 3 for differentiating plant communities, but this level was not mapped at this small scale. This reduction to a two-level system was adopted at the 2014 Helsinki CBVM Workshop to: (1) reduce the complexity of the mapping from the original five-level mapping system (formation type, formation group, formation, bioclimatic subdivision, and geographic variants (Talbot and Meades 2011); (2) simplify legend
description and map coding; and (3) be more consistent with the map on the natural vegetation of Europe (Bohn et al. 2000), which has two main levels and additional subdivisions for some classes. For describing vegetation classes, plant communities/associations were compiled from the literature and simply grouped within the structural and environmental classification at the Formation Level 1 without attempting to do a comprehensive numerical analysis of plant communities. At our mapping scale, the classification of zonal vegetation is roughly equivalent to the alliance level of vegetation classification (Vegetation Subcommittee 2008, Faber-Langendoen et al. 2014). For taxonomic nomenclature we use the Flora of North America and USDA Plants Database.

Mapping used an integrated-terrain-unit approach that involved ten steps. First, existing land cover maps and ground-reference data were obtained from the literature and land management agencies. Second, relationships among vegetation and terrain characteristics were obtained from the literature as a guide for interpreting satellite imagery. Third, ancillary statewide/provincial/territory map data were compiled, including topography (DEM), bedrock geology, surficial geology, land cover, and climatic maps for mean annual air temperature and precipitation (Table 1). Fourth, boreal vegetation was delineated over the MODIS satellite imagery (250-m resolution) through manual image interpretation and digitizing of vector boundaries. Fifth, each polygon was attributed using an integrated-terrain-unit approach that included classifications for bioclimate, physiography, generalized geology, permafrost, disturbance, growth form, geographic sector, water %, and vegetation formation at Level 1. Sixth, the boundaries were reviewed over the ancillary data and higher-resolution Geocover mosaic and revised if needed. Seventh, Level 2 geographic variants were coded by sorting and integrating bioclimate, geographic sector, and formation characteristics. Eighth, a consistency review was done by cross-tabulating attributes and overall review of the coded Level 2 classes with maps of topography, climate, and MODIS imagery. Ninth, polygon sizes were evaluated for consistency with map specifications and undersized polygons (with exceptions for coastal islands and prominent small features such as large volcanoes along the Aleutian islands) were aggregated with adjacent polygons. Tenth, thematic maps were developed for bioclimate, geographic sector, physiography, and vegetation class to illustrate products derived using the integrated-terrain-unit mapping approach.
Results

Bioclimates

Bioclimatic zones were developed using PRISM climate data for the Alaska-Yukon study area (Figures 1 and 2). The primary indices included mean annual temperature (MAT), mean annual precipitation (MAP), mean July temperature, growing degree days (GDD, base 5 °C), and continentality. The climatic indices, primarily continentality and GDD, were used to develop 12 bioclimatic zones with the study region (Figure 3).

The climatic gradient across the region extends from the hypercontinental continentality and cool summers of the Yukon Flats to the hyperoceanic continentality and cold summers of the Aleutians. The bioclimates also show a large topographic gradient, so that within any one region summer temperatures (GDD) can range from cool in the lowlands to frigid at high elevations in the mountains, with the highest mountains having a cryic (nearly continuously frozen) temperature regime.

Fire frequency, which provides an indirect indicator of climatic conditions and is important to successional dynamics, showed large differences across the study area. Fires have been frequent and widespread in areas with continental-cool bioclimate, infrequent and less extensive in areas with subcontinental-cool and continental-cold bioclimates, and absent in areas with oceanic-cold bioclimate. Due to the high-frequency of fires in areas with a continental-cool bioclimate, we classified the vegetation in these areas as having mixed coniferous-broadleaf forests on mesic sites because the high-frequency of disturbance prevents late successional forests without a broadleaf component from becoming dominant.
Figure 1. Maps of mean annual temperatures (top) and precipitation (bottom).
Figure 2. Maps of continentality (top) and growing degree days (bottom). Fire history (gray polygons) is superimposed on continentality.
Figure 3. Bioclimatic zonation based on continentality and growing degree days.
Provinces and Geographic Sectors

The study area, the Alaska-Yukon region of northwestern North America, was divided into two biogeographic provinces, the Alaska-Yukon and Aleutian biogeographic provinces, based on bioclimatic and floristic differences. The extent, dominant bioclimates, characteristic plant species, and problematic issues for defining the provinces are discussed below.

The Alaska-Yukon Province encompasses the central and northern portions of boreal Alaska, most of the Yukon Territory, a portion of adjacent Northwest Territories, and the northwestern boreal region of British Columbia. It is bounded on the north and west by treeline. On the south it extends to the Sitka spruce and hemlock forests of the hyperoceanic bioclimate of southeastern Alaska and to the more temperate Sub-boreal and Engelmann spruce forests of British Columbia. In the east it extends to the eastern edge of the Rocky Mountains in B.C. and the Northwest Territories. The Province has a continental to subcontinental climate and summer temperatures, as indicated by growing degree days (base 5°C), are sufficient for coniferous and broadleaf tree growth. Characteristic tree species that dominate the vegetation include White spruce (Picea glauca), Black spruce (Picea mariana), Tamarack (Larix laricina), Alaska paper birch (Betula neoalaskana), Quaking aspen (Populus tremuloides), and Balsam poplar (Populus balsamifera). The province has roughly 50 endemic species (depending on how isolated occurrences in adjacent regions are treated) and an additional ~10 subspecies and varieties.

The Aleutian Province includes the Aleutian islands and the southern portion of the Alaska Peninsula. It has an oceanic climate with cold summer temperatures and high mean annual precipitation. While it has a distinctive treeless vegetation and bioclimate, its flora is an amalgam of Asia, Arctic, and boreal influences with few endemic species (Talbot et al. 2010, Garroutte and Ickert-Bond 2013). The Panarctic Flora project (2011) suggested that an Aleutian-Bering Sea insular region could be justified floristically, but here we excluded the Northern Bering Sea Islands from the Aleutian Province because of the disparate floristic composition between the island groups (Garroutte and Ickert-Bond 2013).

Geographic sectors were differentiated within the provinces to reflect differences in bioclimates and vegetation ranges, with four sectors within the Alaska-Yukon Province and one sector within the Aleutian Province (Figure 4). The bioclimate and distinguishing biophysical characteristics of each sector are described below.

The Northern Alaska-Yukon sector covers most of the Yukon River basin. It has predominantly continental-frigid and continental-cold bioclimates; continuous permafrost; and vegetation dominated by coniferous woodlands with very little broadleaf forests; and Populus tremuloides and Larix laricina are scarce. Fires are frequent, but vegetation usually recovers to spruce forests during early regeneration. This area was differentiated as having distinct ecoregions by Nowacki et al. (2002), and is noted for being a broad forest-tundra transition zone (Chapin et al. 2006).

The Western Alaska sector is similar to the Northern Alaska-Yukon sector but has slightly more subcontinental climate and permafrost is discontinuous. Vegetation dominated by coniferous woodlands and abundant shrublands, with very little broadleaf forests, and Populus tremuloides and Larix laricina are uncommon. While difference with the Northern Alaska-Yukon sector are minor, we kept this area as a separate sector, because it is transitional and could be useful for future mapping and modeling efforts. This area was differentiated as having distinct ecoregions by Nowacki et al. (2002), and by Simpson et al. (2007) due to the lack of deciduous forest and abundance of shrublands.

The Yukon sector mostly has a continental-cool bioclimate with lesser amounts of continental cold and continental-frigid areas at higher elevations; permafrost is discontinuous with widespread thermokarst; vegetation is dominated by mixed coniferous-broadleaf forests due to high fire frequency; and Populus tremuloides is a common component of the forests. This area is similar to the intermontane boreal zone of Nowacki et al. (2002), the boreal forest of Simpson et al. (2007), and the Boreal Eucontinental Alaskan and the northwestern portions of the Cassiar subsectors of Rivas-Martinez et al. (1999).

The Southern Alaska sector ranges from the Bristol Bay lowlands and Alaska Peninsula to the Wrangell Mountains. It has mostly has a subcontinental cool bioclimate, with subcontinental-frigid at higher elevations, permafrost is mostly sporadic, and glaciers and icefields are widespread. Vegetation dominated by herb-rich mixed forests, subalpine woodlands, and extensive shrublands near the western forest margins, and it has some of the largest coastal meadows in the world. Populus trichocarpa and Betula papyrifera var. kenaica trees are common trees,
Figure 4. Geographic sectors used to help differentiate floristic patterns within the Alaska-Yukon and Aleutian Provinces. State, province, and territory boundaries in gray, NWBLCC boundary in dark blue.
while *Populus tremuloides* is uncommon and *Larix laricina* is absent. It is a transitional area between the continental and oceanic bioclimates and has been differentiated as Alaska Range Transition and Coastal Mountain Transition ecoregions by Nowacki et al. (2002). We include the Aklun Mountains, which was part of the CAVM map, because of the floristic similarity with the rest of this sector. The central flats of the Cooper River Basin is included in this sector for regional continuity, but vegetation in the area was mapped as part of the Yukon sector because of its continental bioclimate and prevalence of fires and aspen.

The Liard-Stikine sector encompasses much of the Liard River and upper portions of the Stikine River basin. It has mostly has a subcontinental cool bioclimate, with subcontinental-frigid at higher elevations; permafrost is mostly sporadic. *Picea glauca* forests and woodlands predominate, while Lodgepole pine (*Pinus contorta*) dominates in some areas with extensive fire history and Subalpine fir (*Abies lasiocarpa*) occurs in some mature forest stands with increasing in prevalence in upper elevation woodlands. *Populus tremuloides* stands, sometimes with a (*Betula neoalaskana*) component, form extensive patches in localized areas with frequent fire history. *Larix laricina* is virtually absent. This area is included in the Alaska-Yukon Province due to its similarity in floristics and its Cordilleran boreal climate. Demarchi (2011) and Ecological Stratification Working Group (1996) separate the Cordilleran boreal from the plateau regions to the east, and Ecological Stratification Working Group (1996) combines the northern British Columbia and southern Yukon cordilleran boreal into a Boreal Cordilleran Ecozone. This region has a less continental climate than other sectors of the Alaska-Yukon province, due to a slightly greater influence of maritime air masses.

The Aleutian sector extends from the middle of the Alaska Peninsula to Attu Island at the east end of the Aleutian Islands in Alaska. The bioclimates are predominately oceanic-cold at low elevations and oceanic-frigid at high elevations, permafrost occurs only at high elevations, vegetation is dominated by dwarf scrub and meadows, and trees are absent. The Eastern Aleutians was differentiated from the Western Aleutians (Commander Islands and westward), because of the more Asiatic influence of the vegetation in the western portion. Our map only covers the Alaskan portion of the province. The boundary of the sector along the Alaska Peninsula is consistent with the bioclimate zonation, although we recognize that the region is a transition zone, particularly for alder thickets (Talbot et al. 2005). The western portion of Kodiak Islands was included in this sector, with the eastern portion of the island excluded from the boreal because of the presence of Sitka spruce, similar to the differentiation of Viereck and Little (1971).

Our regionalization is most similar to that of Rivas-Martinez and Sanchez-Mata (2011), but a comparison of our provinces and sectors with other schemes reveals several problematic areas. First, we differentiated the Aleutians as a boreal province consistent with Rivas-Martinez and Sanchez-Mata (2011) and its exclusion from the circumboreal vegetation map (Walker et al. 2002). While it has a distinctive vegetation and bioclimate, its flora is an amalgam of boreal, Arctic, and Asian influences with few endemics (Talbot et al. 2010, Garrouette and Ickert-Bond 2013) that may be insufficient to justify differentiation at the province level. Many studies, however, differentiate the floristics of the region at the global or continental scale (Dice 1943, Udvardy 1975, Elvebakk et al. 1999). Second, the Liard-Stikine portion of the AY province transitions into zones with more eastern and temperate flora. Our map is consistent with the ecological zonation of northern British Columbia by Meidinger and Pojar (1991), the biotic provinces of Dice (1943), and the Northern Cordillera Boreal Forest of Ricketts (1999), but inconsistent with the ecoregions map of Canada (Wilken 1993). While we recognize that southeastern Yukon and northern British Columbia have some species common with eastern and more temperate regions, there are also many species of Alaska-Yukon distribution and the edge of the Cordillera makes a convenient physiographic boundary. Third, some members of the CBVM team consider the Sitka spruce-Hemlock forest of coastal Alaska and British Columbia part of the boreal biome, but there is a long tradition of distinguishing the coastal rainforest as separate (Rowe 1971, Viereck and Little 1972, Udvardy 1975) because of the large floristic differences. While we note that Rivas-Martinez et al. (1999) and Rivas-Martinez and Sanchez-Mata (2011) place the northern coastal rainforests within a Boreal Oceanic Alaskan Province within the North-Western Pacific Subregion, their floristic analysis also recognizes the large floristic difference by differentiating its vegetation at the highest level (Order Va, *Tsugetalia mertensiano-hetephyllae*).
Vegetation Classification and Mapping

Map Unit Descriptions

Within the Alaska-Yukon (AY) and Aleutian Provinces, 12 zonal and 9 azonal geographic variants were differentiated at Level 2 by combining formations at Level 1 (physiognomic and environmental conditions) with geographic sectors at Level 2. The zonal types represent the large-scale mature (climax) vegetation response to regional climatic conditions under mesic soil conditions, whereas, the azonal classes represents vegetation that is more influenced by edaphic factors than by climate (e.g. wetland, alluvial vegetation, halophytic vegetation). Below, we discuss their dominant and characteristic species, typical landscape conditions, and reference similar vegetation classes described by floristic studies or regional mapping efforts. The descriptions are grouped by zonal and azonal classes, and subsequently ordered by the formation level. Representative photographs are provided in Figures 5–7.

Figure 5. Photographs of alpine and subalpine classes (photos by M. Fleming and Meidinger,).
Figure 6. Photographs of mesic forest classes, scrub, and heath-meadow classes (photos by M. Fleming, Meidinger, and J. Pearson).
Figure 7. Photographs of wet and dry forest, mires, floodplains, and coastal classes (photos by M. Fleming and Jorgenson).
Zonal Vegetation

Central-Northern Alaska-Yukon Alpine Dwarf Scrub and Meadows is dominated by dwarf and prostrate shrubs (Betula nana, Dryas octopetala, Salix arctica, Vaccinium uliginosum, V. vitis-idaea, Loiseleuria procumbens, L. decumbens, Empetrum nigrum, Cassiope tetragona) with graminoids (Hierochloe alpina, Festuca altaica, Carex nardina, Luzula multiflora), forbs (Oxytropis nigrescens), mosses (Hylocomnium splendens, Racomitrium lanuginosum, Rhytidium rugosum), and lichens (Flavocetraria spp., Cladina spp., Stereocaulon spp.) on dry sites, interspersed with herbaceous meadows dominated by sedges (Carex bigelowii, Eriophorum angustifolium, E. vaginatum) and forbs (Saxifraga spp.) on mesic to wet sites. It has a continental-frigid bioclimate, permafrost is continuous, and occurs on residual soils, talus, colluvium, and glacial till. The alpine zone is vegetated between ~1000–2000 m and partially vegetated to barren above 2000 m. The diverse class includes the alpine rocky dry dwarf shrub, alpine rocky moist low shrub, and alpine wet meadows of Jorgenson et al. (2001), alpine non-carbonate and carbonate Dryas dwarf shrub classes of Jorgenson and Heiner (2004), and the Dryas integrifolia-Oxytropis nigrescens association of Pojar and Stewart (1991). This class extends into the more subcontinental bioclimate of the Liard-Stikine sector.

Southern Alaska-Yukon Alpine Dwarf Scrub and Meadows is dominated by dwarf and prostrate shrubs (Vaccinium uliginosum, V. vitis-idaea, Cassiope stelleriana, Luettea pectinata, Phyllodoce aleutica, Empetrum nigrum, Dryas integrifolia, Salix arctica, S. polaris, Ledum decumbens) with forbs (Oxytropis nigrescens, Sanguisorba stipulata, Veratrum viride, Aconitum delphinifolium, Lupinus spp.), graminoids (Hierochloe alpina, Festuca altaica, Luzula multiflora, Carex microchaeta, C. podocarpa) and lichens (Cladina rangiferina, Thamnolia vermicularis). This class is similar to the dwarf alpine scrub of Clark and Duffy (2006); the rocky alpine moist low shrub, moist dwarf shrub, and dry dwarf shrub ecotypes of Jorgenson et al. (2003), and the alpine ecotypes of Wells et al. (2013).

Aleutian Alpine Dwarf Scrub and Meadows is dominated by dwarf and prostrate shrubs (Cassiope lycopodioides, Vaccinium uliginosum, Empetrum nigrum, Phyllodoce aleutica, Salix arctica, Loiseleuria procumbens) and meadows (Calamagrostis nutkaensis, Luzula arcuata spp. unalascensis) with mosses (Racomitrium lanuginosum, R. ericoides) and lichens (Thamnolia vermicularis, Cladina arbuscula). This class has an oceanic-frigid bioclimate, permafrost status is poorly known, and occurs on residual and hillside colluvium at elevations above 300 m. The class includes the Phyllodoce aleutica heath and Vaccinium uliginosum-Thamnolia vermicularis fellfield associations described by Talbot et al. (2010).

Yukon Subalpine Spruce Woodlands and Scrub is dominated by woodland to open spruce (mostly Picea glauca, occasionally P. mariana), interspersed with tall and low shrubs (Salix glauca, S. pulchra, Betula glandulosa, Vaccinium uliginosum). The understory has dwarf shrubs (Empetrum nigrum, V. vitis-idaea, S. reticulata), sedges (C. bigelowii), grasses (Festuca altaica), feathermosses (Hylocomnium splendens, Pleurozium schreberi), and lichens. The class occurs at high elevations (~900–1200 m), and has continental cold to frigid bioclimates, continuous to discontinuous permafrost, and usually occurs on residual soils and hillside colluvium on upper slopes and shoulders. This class is similar to the high elevation coniferous woodland and open forests of Jorgenson et al. (1996), treeline black spruce shrub classes of Jorgenson and Heiner (2004), and the Dryas integrifolia-Oxytropis nigrescens association of Pojar and Stewart (1991). This class extends into the more subcontinental bioclimate of the Liard-Stikine sector.

Southern Alaska Subalpine Spruce Woodlands and Scrub is dominated by white spruce (P. glauca), interspersed with tall and low shrubs (Alnus viridis ssp. crispa, S. alaxensis, Salix glauca, S. barclayi, Betula nana, Dasiphora fruticosa). The understory is dominated by dwarf shrubs (Vaccinium vitis-idaea, Empetrum nigrum, Rubus arcticus), herbs (Chamerion angustifolium, Geranium erianthum, Sanguisorba stipulata, Angelica lucida, Gymnocarpium dryopteris, Dryopteris dilatata ssp. americana), graminoids (Calamagrostis canadensis, Festuca altaica, Carex podocarpa), feathermosses (Hylocomnium splendens, Pleurozium schreberi), and sphagnum mosses. Deciduous forest patches (P. balsamifera) occasionally occur on steep, warm, upper slopes. The climate is subcontinental and permafrost occurs mostly on steep, north-facing slopes. These open forests and woodlands are found on mountain slopes and high plateaus, mostly between about 900-1200m (occasionally to 1500m) elevation. Glacial till and hillside colluvium are the main parent materials. This class is similar to: the boreal subalpine spruce woodland ecotype described by Jorgenson et al. (2008); Interior-dwarf needleleaf permafrost woodlands of the Boreal Low Mountains subsection of Clark and Duffy (2006), white spruce/resin birch/sphagnum and white spruce-paper birch/alder/Sphagnum class of Viereck (1979) for southwestern Alaska; and subalpine classes of Wells et al. (2013).
Liard-Stikine Subalpine Spruce-Fir Woodlands and Scrub is characterized by open stands of white spruce (P. glauca) and subalpine fir (Abies lasiocarpa), interspersed with tall and low shrubs (Salix glauca, Betula nana). The understory includes dwarf shrubs (Vaccinium vitis-idaea, Empetrum nigrum), graminoids (Festuca altaica) and feathermosses (Hylocomium splendens). Stands of lodgepole pine can occur on recent burns, on dry sites, or co-dominating with white spruce and subalpine fir. Deciduous forest patches (Populus tremuloides, P. balsamifera) are uncommon, occurring only on some very steep, warm slopes. Recent burns can be dominated by willows. The climate is subcontinental, but with less maritime influence than areas immediately on the lee of the coastal mountains. Permafrost is mostly restricted to steep, north-facing slopes. These open forests and woodlands are found on mountain slopes and high plateaus, mostly between about 900-1500m elevation. Glacial till and hillside colluvium are the main parent materials. This class is equivalent to the Spruce–Willow–Birch zone of Pojar and Stewart (1991) and similar to the Boreal High of Yukon (Environment Yukon 2015b).

Northern Alaska-Yukon Spruce Woodlands and Scrub has a woodland to open forest canopy of coniferous trees (mostly Picea glauca, occasionally P. mariana), interspersed with shrublands with tall shrubs (Alnus viridis ssp. crispa, Salix bebbiana) and low shrubs (Betula nana, Salix pulchra, S. glauca, Vaccinium uliginosum). The understory commonly has dwarf shrubs (Ledum palustre ssp. decumbens, Empetrum nigrum, V. vitis-idaea), grasses (Calamagrostis canadensis), sedges (Carex bigelowii), feathermosses (Hylocomium splendens, Pleurozium schreberi), and lichens (Cladina rangiferina). Deciduous forest patches (Populus balsamifera, Betula neosalaska) are uncommon and several species (Populus tremuloides, Larix laricina, Alnus incana ssp. tenuifolia, Salix scouleriana) common to central AY rarely occur. The climate is continental cold, permafrost is continuous, and the class occurs on residual soils and hillside colluvium on middle to upper slopes and well drained soils on flats. This class is similar to the Picea glauca-Ledum decumbens (acidic) and Picea glauca-Dryas integrifolia (alkaline) associations of Jorgenson et al. (2009), and the Upland Spruce Forest of Alaska (Jorgenson and Heiner 2004). The vegetation has been referred to as forest-tundra transition (Chapin et al. 2006) or subarctic woodlands, and some of our area falls within the Taiga Cordillera of the Canadian ecological framework (ESWG 1999). Because of little floristic variation with altitude, a subalpine woodland in not differentiated in the Northern Alaska-Yukon sector.

Yukon Mixed Spruce-Birch-Aspen Forests have a mixture of coniferous (Picea glauca) and deciduous (Betula neosalaska) trees across the range of post-fire successional stages. The understory commonly has tall and low shrubs (Alnus viridis ssp. crispa, Rosa acicularis), dwarf shrubs (Vaccinium vitis-idaea. Ledum groenlandicum, Linnea borealis), forbs (Cornus canadensis, Chamerion angustifolium, Geocaulon lividum), grasses (Calamagrostis canadensis) and mosses (Hylocomium splendens, Pleurozium schreberi). The climate is continental-cold, permafrost is discontinuous, and the class occurs on well-drained soils on residual soils, hillside colluvium, and loess. The class is similar to the upland spruce-birch-aspen class of Van Cleve et al. (1983), upland moist needleleaf, mixed, and broadleaf forest ecotypes of Jorgenson et al. (1999), and various spruce, birch, and aspen mixed stands of Youngblood (1993).

Southern Alaska Spruce-Birch-Herb Forests have a mixture coniferous (Picea glauca) and deciduous (Betula kenaica, Populus trichocarpa) trees. The understory has tall (Alnus viridis ssp. sinuata, Salix scouleriana, S. bebbiana), low shrubs (Viburnum edule, Vaccinium vitis-idaea, Empetrum nigrum), ferns (Gymnocarpium dryopteris, Dryopteris dilatata, Athyrium filix-femina), herbs (Cornus sutchuen, Linnaea borealis, Trientalis europaea ssp. arctica, Geranium erianthum, Aconitum delphinifolium, Streptopus amplexifolius), and grasses (Calamagrostis canadensis). The climate is subcontinental-cold, permafrost occurs only in isolated patches, and well drained soils occur on hillside colluvium, glacial till, and outwash. The class is similar to the upland rocky mixed forest ecology of Jorgenson et al. (2003), the lowland loamy mixed forest ecotype of Wells et al. (2013), and the forest types of Wibbenmeyer (1982).

Liard-Stikine Spruce-Birch-Aspen Forests are dominated by mixtures of spruce (Picea glauca) and deciduous (Populus tremuloides, Betula neosalaska) trees, with occasional lodgepole pine (Pinus contorta) in a range of successional stages after fire. The understory includes tall shrubs (Alnus viridis ssp. crispa), low shrubs (Shepherdia canadensis, Rosa acicularis, Viburnum edule), dwarf shrubs (Vaccinium vitis-idaea, Linnaea borealis) and feathermosses (Pleurozium schreberi, Hylocomium splendens). Populus tremuloides and Pinus contorta form more extensive forests in areas of frequent fires. Picea mariana forests are rare on uplands, but dominate wetlands. Abies lasiocarpa stands are sometimes present, particularly at higher elevations or in areas that have escaped fire for long periods. It has a subcontinental to continental-cold bioclimate, permafrost occurs in isolated patches, and occurs on glacial till and hillside colluvium on lower mountain slopes below 900-1000 m elevation. These forests are in the Boreal White and Black Spruce zone (DeLong et al. 2011) of British Columbia (mostly ‘Dry Cool’ subzone; part of ‘Moist Cool’ subzone) and Boreal Low Zone (Environment Yukon 2015a) of Yukon (Liard Basin subzone).
Southern Alaska Alder-Willow-Dwarf Birch Scrub comprised of both tall scrub (Alnus viridis ssp. sinuata, Salix barclayii, S. scouleriana, Sambucus racemosa) and low scrub classes (Betula nana, Salix pulchra, Vaccinium uliginosum). The alder tall shrub class has abundant herbs (Gymnocarpium dryopteris, Dryopteris dilatata ssp. americana, Heracleum maximum, Trientois europaea, Chamerion angustifolium, Aconitum delphiniiolium) and grasses (Calamagrostis canadensis). In the low shrub class, other common species include Rubus arcticus, R. chamaemorus, Spirea beauverdiana, lichens in drier areas and Sphagnum mosses in wetter areas. This type has a subcontinental-cold bioclimate, permafrost is absent, and it occurs on hillside colluvium and glacial till. The alder tall shrub type is abundant at higher elevations along the mountains in the Alaska Peninsula and Akun mountains and has been described by Talbot et al. (2005), Jorgenson et al. (2003), Clark and Duffy (2005), and Wells et al. (2013). Low shrub classes have been described by Wells et al. (2012) and Wibbenmeyer et al. (1982).

Aleutian Heaths and Meadows is dominated by dwarf shrubs (Empetrum nigrum, Cassiope lycopodioides, Salix arctica), sedges (Carex circinata) and forbs (Geum calthifolium), interspersed with meadows with tall herbs (Heracleum maximum, Angelica lucida, Athyrium filix-femina, Geum macrophyllum, Claytonia sibirica, Cardamine oligosperma var. kamtschatka) and graminoids (Calamagrostis nutkaensis, Carex macrochaeta). The class has an oceanic-cold bioclimate, permafrost is absent, and occurs on residual soils, hillside colluvium, and glacial till. The class comprises the heath and mesic meadow associations described by Talbot et al. (2010).

Azonal Vegetation

Alaska-Yukon Wet Black Spruce Woodlands and Scrub Coniferous is dominated by spruce woodlands (Picea mariana) with minor Tamarack (Larix laricina), interspersed with shrublands dominated by low and dwarf shrubs (Ledum groenlandicum, Vaccinium uliginosum, Vaccinium vitis-idaea, Dasiphora fruticosa). Understory has horsetails (Equisetum sylvaticum), forbs (Rubus chamaemorus), sedges (Carex bigelowii, Eriophorum vaginatum), and abundant mosses (Hylcomium splendens, Pleurozium schreberi, Sphagnum fuscum). Birch forest (Betula nealaskana) occasionally occur. This class has a subcontinental- to continental-cold bioclimate, permafrost is discontinuous with abundant thermokarst in the Yukon sector, and occurs on wet soils associated with abandoned floodplains, retransported, and lacustrine deposits. This class includes the: wet acidic and nonacidic lowland communities of Hollingworth et al. (2006), Picea mariana dominated communities of Foote (1983), lowland wet needleleaf forests and low scrub of Jorgenson et al. (1999), Picea mariana – Vaccinium vitis-idaea alliance of Krestov (2000), and the Picea mariana-Equisetum-Sphagnum association of DeLong et al. (1991).

Yukon Dry Spruce-Aspen Forests have mixtures of coniferous (Picea glauca) and deciduous forests (Populus tremuloides, Betula nealaskana) trees in a range of post-fire successional stages. The understory has low shrubs (Salix glauca, Sheperdia canadensis, Ledum groenlandicum), dwarf shrubs (Arctostaphylos uva-ursi, Dryas integrifolia in northern areas), forbs (Cornus canadensis, Linnea borealis), grasses (Calamagrostis purpurascens, Festuca altaica), lichens (C. stellaris, C. rangiferina, Stereocalon spp.) and mosses (Hylcomium splendens, Pleurozium schreberi). The class has a continental to hypercontinental-cool bioclimate, permafrost is discontinuous to sporadic, and it has excessively drained soils often on eolian sand. Small stands occur, south-facing bluffs grading into steppe bluff vegetation, and rarely occurs in the southern AY. The class includes the: dry forests of Johnson and Vogel (1966); Populus tremuloides-Arctostaphylos uva-ursi community of Youngblood (1993); Populus tremuloides-Shedepria canadensis of DeVelice (1999); upland dry broadleaf forests of Jorgenson et al. (2001); and upland white spruce-drays woodland of Jorgenson et al. (2009).

Yukon Sphagnum Bogs and Herbaceous Fens includes Sphagnum-dominated bogs with dwarf shrubs (Ledum palustre ssp. decumbens, Vaccinium oxyccocus, Andromeda polifolia, Salix fuscus), herbs (Drosera rotundifolia), sedges (Eriophorum scheuchzeri, Carex rariflora, C. limosa, C. livida) and mosses (Sphagnum fuscum, S. balticum, S. flexuosum, S. rubellum, S. angustifolium, S. riparium), interspersed with herbaceous fens with forbs (Menyanthes trifoliata, Equisetum fluviatile, Comarum palustre, Cicutia virosa, Epilobium palustre, Galium trifidum) and sedges (C. rostrata, C. diandra, C. canescens). The bioclimate is subcontinental- to continental cool, permafrost is absent, and occurs on thick organic deposits often associated with thermokarst in the Yukon sector. The class includes the: peat bogs of Drury (1956); lowland bog and fen meadow ecotypes of Jorgenson et al. (1999), and thermokarst bog of Jorgenson et al. (2013).

Southern Alaska Sphagnum Bogs and Herbaceous Fens have Sphagnum-dominated bogs with dwarf shrubs and fens that commonly form distinct string bog patterns, termed boreal aapa mire complexes in Europe. Nutrient-poor fens comprise the majority of the mires and are dominated by sedges (Carex aquatilis, Triophorum caespitosum ssp. caespitosum, C. livida, C. limosa, C. pauciflora, C. chordorrhiza, Eriophorum angustifolium, E.
russeolum), herbs (Comarum palustre, Menyanthes trifoliata, Drosera spp., Equisetum fluviatile), and dwarf shrubs (Andromeda polifolia, Betula nana, Chamaedaphne calyculata, Myrica gale, Salix fuscescens). Common mosses include Drepanocladus aduncus, Sphagnum lindbergii, S. fimbriatum, S. teres, and S. girgensohnii. Islands of wet black spruce woodlands are common. This class includes patterned bogs and bog meadow communities of Rosenberg (1986), and organic-rich bog and sedge meadow ecotypes of Wells et al. (2012).

**Yukon Floodplain Spruce-Poplar Forests and Scrub** are dominated by forests with mixed coniferous (*Picea glauca*) and deciduous (*Populus balsamifera*) trees, interspersed with tall and low scrub (*Alnus incana* spp. *tenuifolia*, *Viburnum edule*, *Salix alaxensis*, *Salix arbusculoides*, *Rosa acicularis*). Other common species include grasses (*Calamagrostis canadensis*), herbs (*Equisetum arvense*), and mosses (*Hylocomium splendens*, *Rhytidiadelphus triquetrus*). In the Northern Y sector, *Dryas* spp. are common on gravelly floodplain steps. The class has a continental-cool to cold bioclimate, permafrost is mostly absent, and occurs on silty to gravelly fluvial deposits. The diverse class includes the: floodplain forests and scrub of Viereck et al. (1993); and riverine ecotypes of Jorgenson et al. (1999, 2004, 2009).


**Southern Alaska Coastal Meadows** is dominated by halophytic wet meadows on tidal flats with graminoids (*Carex ramenskii, Puccinellia phryganodes, C. lymbyae*) and forbs (*Triglochin maritima, Plantago maritima, Argentina egedii* ssp. *gedii*), and dry dunes dominated by graminoids (*Leymus mollis*, *C. macrocephela*, *C. gmelini*) and forbs (*Lathyrus japonicus*, *Ligusticum scoticum*, *Mertensia maritima*). This class has a subcontinental-cool bioclimate, lacks permafrost, and occurs on tidal flats and dunes. This diverse class includes the: halophytic wet meadow and slough and riverbanks communities of Rosenberg (1986), coastal marsh communities of Tande (1996), coastal ecotypes of Jorgenson et al. (2003), and coastal communities of Jorgenson et al. (2010).

**Alaska-Yukon Freshwater and Aquatic Forbs** includes large lakes with or without submergent vegetation (*Nuphar lutea* ssp. *polysepala*, *Sparganium* spp., *Utricularia* spp., *Myriophyllum spicatum*, *Zannichellia palustris*, *Lenma minor*, *Hippuris vulgaris*, *Potamogeton* spp., and *Calliergon* spp.). Regional variation for this class is not well documented. Only very large lakes are mapped. The class includes the: deep marshes and floating-leaved emergents of Rosenberg (1986); aquatic herbaceous communities of DeVelice (1999); lakes and ponds ecotype of Jorgenson et al. (1999); boreal lacustrine pondlily ecotype of Jorgenson et al. (2008); lowland lake ecotype of Jorgenson et al. (2009).

Glaciers and Icefields includes large ice fields and glaciers without vegetation, although nunatak peaks extending above the ice may be sparsely vegetated.
Mapping

The CBVM map for the Alaska-Yukon region encompassed 1,639,751 km², and included the Alaska boreal forest regions, Aleutians, most of the Yukon Territory, and portions of northern British Columbia and western Northwest Territories. The Alaska-Yukon boreal province encompasses 1,590,712 km² and the Aleutians (eastern sector in Alaska only) encompasses 49,039 km².

Vegetation formations were differentiated into 13 classes at Level 1, and were dominated by Alpine Dwarf Scrub and Meadows, Mixed Coniferous and Broadleaf Forests, Subalpine Woodlands and Scrub, and Coniferous Woodlands and Scrub (Figure 8, Table 3). The Aleutian province was dominated by Dwarf Shrub Heaths and Meadows (Oceanic).

Geographic variants were differentiated into 21 classes at Level 2, and were dominated by Yukon Spruce-Birch-Aspen Forests, Central-Northern Alaska-Yukon Alpine Dwarf Scrub and Meadows, Yukon Subalpine Spruce Woodlands and Scrub, Northern Alaska-Yukon Spruce Woodlands and Scrub, and Southern Alaska-Yukon Alpine Dwarf Scrub and Meadows (Figure 9, Table 3). The Aleutian Province was dominated by two vegetation types, Aleutian Dwarf Shrub Heaths and Meadows and Aleutian Alpine Dwarf Scrub and Meadows.

In support of the Northwest Boreal Landscape Conservation Cooperative (NWBLCC), we summarized areal extent of the boreal vegetation types within NWBLCC boundaries (Figure 10, Table 4). Most of the NWBLCC was within the boundaries of the Alaska-Yukon Province, but small portions of the NWBLCC extends into arctic tundra in northern Alaska, Yukon, and Northwest Territories (Arctic Tundra undifferentiated), the coastal rainforests (Northern Pacific Maritime undifferentiated), and temperate coniferous forests in northern British Columbia (BC temperate undifferentiated). Because we did not want to develop detailed classifications for vegetation outside of our study area, we simplify grouped the areas into broad undifferentiated classes.

When comparing our small-scale vegetation mapping with the moderate-resolution land cover mapping of Selkowitz and Stehman (2011), there was substantial correspondence between the land cover types and the regional classification (Figure 11). Our alpine and subalpine classes usually had barren and dwarf shrub land cover types. Our Alaska-Yukon Wet Black Spruce Woodlands and Scrub frequently had the woody wetlands land cover type. Our Yukon Spruce-Birch-Aspen Forests frequently had the deciduous forests and evergreen land cover types.
Figure 8 Map of vegetation formations (level 1) in the Alaska-Yukon region.
Figure 9. Map vegetation geographic variants (level 2) in the Alaska-Yukon and Aleutian boreal provinces.
Table 3. Areal extent (km², Albers Alaska projection) of vegetation formations and geographic variants by boreal province.

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<td>E-Coniferous Woodlands and Scrub</td>
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<td>G-Mixed Coniferous and Broadleaf Forests</td>
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<td>H-Tall and Low Scrub</td>
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<tr>
<td>I-Dwarf Shrub Heaths and Meadows (Oceanic)</td>
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<td>N-Dry Mixed Coniferous and Broadleaf Forests</td>
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<td>O-Mires (organic, peatlands, thermokarst)</td>
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<td>R-Floodplain Mixed Forests and Scrub</td>
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<td>S-Coastal Meadows</td>
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<td>W-Freshwater and Submergent Herbs</td>
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<td>X-Glaciers and Ice Fields</td>
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<tr>
<td><strong>Total</strong></td>
<td>1590712</td>
<td>49039</td>
<td>1639751</td>
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<td><strong>Geographic Variant (Level 2)</strong></td>
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<td>Glaciers and Icefields</td>
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<td><strong>Total</strong></td>
<td>1590712</td>
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</table>
Figure 10  Map of vegetation geographic variants (level 2) within the boundaries of the Northwest Boreal Landscape Conservation Cooperative.
Table 4. Areal extent (km², Albers Alaska projection) of vegetation geographic variants within the boundaries of the Northwest Boreal Landscape Conservation Cooperative. Areas outside of the CBVM boreal region are listed as undifferentiated at the bottom of the table.

<table>
<thead>
<tr>
<th>Vegetation (Geographic Variant, Level 2)</th>
<th>Area (km²)</th>
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<tbody>
<tr>
<td>Central-Northern Alaska-Yukon Alpine Dwarf Scrub and Meadows</td>
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<td>Southern Alaska Alpine Dwarf Scrub and Meadows</td>
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<td>Northern Alaska-Yukon Spruce Woodlands and Scrub</td>
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<td>Glaciers and Icefields</td>
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<tr>
<td>Arctic, undifferentiated</td>
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<tr>
<td>BC Temperate Undifferentiated</td>
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<tr>
<td>NWT Boreal undifferentiated</td>
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<tr>
<td>Northern Pacific Maritime (Undifferentiated)</td>
<td>4769</td>
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<td>NPM Glaciers and Icefields</td>
<td>6510</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,365,932</strong></td>
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</tbody>
</table>
Figure 11. Portion of the CBVM map overlain on the NLCD land cover map of Alaska, illustrating the correspondence between the two disparate vegetation mapping approaches.
Our mapping of the Alaska-Yukon region has several implications for the broader CBVM mapping effort. First, both the MODIS (with review with Landsat) and topoclimate indices (PRISM climate data that incorporates topography) were useful for polygon delineation. The topoclimate is particularly useful for alpine and subalpine delineation. Second, assigning mean climate and elevation values to complete polygons was useful for coding the bioclimatic and vegetation formation attributes of the polygons. Third, extensive review of plant distributions was needed to establish the geographic sectors. This could be more reliably be done with integrated databases of plot information, but such comprehensive data were lacking for our entire region. Fourth, the simplification of the vegetation classification hierarchy into two levels greatly simplified the coding and made the map more consistent with the vegetation map for Europe (Bohn et al. 2000). Fifth, while the minimum size for many of our polygons was below the 560 km² standard, most of these small polygons were coastal islands, and important features, such as high volcanoes along the Aleutians, and large lakes. Our level of detail is consistent with the detail of the European vegetation map (Bohn et al. 2000, 1:10M scale) and the Alaska vegetation map (Viereck and Little 1972, 1:5M scale) that also have numerous small polygons for distinctive features.

Summary and Conclusions

A map of boreal vegetation for the Alaska-Yukon region was developed to contribute to the circumboreal vegetation mapping (CBVM) project. The effort included developing a map of bioclimes with 12 bioclimatic zones, a map of biogeographic provinces with Alaska-Yukon and Aleutian provinces, and a map of geographic sectors with six sectors that provided the basis for classification of boreal vegetation. Vegetation mapping was done at 1:7.5 million scale using the mapping protocols of the CBVM team. Mapping used MODIS imagery as the basis for manual image interpretation and an integrated-terrain-unit approach, which included classifications for bioclimatic, physiography, generalized geology, permafrost, disturbance, growth from, geographic sector, and vegetation. Vegetation was mapped at two hierarchical levels, including: (1) 13 formation groups differentiating zonal and azonal systems; and (2) 21 geographic variants based on bioclimatic zonation and dominant species that characterize broad longitudinal regions or biogeographic provinces. Each of the geographic variants was described by identifying the dominant and characteristic species and its climatic and landscape characteristics, as well as references that relate to the unit.
References


Raynolds, M. K., D. A. Walker and H. A. Maier. 2006. Alaska Arctic Tundra Vegetation Map, Scale 1:4,000,000. U.S. Fish and Wildlife Center, Anchorage, AK.


Simpson, J. J., M. C. Stuart and C. Daly. 2007. A discriminant analysis model of alaskan biomes based on spatial
climatic and environmental data. Arctic 60 (4): 341-369.


Appendix of Mapping Attributes

Conventions

► Published Scale: 1:7.5 M
► Delineation scale: 1:4 M (floodplains @ 1:2 M, 1 mm)
► Minimum size:
  • 3 mm, ~23x23km, 560 km², 560,250,000 m², typical
  • 2 mm, ~15x15km, 225 km², 225,000,000 m², rare-special features
  • 1 mm width for linear features (floodplains, coast) for continuity
► Complexes: Not used, described within Unit description, after Bohn 2000
► Initially identify map units of MODIS, then refine on Landsat

Input layers

► Modis Imagery (USGS)
► GeoCover (Landsat mosaic)
► DEM hillshade (gt30)
► Hydrography (DCW, simplification USGS, CAVM algorithm)
► Bedrock Geology (regional)
► Surficial Geology (regional)
► Glaciation Limits
► Climate Temperature
► Climate Precip.
► Fire History
► Treeline (Growing Degree Days Base 5 deg C: 680 to 740)

Bioclimates

(Required, 2-letter code, continentality-thermotype, e.g. CM)
Continentality Index (Ic), Obrothermic Index (Io), Mean annual temperature (T deg C)

Continentality

H Hyperoceanic (Ic<11, Io>3.6, T<6.0)
O Oceanic Ic=11-21, Io>3.6, T<5.3)
S Subcontinental (Ic=21-28, Io>3.6, T<4.8)
C Continental (Ic=28-46, Io>3.6, T<3.8)
Y Hypercontinental (Ic=>46, Io-, T<0.0)
X Xeric (Ic=>46, Io>3.6, T<3.8)

Thermotype

W Warm (GDD>1200) Approx. Thermoboreal (Tp> 680)
M Meso (GDD=900-1200) Approx. Mesoboreal (Tp=580-680)
C Cold (GDD=700-900) Approx. Supraboreal (Tp=480-580)
F Frigid (GDD=300-700) Approx. Oroboral (Tp=380-480)
Y Cryic (GDD=100-300) Approx. Cryoboreal (Tp=1-380)

Where: Tp=sum of tenths of degrees centigrade of the mean monthly temperatures, above 0°, ΣTi1-12 > 0°C

Physiography

(required)

► I Icefields and Glaciers
► MH Mountains, High (rugged)
► ML Mountains, Low (rounded)
► P Plateau (High flats)
► G Glaciated Uplands
► U Uplands/Hills (without alpine, water shedding)
► O Rolling (low gentle hills, Mixed upland and lowland)
### Geology (optional)

#### Unconsolidated
- **C**: Colluvium (hillside creep, rocky-loamy)
- **Ei**: Eolian silt (loess)
- **Es**: Eolian sand
- **Fy**: Fluvial, young (active-inactive floodplains)
- **Fo**: Fluvial, old (abandoned floodplains, terraces)
- **Fs**: Retransported (lower slopes, valley bottoms)
- **Gd**: Glacial (late Pleistocene, LGM)
- **Gi**: Glaciers and Ice Sheets
- **GL**: Glaciolacustrine
- **GF**: Glaciofluvial Outwash
- **L**: Lacustrine
- **R**: Marine
- **O**: Organic (>40cm, peatlands)
- **W**: Water
- **U**: Undifferentiated

#### Bedrock
- **Sc**: Sedimentary, carbonate
- **Sn**: Sedimentary, noncarbonate
- **Sm**: Sedimentary, mixed
- **Vfy**: Volcanic-felsic and intermediate-younger (partially)
- **Vfo**: Volcanic-felsic and intermediate -older
- **Vmy**: Volcanic-mafic-younger
- **Vmo**: Volcanic-mafic-older
- **Vp**: Volcanic-pyroclastics (tephra)
- **If**: Intrusive-felsic and intermediate (e.g., granitic)
- **Im**: Intrusive-mafic (e.g., gabbro)
- **Iu**: Intrusive-ultramafic (e.g., dunite, serpentine)
- **Mc**: Metamorphic, carbonate
- **Mn**: Metamorphic, noncarbonate
- **Mm**: Metamorphic, mixed
- **BC**: Bedrock Complex

### Permafrost (optional)

#### Continuity
- **C**: Continuous (>90%)
- **D**: Discontinuous (50-90%)
- **S**: Sporadic (10-50%)
- **I**: Isolated (>0-10%)
- **A**: Absent (0%)

Informed by permafrost map, but improve when possible

### Disturbance Factors (optional)
- **Fh**: Fire-high frequency
- **Fl**: Fire-low frequency
Growth Form
(Required, dominant structure)
A Aquatic-Water
P Partially vegetated (<30% veg cover)
B Bryophytes, Mosses
L Lichen
H Herbaceous
Hm Mixed Graminoid/Forb Meadows
Hg Graminoid
Hgt Tussock graminoid
S Shrub
Sp Prostrate Shrub (used in tundra mapping)
Sd Dwarf Shrub (<25 cm)
Sl Low Shrub (25-1.5 m)
St Tall Shrub (>1.5 m)
Fb Broadleaf Forest (deciduous, small leaved, Betula, Populus)
Fm Mixed Forest (needleleaf and broadleaf)
Fn Needleleaf (use coniferous?)
Fned Needleleaf Evergreen Dark-leaved (Picea-Abies)
Fnel Needleleaf Evergreen Light-leaved Forest (Pinus)
Fnm Needleleaf Mixed (Picea, Abies, Pinus, Larix)
Fnd Needleleaf Deciduous Forest (Larix)
I Ice
ND Not determined

Province
Biogeographic province having distinctive flora assemblage, endemics, or vegetation patterns

Geographic Sector
(Required, GeogSector, Province)
Subregion of Province with unique dominant vegetation
NE Northern European (00 series)
SW Western Siberian (10)
SC Central Siberian (20)
SE Eastern Siberian (30)
NS Northeastern Siberian (40)
AS Altai-Sayan (50)
Vegetation Formation

(Level 1, required)

Zonal

- C Alpine Dwarf Scrub and Meadows (vegetation in boreal zone)
- D Subalpine Woodlands and Scrub
- E Coniferous Woodlands and Scrub (10-25% cover)
- F Coniferous Forests (open 25-60% to closed >60%)
- G Mixed Coniferous and Broadleaf Forests
- H Tall and Low Scrub
- I Dwarf Shrub Heaths and Meadows (Oceanic)

Extrazonal

- A Arctic Tundras
- J Broadleaf Forests (extrazonal, or not used?)
- K Dry Grasslands (Steppes)

Azonal

- M Wet Coniferous Woodlands and Scrub (lowlands, permafrost)
- N Dry Mixed Coniferous and Broadleaf Forests (sand dunes, dry soils)
- O Mires (organic, peatlands, thermokarst)
- R Floodplain Mixed Forests and Scrub (riverine)
- S Coastal Meadows (salt-affected)
- W Freshwater and Submergent Herbs
- X Glaciers and Ice Fields
- Y Rock (mountain barrens, lava flows)
- U Undifferentiated

FormSectCode

Unique code for each GeogVari
Code uses Formation code and number for Sector

GeogVari-GEOGRAPHIC VARIANT (Level 2, MapUnit)

Full name Based on combing Formation and Geographic Sector
Bioclimate is provided in description
Name includes dominant species
eg. Yukon Spruce-Birch-Aspen Forests (Continental Cold Boreal)