CAVM Metadata

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Map projection, extent and boundaries

Map projection:

The Lambert Azimuthal Equal Area Projection (LAEA) is the default projection for all CAVM data. Source data not in the default projection was projected to the LAEA projection using either ArcInfo 8.0.2 for unix or ArcGIS 8.3 for windows (ESRI 2000, ESRI 2002).

Projection Parameters:
Longitude of Projection Center = -180
Latitude of Projection Center = 90
False Easting = 0
False Northing = 0
Radius of reference sphere = 6370997

Contents of ArcInfo Projection file:

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Projection    LAMBERT_AZIMUTHAL
Datum         NONE
Zunits        NO
Units         METERS
Xshift        0.0000000000
Yshift        0.0000000000
Parameters 6370997.0000000000  0.0000000000
6370997.00000 /* radius of the sphere of reference
-180  0  0.000 /* longitude of center of projection
90  0  0.000 /* latitude of center of projection
0.00000 /* false easting (meters)
0.00000 /* false northing (meters)
```

Map extent

The map extent is the Arctic, defined as the Arctic Bioclimate Zone [Is this the same the cavm bioclimate subzones or do we need to cite a ref?], the area of the Earth with tundra vegetation and an Arctic climate and Arctic flora. It excludes tundra regions that lack an Arctic flora, such as the boreal oceanic areas of Iceland, the Aleutian Island, and the alpine tundra regions south of latitudinal tree line. Tundra is a physiognomic descriptor of low-growing vegetation beyond the cold limit of tree growth, both at high elevation (alpine tundra) and at high latitude (arctic tundra). Tundra vegetation types are composed of various combinations of herbaceous plants, shrubs, mosses and lichens.
Tree line defines the southern limit of the Arctic Bioclimate Zone. In some regions of the Arctic, especially Canada and Chukotka, the forest tundra transition is gradual and interpretation of treeline

directly from the AVHRR imagery was not possible. Treeline for the CAVM was based on a variety of sources including:

Canada tree line

The treeline for western Canada (Hudson Bay to the Alaskan border) was determined using the northern limit of trees from Timoney, et al. (1992). Timoney defined this border as having a ratio of tree cover to upland tundra of 1:1000. We obtained original maps from Timoney showing treeline and major hydrological features, and redrew the treeline over 1:4 million scale AVHRR imagery as a basemap (see metadata for AVHRR image) and Digital Chart of the World (ESRI 1993) hydrology layers for reference.   Treeline for Eastern Canada (Quebec and Labrador) are based on Payette (1983, 1993) and Zoltai (pers. comm.) with the northern limit of spruce redrawn over the AVHRR 1:4 million baseline map using DCW (ESRI 1993) hydrologic features for reference.

Greenland tree line

All of Greenland is north of tree line, but there are some boreal inclusions mapped on the interior portions of the southern tip of the island. See the metadata for the vegetation mapping of Greenland for more details.

Iceland tree line

Treeline in Iceland was determined by Eythór Einarsson and Gudmundur Gudjónsson. The boundary is based on historical records of the extent of woody vegetation when people first settled the island. Deforestation and erosion since that time make it difficult to determine tree line based on existing vegetation. The true arctic part of Iceland is a low-shrub subzone in northern Iceland. The tundra regions of the Central Highlands of Iceland are alpine rather than arctic. The resulting boundary is in agreement with other Icelandic vegetation maps (Einarsson et al. 2000). A full discussion of these issues can be found in Einarsson and Gudjónsson (2002) **[See note below]**.

Norway tree line

All of the islands of Svalbard, Bjørnøya and Jan Mayen are north of tree line. On the Fennoscandian Peninsula, alpine tundra and boreal inclusions occur along the northern coast. Only a few small areas of arctic vegetation occur close to sea level in northern Norway. Elvebakk (1994) noted that the line demarking these areas coincides well with the 10^{o}C mean July temperature isotherm, the approximate temperature limit for tree growth. Other treeless areas in mainland Norway and on the Kola Peninsula of Russia were considered either alpine or anthropogenic.

Russia tree line

Tree line in Russia was based on Belov (1990) and the Arctic Atlas (Treshnikov 1985). In addition, Andreev (1987) was consulted for Yakutia, Sochava et al. (1976) for Western Siberia, and Belikovich (2001) for the Anadyr area in Far East Russia.

United States tree line

Initial treeline for the Alaska portion of the CAVM was taken from the Major Ecosystems of Alaska 1:2,500,000 map (Joint Federal State Land Use Planning Commission for Alaska, 1973). The Seward Peninsula treeline was obtained from a map produced by the Soil Conservation Service (Swanson, et al., 1985). The boundary in southwestern Alaska is along the watershed between the Kuskokwim (included) and the Nushagak (excluded) Rivers. There are tundra areas south and west of this line, but they have more of a boreal than arctic flora, and are treeless due to the marine influence. Tree line for the Yukon-

Kuskokwim Delta and Seward Peninsula was then adjusted by Martha Raynolds from photo interpretation of the AVHRR image to more precisely follow valleys, ridges, and visible changes in vegetation. Areas with trees appeared darker on the image than areas without trees. **[Skip?, was anything similar done for the north slope?]**

Tree line references

Andreev, V.N. et al. (eds.) 1987. Vegetation Map *in* Agricultural Atlas of Yakutia. Scale 1:5,000,000.

Belikovich, A.V. 2001. Vegetation cover of the northern part of the Koryak Uplands. Russian Academy of Sciences. Far Eastern Branch, Institute of Biology and Soil Science. Vladivostok, Dalnauka. 415p

Belov, V.A. (ed.) et al. 1990. Vegetation map of the USSR. Scale 1:4,000,000. Moscow, Novosibirsk. Head Office of Geodesy and Cartography of the Soviet Ministry of USSR

Einarsson, E. and F. Gudjónsson. 2002. The situation of Iceland in the system used the CAVM mapping **[The paper is listed in of02-181 as "The Position of Iceland in the System Used in the Cavm Mapping" p. 35-39, w/ Einarsson as the sole author. Is this what you want to cite or is there another reference?]**. Pages 43-48 *in* Raynolds, M.K and C. J. Markon. 2002. Fourth International Circumpolar Arctic Vegetation Mapping Workshop. Russian Academy of Sciences, Moscow, Russia. 10-13 April 2001. USGS Open-file Report 02-181 (http://pubs.usgs.gov/of/2002/of02-181/ and http://www.geobotany.uaf.edu/library/reports/of02-181.pdf)

Einarsson, E., Gudjónsson, G., Hansen, H. H. & Jónsson, Th. H. (2000) Map of the Natural Vegetation of Iceland. In: Map of the Natural Vegetation of Europe (eds. Bohn, U., Gollub, G. and Hettwer). Bundesamt fur Naturschutz, Bonn.

Elvebakk, A. 1996. Vegetation zone mapping of northern Fenoscandia and Svalbard. pp45-51 *in* D.A. Walker and C.J. Markon (eds) Circumpolar Arctic Vegetation Mapping Workshop. USGS Open File Report 96-251.ESRI. 1993. Digital Chart of the World. September 1993, Ed. 1. Environmental Systems Research Institute Inc. Redlands, CA, USA

Joint Federal State Land Use Planning Commission for Alaska. July 1973. Major Ecosystems of Alaska 1:2,500,000 map.

Payette, S. 1983. The forest-tundra and present tree-lines of the northern Quebec-Labrador peninsula. *Tree-Line Ecology*. Proceedings of the Northern Quebec Treeline Conference. (eds. P. Morisset and S. Payette) Nordicana, 47:3-23.

Payette, S. 1993. The range limit of boreal tree species in Quebec-Labrador: and ecological and paleoecological interpretation. Review of Paleobotany and Palynology. 79(0993):7-30.

Sochova, V.B. et al. (eds.) 1976. Vegetation map of the West-Siberian plain. Scale 1:1,500,000. Moscow . Head Office of Geodesy and Cartography of the Soviet Ministry of USSR.

Swanson, J.D., Schuman, M., Scorup, P.C. 1985. Range Survey of the Seward Peninsula Reindeer Ranges, Alaska. US Dept. of Agriculture, Soil Conservation Service. 77pp + maps.

Timoney, K.P., G.H. La Roi, et al. 1992. The high subarctic forest-tundra of northwestern Canada: position, width, and vegetation gradients in relation to climate. Arctic, 45(1):1-9.0

Treshnikov, A. F. et al. (eds.) 1985. Arctic Atlas. Head Office of Geodesy and Cartography of the Soviet Ministry of USSR. Moscow. 204pp

Coastline & Islands

The coastline for the CAVM project came from the Digital Chart of the World (DCW; ESRI 1993). This coastline was at a much finer scale than needed for the CAVM project. We simplified the coastline by deleting all the attributes from the DCW and deleting all islands smaller than 49 km^2 using the ARC/INFO ELIMINATE command (Appendix A). The coastline was further simplified by removing any arc verticies that were closer together than 5000m (Arc generalize command, 5000 m weed tolerance, bendsimplify option), and combining any two lines closer than 500m (Arc fuzzy tolerance = 500m). After the initial simplification of the coastline data all subsequent processing of the vegetation data were performed using a 200m fuzzy tolerance.

ESRI. 1993. Digital Chart of the World. September 1993, Ed. 1. Environmental Systems Research Institute Inc. Redlands, CA, USA

Glaciers

The glacier boundaries were taken from the Digital Chart of the World (ESRI 1993). This coverage was much more detailed than needed for the CAVM project, with many tiny polygons below the minimum mapping size. It was simplified in the same way as the coast, deleting all glaciers smaller than 49 km^2, generalizing the arcs, and combining lines closer than 500 m (see Coastline & Islands above). For Canada and Greenland, the glacier coverage was appended to the CAVM coastline file, and became the basis for the polygon coverage. Alaskan glaciers were manually digitized [**NOTE: we need a reference for the source map**]. In some areas of Greenland and northern Canada, polygons were digitized around complexes of ice and land, where the area was < 75% ice. These are shown as nunatak polygons on the CAVM.

ESRI. 1993. Digital Chart of the World. September 1993, Ed. 1. Environmental Systems Research Institute Inc. Redlands, CA, USA

Raster Images

AVHRR image

Advanced Very High Resolution Radiometer (AVHRR) data were obtained from theUSGS Global AVHRR 10-day composite data. (http://edcdaac.usgs.gov/1KM/1kmhomepage.asp). Glaciers and oceans were masked out using information from the Digital Chart of the World (ESRI 1993). The image is composed of 1 x 1-km pixels. The color of each pixel was determined by its reflectance at the time of maximum greenness, selected from 10-day composite images from 11 July to 30 August 1993 and 1995. These intervals cover the vegetation green-up-to-senescence period during two relatively warm years when summer-snow cover was at a minimum in the Arctic. Maximum greenness was determined from the normalized difference vegetation index (NDVI) (Markon et al. 1995). Vegetation greenness is calculated as: NDVI = (NIR - R) / (NIR + R), where NIR is the spectral reflectance in the AVHRR near-infrared channel (0.725-1.1 µ, channel 2) where light-reflectance from the plant canopy is dominant, and R is the reflectance in the red channel (0.58 to 0.68 µ, channel 1), the portion of the spectrum where chlorophyll absorbs maximally. The resulting image shows the Arctic with minimum snow and cloud cover. The selected pixels were then printed as a false-color CIR image (RGB = ch. 2, ch. 1, ch. 1).

Markon, C.J. M.D. Fleming and E.F. Binnian. 1995. Characteristics of vegetation phenology over the Alaskan landscape using AVHRR time-series data. *Polar Record* 31:179-190.

Maps derived from AVHRR image

Elevation

Taken from ESRI. 1993. Digital Chart of the World. September 1993, Ed. 1. Environmental Systems Research Institute Inc. Redlands, CA, USA. *More metadata from Hilmar*

NDVI

The normalized difference vegetation index (NDVI) is a measure of greenness. NDVI was calculated as: NDVI = (NIR - R) / (NIR + R), where NIR is the spectral reflectance in the AVHRR near-infrared channel (0.725-1.1 µ, channel 2) where light-reflectance from the plant canopy is dominant, and R is the reflectance in the red channel (0.5 to 0.68 µ, channel 1), the portion of the spectrum where chlorophyll absorbs maximally (Markon et al. 1995). The grid of NDVI values was produced from the same

AVHRR data as the false-color CIR image **[We should move all of this to the section describing the source of the image**.] Values for NDVI (NDVI=0.008(Gridvalue-127)), which ranged from -0.112 to 1.000 (grid integer values 113 to 252), were divided into 8 categories that were useful in distinguishing vegetation patterns: <0.03, 0.03-0.14, 0.15-0.26, 0.27-0.38, 0.39-0.50, 0.51-0.56, 0.57-0.62, >0.62. Areas with NDVI < 0.03 are bare rock or ice. Areas with NDVI = 0.03-0.14 are very sparsely vegetated. The remaining categories were evenly divided, except for the highest NDVI categories, which were split up to distinguish very shrubby areas in the southern Arctic.

ESRI. 1993. Digital Chart of the World. September 1993, Ed. 1. Environmental Systems Research Institute Inc. Redlands, CA, USA

Markon, C.J. M.D. Fleming and E.F. Binnian. 1995. Characteristics of vegetation phenology over the Alaskan landscape using AVHRR time-series data. *Polar Record* 31:179-190.

Phytomass (above-ground plant biomass per unit area)

The above-ground plant biomass map was created by applying a regression equation to the AVHRR data (Walker et al. 2003). The regression quantified the relationship between NDVI and aboveground plant biomass, calculated from clip harvest data. Phytomass was calculated for each pixel, based on the equation:

phytomass **= int(24.907 * exp((ndvi_final - 127) * 0.0573))**

Phytomass values, which ranged from 19 to 2965 g/m^2, were divided into 8 categories that were useful in distinguishing vegetation patterns: < 50, 50-100, 101-250, 250-500, 501-1000, 1001-1500, 1501-2000, and >2000 g/m^2. The smaller ranges for the low-end phytomass values made it possible to visually distinguish between northern parts of the Arctic (subzones A, B and C), which have less than 500 g/m^2 of phytomass.

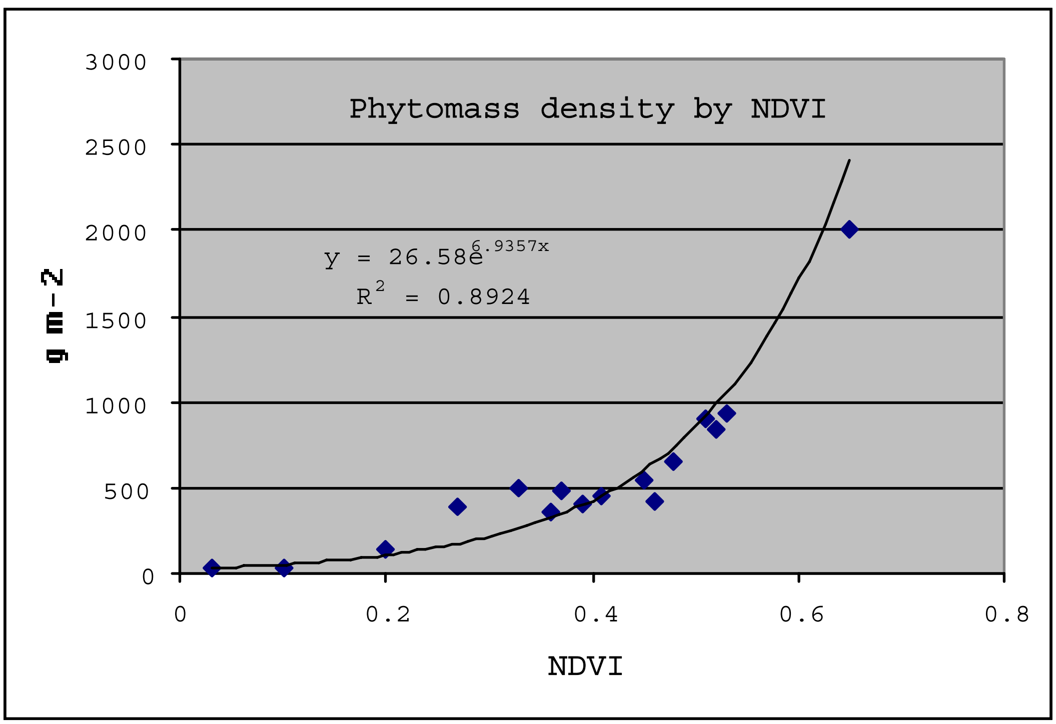

Figure 1. Relationship between phytomass (above-ground plant biomass per unit area) and NDVI.

Walker, D. A., H. E. Epstein, J. G. Jia, A. Balser, C. Copass, E. J. Edwards, W. A. Gould, J. Hollingsworth, J. Knudson, H. Maier, A. Moody and M. K. Raynolds. 2003. Phytomass, LAI, and NDVI in northern Alaska: relationships to summer warmth, soil pH, plant functional types and extrapolation to the circumpolar Arctic. *Journal of Geophysical Research*. Vol. 18 No. D2, 8169, doi: 10.1029/2001JD000986.

ARC/INFO Coverages

Vegetation map

The CAVM map is a single ARC/INFO polygon coverage. Each polygon within this coverage has 7 attributes in common: bioclimatic subzone, floristic province, substrate chemistry, percent lake cover, landscape, and vegetation. During the production of the map, coverages were created for each separately mapped area. These were then combined for the final map into a single coverage.

Mapping methods

The methods, basic subdivisions of the Arctic, and people who would do the mapping were chosen at a series of international workshops (Walker and Markon 1996, Walker and Lillie 1997, Markon and Walker 2000, Gonzalez et al. 2000, Raynolds and Markon 2001). An integrated mapping procedure was used to delineate vegetation polygons for the CAVM (Walker 1999). The method is based on landscape-guided mapping developed by the International Training Centre for Aerial Survey (ITC, now called the Institute of Aerospace Survey and Earth Sciences) in the Netherlands (Zonneveld 1988), and is based on the principle that soil and vegetation boundaries on maps are controlled by physiographic landscape features. The Integrated Terrain Unit Mapping (ITUM) approach is a similar method applied to geographic information system (GIS) technology (Dangermond and Harnden 1990). The geobotatical mapping procedures used in arctic Alaska at the Alaska Geobotany Center are based on the same philosophy (Walker et al. 1980), as are the procedures used in the "landschaft" approach developed by the Earth Cryosphere Institute in Moscow (Melnikov 1988, 1998).

The first step in the integrated mapping procedure was to collect and evaluate all the relevant maps and literature for a region. Map sources included remote sensing imagery, topography and hydrology based on the Digital Chart of the World, vegetation maps, surficial geology, bedrock geology, soils, percentage water cover, bioclimate subzones, and floristic provinces. Hard copy maps that were deemed useful for helping to define vegetation boundaries were then photographically reproduced to 1:4 million scale. In some cases, the source maps had more detail than was useful for the vegetation map, so simplified source maps were created. These maps were then used as overlays on the 1:4 million AVHRR false-CIR image, and the boundaries were adjusted to match the image features.

AVHRR false-CIR images were printed for each country. These were sent to local experts, who mapped their respective regions. Vegetation polygons boundaries were hand-drawn on an acetate overlay, combining the terrain information and following features visible on the 1:4 million AVHRR base image. These polygons were digitized and used to create ARC/INFO polygon coverages.

Minimum mapping unit

The minimum polygon size for the CAVM project was defined as 3.5 mm on a side or 2 mm across for linear features, at 1:4 M scale. This translates to 14 km (14 pixels) on a side or 196 , and 8 km across for linear features. In practice, most mappers ended up with smaller units. Polygons as small as 50 km^2 were used, especially in areas of small islands, fjords and glaciers. Linear features that were only 5 km across were often mapped. Excluding all linear features narrower than 8 km would have eliminated too many valleys. We kept these small polygons in the final combined coverage, though the smallest cannot be seen on the 1:7.5 M printed version. **[COMMENT: Maybe we should say something like *most areas used a MMU of ….., however in ecologically important areas/regions areas smaller than this were mapped.* We should try to define the criteria used to keep smaller units or we need to state that our MMU was 7x7 pixels]**

Legend

Vegetation, especially in the Arctic, is not homogeneous. Thus, each CAVM polygon, which covers at least 50 km^2, contains many vegetation types. The map portrays the dominant *zonal* vegetation. This is the vegetation that develops under the prevailing climate, uninfluenced by extremes of soil moisture, snow, soil chemistry, or disturbance. Zonal sites are flat or gently sloping, moderately drained, with fine-grained soils. Areas of extensive *azonal* vegetation, those that are dependent on specific soil or hydrological conditions, such as mountain ranges, large wetlands, and river systems, were also mapped.

The 400 plant community types were grouped into five major physiognomic units, coded with alphabetic codes:

Major Physiognomic Unit	Unit Code
Barrens	B
Graminoid tundras	G
Prostrate-shrub tundras	P
Erect-shrub tundras	S
Wetlands	W

These were subdivided into 15 vegetation mapping units with numeric codes added to the alphabetic codes. The mapping units were named according to the dominant *plant functional types* (except in the mountains where complexes of vegetation were named according to the dominant bedrock (Carbonate and Noncarbonate mountain complexes). The plant functional types were based on a variety of criteria including growth form (e.g., graminoids, shrubs), size (e.g., dwarf and low shrubs), and taxonomical status (e.g., sedges, rushes, grasses).

Vegetation Mapping Unit	Unit Code
Cryptogam, herb barrens	B1
Cryptogam, barren complex (bedrock of the shield areas)	B2
Noncarbonate mountain complex	B3
Carbonate mountain complex	B4
Rush/grass, forb, cryptogam tundra	G1
Graminoid, prostrate dwarf-shrub, forb tundra	G2

Nontussock sedge, dwarf-shrub, moss tundra	G3
Tussock sedge, dwarf-shrub, moss tundra	G4
Prostrate dwarf-shrub, herb tundra	P1
Prostrate/hemiprostrate dwarf-shrub tundra	P2
Erect dwarf-shrub tundra	S1
Low shrub tundra	S2
Sedge/grass, moss wetland	W1
Sedge, moss, dwarf-shrub wetland	W2
Sedge, moss, low-shrub wetland	W3

The legend takes into special consideration the stature of woody shrubs, which is a major diagnostic feature of zonal vegetation in the Arctic. Zonal areas in Bioclimate Subzone A lack woody shrubs and are generally are either nearly totally barren (Map Unit BI) or consist of a thin cover of herbaceous plants, mosses and lichens (Map Unit G1). In Subzone B, *prostrate dwarf shrubs* are a major component of the zonal vegetation (Map Units G2 and P1). In Subzone C, *hemiprostrate dwarf shrubs*, particularly *Cassiope tetragona* , often form a major component of the vegetation, (Map Unit P2). Hemiprostrate dwarf shrub are very short, generally less than 0.15 m tall, with a semi-erect or trailing stem) In Subzone D, *erect dwarf shrubs*, less than 0.4 m tall, are common (Map Units G3, G4, S1, and W2). And in Subzone E, *low shrubs*, 0.4 m to 2 m tall, are common (Map Units S2 and W3).

The colors of the map units are suggestive of the general outward appearance of vegetation (physiognomy). Grays correspond to barren types, browns to graminoid dominated types in the mineral-dominated soils of the High Arctic (Subzones A, B, and C), yellows to graminoid dominated types on peaty soils of the Low Arctic (subzones D and E). Pinks correspond to prostrate dwarf-shrub types of the High Arctic, and greens to the erect-shrub types of the Low Arctic. Blue greens correspond to the wetland types. The relationship of the mapping units to the summer temperature (bioclimate subzones) and soil moisture gradients is shown in the figure on the upper left of the CAVM vegetation map.

Mapping elevation zonation in the mountains

Vegetation in mountainous regions changes with elevation, forming distinctive elevational belts which correspond approximately to the bioclimatic subzones. For every 333-m elevation gain, the mean July temperature decreases by about 2˚C, as predicted by the adiabatic lapse rate of 6˚ C per 1000 m. Since only one elevational belt can be represented on each polygon, the color of the lowest belt was used for the polygon, though higher elevational belts may exist in that polygon.

Mountainous areas of the map are shown with *hachures*. The background color indicates the nature of the bedrock (magenta for non-carbonate bedrock - mainly sandstone and granite, blue-purple for carbonate bedrock such as limestone and dolomite). The color of the stripes of the hachures correspond to the colors of the bioclimate subzone in which the mountains occur (purple, Subzone A; blue, Subzone

B; green, Subzone C; yellow, Subzone D; and red, Subzone E). The code numbers in mountainous areas have an additional small alphabetic suffix that indicates the subzone at the base of the mountains. Carbonate mountains (map code B4) in Subzone E have a small e added to the (map code B4e). Such mountains could have six elevation belts, Belts a-e (if they were high enough). Mountains in Subzone A have only one elevation belt (Belt a), because any additional altitude results in permanent snow-cover.

The lowest belt, Belt e is dominated by low-shrub tundra (S2); the next higher belt, Belt d has erect dwarf-shrub tundra (S1); Belt c has prostrate dwarf-shrub, herb tundra (P1); Belt b has rush/grass, forb, cryptogam tundra (G1); Belt a has cryptogam, herb barrens (B1). Vegetation is modified by local slope, aspect, and cold-air drainage.

Vegetation mapping references

Dangermond, J., and E. Harnden. 1990. Map data standardization: a methodology for integrating thematic cartographic data before automation. ARC News **12**:16-19.

ESRI. 1993. Digital Chart of the World, Sept. 1993 Edition 1. Environmental Systems Research Institute, Inc. Redlands, CA.

Gonzalez, G., W. A. Gould and M.K. Raynolds. 2000. 1999 Canadian Transect for the Circumpolar Arctic Vegetation Map, Data Report, Institute of Arctic Biology, University of Alaska, Fairbanks 89 pages.

Markon, C. J., and D. A. Walker. 2000. Proceedings of the 3rd International Circumpolar Arctic Vegetation Mapping Workshop, U S Geological Survey Open File Report. **99-551**.

Melnikov, E. S. 1988. Natural geosystems of the plain cryolithozones. Pages 208-212 *in* Permafrost Proceeding of the Fifth International Permafrost Conference, Trondheim, Norway.

Melnikov, E. S. 1998. Uniting basis for creation of ecological maps for the Russian cryolithozone. Pages 719-722 *in* Proccedings of the Seventh International Conference on Permafrost, Yellowknife, Canada.

Raynolds, M. K., and C. J. Markon (eds.) 2002. Fourth International Circumpolar Arctic Vegetation Mapping Workshop. *in*. Russian Academy of Sciences, Moscow, Russia. 10-13 April, 2001. US Geological Survey Open File Report 02-181.

Walker, D. A., K. R. Everett, P. J. Webber, and J. Brown. 1980. Geobotanical atlas of the Prudhoe Bay Region, Alaska. CRREL Report 80-14, U.S. Army Cold Regions Research and Engineering Laboratory.

Walker, D. A., and C. J. Markon. 1996. Circumpolar arctic vegetation mapping workshop: abstracts and short papers. 96-251, Reston, Virginia.

Walker, D. A., and A. C. Lillie. 1997. Proceedings of the Second Circumpolar Arctic Vegetation Mapping Workshop, Arendal, Norway, 19-24 May 1996 and the CAVM-North America Workshop, Anchorage, Alaska, USA, 14-16 January 1997. Pages 61 *in* D. A. Walker and A. C. Lillie, editors. Institute of Arctic and Alpine Research Occassional Paper.

Walker, D. A. 1999. An integrated vegetation mapping approach for northern Alaska (1: 4 M scale). International Journal of Remote Sensing **20**:2895-2920.

Walker , D.A., M.K. Raynolds, F.J.A. Daniëls, E. Einarsson, A. Elvebakk, W.A. Gould, A.E. Katenin, S.S. Kholod, C.J. Markon, E.S. Melnikov, N.G. Moskalenko, S.S. Talbot, B.A. Yurtsev. (draft). A vegetation map of the arctic tundra biome (scale 1:7 500 000). I. Overview, methods and legend. For submission to Journal of Vegetation Science.

Zonneveld, I. S. 1988. The ITC method of mapping natural and semi-natural vegetation. Pages 401-426 *in* A. W. Küchler and I. S. Zonneveld, editors. Vegetation mapping. Kluwer Academic Publishers, Boston.

Canada vegetation mapping

The Canadian mapping effort was initiated by Stephen Zoltai of Natural Resources Canada. It was continued after his death by William Gould (University of Colorado, Boulder at that time), with assistance from Martha Raynolds (University of Alaska Fairbanks).

Background ancillary data on landscape, substrate type (saline/acid/non-acid from bedrock, surface geology and soils), and percent lake cover were combined into Integrated Landscape Units (ILUM), which were mapped based on interpretation of the AVHRR false-CIR image. References for the Canadian mapping are listed in Appendix C.

A lookup table was then created which assigned each combination of ILUM and bioclimate subzone to one of the vegetation physiognomy units (Table 1).This cross-walk table was modified based on input from Sylvia Edlund and Lawrence Bliss, to reflect their knowledge of Canadian arctic vegetation types and distributions.

Vegetation subzone 1	subzone 2	subzone 3	subzone 4	subzone 5	IVCM unit	Veg code in GIS
Grass-moss tundra.	Grass-moss tundra.	Sedge-moss tundra.	Sedge-moss tundra.	Low shrub-sedge-moss tundra	Acidic mire complex, < 25% lakes.	170
Grass-moss tundra.	Grass-moss tundra.	Sedge-moss tundra.	Sedge-moss tundra.	Low shrub-sedge-moss tundra	Nonacidic mire complex, < 25% lakes.	190
Grass-moss tundra.	Grass-moss tundra.	Sedge-moss tundra.	Sedge-moss tundra.	Low shrub-sedge-moss tundra	Nonacidic mire complex, 25-75 lakes.	200
Grass-moss tundra.	Grass-moss tundra.	Sedge-moss tundra.	Sedge-moss tundra.	Low shrub-sedge-moss tundra	Saline deltas and coastal wetlands.	210
Grass-moss tundra.	Grass-moss tundra.	Sedge-moss tundra.	Sedge-moss tundra.	Low shrub-sedge-moss tundra	Acidic mire complex, 25-75 lakes.	180
Graminoid-forb tundra.	Prostrate dwarf shrub-lichen tundra (acidic)	Hemiprostrate dwarf shrub tundra (acidic).	Erect dwarf shrub tundra (acidic).	Low shrub tundra.	Acidic hill complex with rare bedrock outcrops, medium to fine deposits.	100
Graminoid-forb tundra.	Prostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub tundra (acidic).	Erect dwarf shrub tundra (acidic).	Low shrub tundra.	Acidic rolling plain complex (noncoastal).	240
na	na	na	Erect dwarf shrub tundra (acidic).	Low shrub tundra.	Low- to high-shrub tundra complex on uplands.	140
na	na	na	na	Low shrub tundra.	Open evergreen-lichen woodlands	160
na	na	na	na	Low shrub tundra.	Acidic rolling coastal plain complex	245
Graminoid-forb tundra.	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Erect dwarf shrub-graminoid tundra (nonacidic).	Low shrub-graminoid tundra.	Nonacidic mesic coastal plain complex.	230
Cushion-forb barrens.	Prostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub tundra (acidic).	Erect dwarf shrub tundra (acidic).	Low shrub-graminoid tundra.	Acidic mesic coastal plain complex.	220
Graminoid-forb tundra.	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Erect dwarf shrub-graminoid tundra (nonacidic).	Low shrub-graminoid tundra.	Nonacidic rolling plain complex (noncoastal).	250
Graminoid-forb tundra.	Graminoid-forb tundra.	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Erect dwarf shrub-graminoid tundra (nonacidic).	Low shrub-graminoid tundra.	Nonacidic hill complex with rare bedrock outcrops, medium to fine deposits.	120
Cushion-forb barrens.	Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Nonacidic mountain complex - coarse rubbly deposits.	20
Graminoid-forb tundra.	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Strongly calcareous rolling plain complex (noncoastal).	255
Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Strongly calcareous mesic coastal plain complex.	235
Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Nonacidic plateau complex - level plain, medium to fine deposits.	90
Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Nonacidic hill complex with occasional bedrock outcrops, coarse deposits.	130
Cushion-forb barrens.	Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub-graminoid tundra (nonacidic).	Nonacidic plateau complex - strongly dissected, coarse rubbly deposits.	70
Cushion-forb barrens.	Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub-lichen tundra (acidic).	Erect dwarf shrub tundra (acidic).	Acidic escarpment complex - coarse rubbly deposits.	30
Cushion-forb barrens.	Graminoid-forb tundra.	Hemiprostrate dwarf shrub tundra (acidic).	Hemiprostrate dwarf shrub tundra (acidic).	Erect dwarf shrub tundra (acidic).	Acidic hill complex with occasional bedrock outcrops, coarse deposits.	110
Cushion-forb barrens.	Prostrate dwarf-shrub-lichen tundra (acidic)	Hemiprostrate dwarf shrub tundra (acidic).	Hemiprostrate dwarf shrub tundra (acidic).	Erect dwarf shrub tundra (acidic).	Acidic plateau complex - level plain, medium to fine deposits.	80
Cushion-forb barrens.	Cushion-forb barrens.	Cushion-forb barrens.	Erect dwarf shrub tundra (acidic).	Erect dwarf shrub tundra (acidic).	Strongly acidic mesic coastal plain complex.	225
Cushion-forb barrens.	Prostrate dwarf shrub-lichen tundra (acidic).	Prostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub-lichen tundra (acidic).	Acidic high plateau complex- strongly dissected, coarse rubbly deposits.	65
Cushion-forb barrens.	Cushion-forb barrens.	Cushion-forb barrens.	Hemiprostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub-lichen tundra (acidic).	Acidic mountain complex - coarse rubbly deposits.	10
Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub-lichen tundra (acidic).	Hemiprostrate dwarf shrub-lichen tundra (acidic).	Acidic plateau complex- strongly dissected, coarse rubbly deposits.	60
Cushion-forb barrens.	Cushion-forb barrens.	Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Strongly calcareous plateau complex - level plain, medium to fine deposits.	95

Cushion-forb barrens.	Forb-graminoid barrens.	Low shrub-graminoid-forb complex.	Low shrub-graminoid-forb complex.	Low shrub-graminoid-forb complex.	Riparian complex.	260
Cushion-forb barrens.	Forb-graminoid barrens.	Forb-graminoid barrens.	Low shrub-graminoid-forb complex.	Low shrub-graminoid-forb complex.	River floodplains.	265
Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Strongly calcareous plateau complex - strongly dissected, coarse rubbly deposits.	75
Cushion-forb barrens.	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Prostrate dwarf shrub tundra (nonacidic).	Nonacidic escarpment complex - coarse rubbly deposits.	40
Graminoid-forb tundra.	Prostrate dwarf shrub-graminoid tundra (nonacidic).	na	na	na	Glaciated valley and moraine complex - medium to fine deposits.	50
na	na	na	na	na	Water or lake complex , > 75% water cover.	270
na	na	na	na	na	Glacier complex, > 75% glacier cover.	280
na	na	na	na	na	Nunatak complex.	285

Greenland vegetation mapping

Greenland was mapped by Fred Daniëls, with assistance from Maike Wilhelm, both at the Institute of Plant Ecology in Münster, Germany.

Greenland was mapped in ARC/VIEW. The initial effort was to generalize the coastline and glacier boundaries in a way that was useful for the scale of the CAVM (see metadata for coastline and glaciers). Nunatak polygons were digitized around complexes of ice and land, where the area was < 75% ice.

Since most of Greenland is mountainous, vegetation distribution is mainly controlled by bioclimate subzone and surface topography. 41 different Integrated Landscape Units (ILUM) were described, combining moisture, substrate pH, elevation and slope attributes. All polygons were also given a vegetation code by the mappers, based on the ILUM code and existing maps and ground data on vegetation type distribution. The shape file was converted into an ARC/INFO coverage, and the vegetation codes were used to assign CAVM vegetation physiognomy units according to the cross-walk table below (Table 2).More details describing the mapping of Greenland, and references can be found in "On the way to an integrated vegetation map of Greenland" by F.J.A. Daniels and M. Wilhelm in Raynolds and Markon (2002).

Table 2. Cross-walk between Greenland ILUM codes and CAVM vegetation physiognomy units

Arc/View code	Arc/View legend	Vegetation code	CAVM unit
1	dry acidic lowland < 100m	5,8a,11,13	P1,P2,S1,S2
2	dry non-acidic lowland < 100m	3,5,8a,11	B1,P1,P2,S1
3	dry calcareous lowland < 100m	3,5,8b	B1,P1,P2
4	mesic acidic lowland < 100m	11	S1
5	mesic non-acidic lowland < 100m	11	S1
6	dry acidic lowland 100-350 m	5,8a, 11,13	P1,P2,S1,S2
7	dry non-acidic lowland 100-350 m	3,5,8a11	B1,P1,P2,S1
8	dry calcareous lowland 100-350 m	5,8b	P1,P2
9	mesic acidic lowland 100-350 m	11,13,17	S1,S2
10	mesic non-acidic lowland 100-350 m	11	S1
11	dry acidic low plateaus 350-700 m	18.8c	B3
12	dry non-acidic low plateaus 350-700 m	18.3	B3
13	dry calcareous low plateaus 350-700 m	19.3	B3
14	mesic acidic low plateaus 350-700 m	18.8c	B3
15	mesic non-acidic low plateaus 350-700 m	18.8a	B3
16	moist acidic low plateaus 350-700 m	18.11	B3
17	dry acidic middle-high plateaus 700-1000 m	18.3	B3
18	dry non-acidic middle-high plateaus 700-1000 m	18.5	B3
19	dry calcareous middle -high plateaus 700-1000 m	19.1b	B4
20	mesic acidic moiddle-high plateaus 700-1000 m	18.8a	B3
21	mesic non-acidic middle-high plateaus 700-1000 m		
22	moist acidic middle-high plateaus 700-1000 m	18.8a	B3
23	dry acidic high plateaus 1000-1500 m	18.1a	B3

24	dry non-acidic high plateaus 1000-1500 m	18.1a	B3
25	dry calcareous high plateaus 1000-1500 m	19.1b	B4
26	mesic acidic high plateaus 1000-1500 m	18.3	B3
27	mesic non-acidic high plateaus 1000-1500 m	18.5	B3
28	dry acidic very high plateaus > 1500 m	18.1a	B3
29	dry non-acidic very high plateaus > 1500 m	18.1a	B3
30	acidic low mountains < 700 m	18.8c	B3
31	non-acidic low mountains < 700m	18.1a	B3
32	acidic middle high mountains 700-1000 m	18.5	B3
33	non-acidic middle high mountains 700-1000 m	18.5	B3
34	acidic high mountains 1000-1500 m	18.3	B3
35	non-acidic high mountains 1000-1500 m	18.1a	B3
36	acidic very high mountains > 1500 m	18.1a	B3
37	non-acidic very high mountains >1500 m	18.1a	B3
38	acidic nunatak complex	20	nunatak
39	non-acidic nunatak complex	20	nunatak
40	lake in non acidic low plateaus (350m-700m altitude)	21	lake
41	glacier complex		glacier

Iceland vegetation mapping
Iceland was mapped by Eythór Einarsson and Gudmundur Gudjónsson, at the Icelandic Institute of Natural History. The main issue in mapping Iceland was deciding on the boundary of the Arctic (see tree line metadata). Only the northern rim of Iceland was considered Arctic and mapped by Eythor Einarsson as part of the CAVM. All of the polygons were mapped as low shrub, except for one glacier. For more discussion of the location of the Arctic boundary and references, see "The position of Iceland in the system used in the CAVM mapping" by E. Einarsson in Raynolds and Markon (2002).

Norway vegetation mapping
Norway was mapped by Arve Elvebakk with help from Bernt Johansen, both from the University of Tromsø in Norway. For mainland Fennoscandia, the primary issue was the location of the Arctic boundary (see tree line metadata). For Svalbard, Arve Elvebakk created detailed vegetation maps. These were digitized to create an ARC/INFO coverage. His vegetation types were mapped as CAVM vegetation physiognomy units according to the cross-walk table below (Table 3). For more discussion of the vegetation mapping and references, see "A draft circumarctic vegetation map of the Norwegian Arctic" by A. Elvebakk in Raynolds and Markon (2002).

Table 3. Cross-walk between Norway vegetation codes and CAVM vegetation physiognomy units

Vegetation code from A. Elvebakk	Description	CAVM unit
A	Ice caps or glaciated areas with a low, <20%, cover of polar desert nunataks	glacier
B	High mountains/nunataks with *Papaver* polar desert vegetation, glaciers covering <80%	nunatak
C	Acidic polar desert hills/lowlands with *Luzula confusa* vegetation	G1
D	Calcareous/circum neutral polar desert hills/lowlands with *Papaver* vegetation	G1

E	Alkaline, fine-textured, northern arctic tundra plains and low hills with *Poa alpina* vegetation and elements of unit F	G2
F	Circumneutral gravelly, northern arctic tundra plains and low hills with *Saxifraga oppositifolia*, *Cetreriella delisei*, *Dryas octopetala* and *Deschampsia* vegetation	P1
G	Acidic, gravelly, northern arctic tundra plains and low mountains with *Luzula confusa* vegetation rich in lichens	G1
H	Poorly drained and partly manured, circumneutral, northern arctic tundra plains with *Deschampsia alpina* and *Tomentypnum nitens* vegetation, with elements of unit F	W1
I	Acidic to circumneutral, middle arctic valleys and low mountains with *Cassiope tetragona* vegetation, in mosaic with *Dryas octopetala* vegetation on ridges, and fens in depressions	P2
J	Acidic to circumneutral middle arctic valleys and low mountains with *Dryas octopetala* vegetation and fens. *Cassiope tetragona* is minor or lacking, but other thermophibus species are present	P2
K	Middle arctic and lowland slopes with alkaline, fine-textured soils, and an open steppe-like vegetation characterized by *Potentilla pulchella* and *Poa hartzii*	G2
L	Middle arctic lowland valley bottoms with weakly acidic mires with *Dicranum* and *Sphagnum* in mosaic with *Hierochloe alpina* ridges and *Cassiope tetragona*	W1
M	Middle arctic lowland valley bottoms with calcareous fens in mosaic with ridges with *Dryas octopetala* vegetation	W1
N	Oceanic middle arctic vegetation without *Cassiope* or *Dryas*. *Salix reticulata* and exposed moss heaths with *Racomitrium* spp.	P2
O	Arctic shrub tundra on coastal oligorophic sandstones in low mountains, dominated by *Empetrum* heathlands with *Eriophorum angustifolium* mires bordered by *Salix glauca* thickets	S2

Russia vegetation mapping

Sergei Kholod of the Komarov Institute, St. Petersburg mapped the polygons of European Russia. Natalia Moskalenko of the Earth Cryosphere Institute, Moscow mapped the Yamal and Gydan Peninsulas. Adrian Katenin of the Komarov Institute, St. Petersburg mapped Yakutia and Chukotka. Boris Yurtsev, also of the Komarov Institute, edited the zonation boundaries, and the mapping of Wrangel Island and Chukotka. Nadezhda Matveyeva and Elena Pospelova revised the mapping of the Taymyr Peninsula. More information on the Russia mapping process, and references can be found in the chapters of Markon and Raynolds (2002) titled: "Vegetation map of European Russia" by S.S. Kholod and G.V. Ananjeva, "Vegetation map of west Siberia, Taimyr, Yakutia" by N.G. Moskalenko, "Landscape map of the Russian Arctic" by D.S. Drozdov and G.V. Ananjeva., "Peculiarities of the legend of Chukotka vegetation map" by A.E. Katenin, and "Some questions of mapping circumpolar Arctic vegetation (CAVM)" by B.A. Yurtsev.

Natalia Moskalenko took the separate vegetation maps and combined their units into one legend with 110 types (see Appendix D), which were assigned as the vegetation id's for the polygons. The vegetation polygons were combined with information from landscape, surface geology and bedrock geology maps by Dmitry Drozdov and Yuri Korostelev of the Earth Cryosphere Institute in Moscow. The result was a vector file that could be imported into ARC/VIEW. The file was converted from a shape file to a polygon coverage, and flipped to the CAVM projection (the Russians used a projection with 45^{o}E at the bottom). Additional lake polygons were added by M.K. Raynolds, as very few were in the original cover. Llakes were digitized following outlines visible on the AVHRR false-CIR. Each polygon had a long code which was made up of codes for zone, landscape, lithology and substrate. This code was divided up into four separate items in the ARC/INFO coverage. An initial CAVM vegetation physiognomy type was chosen based on the description of the vegetation type and the landform information (see Table 4). This assignment of codes was reviewed by Natalia Moskalenko and Martha Raynolds in Fairbanks in August 2001. These codes were used to make maps which were reviewed in detail during a meeting between Martha Raynolds and the Russian mappers in Moscow during October 2002.

Table 4. Russian vegetation types corresponding to Integrated Landscape Units.

Integrated Landscape-Unit Map (ILUM).		**Russian Equivalent**	
Arc/Info code ILUM	*Map unit*	*Landschaft*	*Vegetation*
Mountains - elevation change with zonation			
10	Acidic mountain complex - course rubbly deposits.	14,15	4,18,19,20,21,39,40,41,72,,73,74,104,105,
20	Nonacidic mountain complex - course rubbly deposits.	14,15	22,23,106,107,108
30	Acidic escarpment complex - course rubbly deposits.	14,15	N/A
40	Nonacidic escarpment complex - course rubbly deposits.	14,15	N/A
Plateaus			
50	Plateau - > 500 m elevation. Relatively level plain	5,6,8	6,7,8,24,25,42,43,44,46,47,48,75,76,77,79, 80,109
60	Acidic plateau complex- strongly dissected, course rubbly deposits.	7	6,7,8,24,25,42,43,44,46,47,48,75,76,77,79, 80,109
65	Acidic bedrock - Canadian shield	N/A	1
70	Nonacidic plateau complex - strongly dissected, course rubbly deposits.	7	45,78
75	Strongly calcareous plateau complex - strongly dissected, course rubbly deposits.	7	N/A
80	Acidic plateau complex - level plain, medium to fine deposits.	5,6,8	6,7,8,24,25,42,43,44,46,47,48,75,76,77,79, 80,109
90	Nonacidic plateau complex - level plain, medium to fine deposits.	5,6,8	45,78
95	Strongly calcareous plateau complex - level plain, medium to fine deposits.	5,6,8	N/A
Hills - elevation change with no zonation			
100	Acidic hill complex with rare bedrock outcrops, medium to fine deposits.	9,10,11,12, 13	6,7,8,24,25,42,43,44,46,47,48,75,76,77,79, 80,109
110	Acidic hill complex with occasional bedrock outcrops,coarse deposits.	9,10,11,12, 13	6,7,8,24,25,42,43,44,46,47,48,75,76,77,79, 80,109
120	Nonacidic hill complex with rare bedrock outcrops, medium to fine deposits.	9,10,11,12, 13	45,78
130	Nonacidic hill complex with occasional bedrock outcrops, coarse deposits.	9,10,11,12, 13	45,78
140	Low- to high-shrub tundra complex on uplands.	9,10,11,12, 13	N/A?
150	Subalpine shrubland complex.	9,10,11,12, 13	N/A?
160	Mixed evergreen and deciduous forest on uplands.	9,10,11,12, 13	110
Plains - wetlands			

170	Acidic mire complex, < 25% lakes.	1,2,3	15,33,34,59,60,61,62,63,64,65,89,90,91,92,93,94
180	Acidic mire complex, 25-75 lakes.	1,2,3	15,33,34,64,65,94
190	Nonacidic mire complex, < 25% lakes.	1,2,3	none
200	Nonacidic mire complex, 25-75 lakes.	1,2,3	none
210	Saline deltas and coastal wetlands.	1,2,3	35,66,67,95,96
Plains - mesic			
220	Acidic mesic coastal plain complex.	1,2,3	2,9,10,11,14,26,27,28,29,30,31,50,51,52,53,54,55,56,57,81,82,83,84,85,86,87
225	Coastal sand barrens	1,2,3	49
230	Nonacidic mesic coastal plain complex.	1,2,3	3,12,13,32,58,88
235	Strongly calcareous mesic coastal plain complex.	1,2,3	N/A
240	Acidic rolling plain complex (noncoastal).	1,2,3	2,9,10,11,14,26,27,28,29,30,31,50,51,52,53,54,55,56,57,81,82,83,84,85,86,87
250	Nonacidic rolling plain complex (noncoastal).	1,2,3	3,12,13,32,58,88
255	Strongly calcareous rolling plain complex (noncoastal).	1,2,3	N/A
Riparian			
260	River floodplain complex.	2,5,10	16,17,36,37,38,68,69,70,71,97.98.99.100.101.102.103
265	Esker complex, dry/barren	N/A	N/A
Water and glaciers			
270	Water or lake complex , > 75% water cover.		170
280	Glacier complex, > 75% glacier cover.		168
285	Rock & ice - nunatak complex		N/A
290	Tree island		

United States vegetation mapping

Donald (Skip) Walker mapped the North Slope of Alaska, Carl Markon mapped southwest Alaska, and Martha Raynolds mapped the Seward Peninsula. The North Slope and the Seward Peninsula of Alaska were mapped following the methods described above (Walker 1999). Background ancillary data on landscape, substrate type (saline/acid/non-acid from bedrock, surface geology and soils), and percent lake cover were integrated into Integrated Landscape Units (ILUM), which were mapped based on interpretation of the AVHRR false-CIR image. CAVM vegetation physiognomy units were assigned to the polygons based on bioclimate subzone and ILUM value, using a lookup table (see table in Canada section, above). D.A. Walker's mapping of the North Slope of Alaska is documented in Walker (1999). M.K. Raynolds followed similar procedures for mapping the Seward Peninsula. (References are listed in Appendix E.

Carl Markon mapped southwest Alaska, creating as a set of ARC/VIEW shape files, one for each type of background data. References are listed in Appendix F. An effort was made to make congruent lines identical in the separate coverages, however most of the separate lines and polygons from the ancillary data were kept. No separate polygon coverage was drawn based on interpretation of the AVHRR image. Martha Raynolds combined all of the ARC/VIEW files into one ARC/INFO polygon coverage. This process created many sliver polygons, which were edited by hand. Arcs were deleted to combine polygons that were either too small or very similar to an adjacent polygon. Arcs were also added and changed to match the AVHRR image (particularly lake boundaries). Attributes for each polygon were brought in from the shape files. Carl Markon mapped 18 vegetation and 9 landscape categories (Table

5). These were used to assign ILUM categories to the polygons. The final step followed the same method as the rest of Alaska and Canada: CAVM vegetation physiognomy units were assigned to the polygons based on bioclimate subzone and ILUM value, using the a lookup table (see table in Canada section, above).

Table 5. Yukon-Kuskowkim Delta legends

Calcareous (Substrate.shp) from pH data, soils & surfgeo layers

Category	*Arcinfo code*
acidic (<= 5.5)	1
non-acidic (> 5.5)	2

Phyto (Florprov.shp) Elvebakk 1999

Category	*Arcinfo code*
erect dwarf-shrub	3
low shrub	4
treeless portion of boreal zone (oceanic herb low-shrub)	5

Zone

Category from Elvebakk 1999	*Arcinfo code*
low shrub	5

Moisture (Gradient.shp) USFWS MSSveg.map

Category	*Arcinfo code*
wet	1
mesic	2
dry exposed	3
riparian	4

Percentlakes (Perlakes.shp) 1:250000 quad maps

Category	*Arcinfo code*
<2	1
2-10	2
10-25	3
25-50	4
50-100	5
ocean	not used

Soil (Soils.shp) Reiger et al. 1979

Category	*Arcinfo code*
lava flows	9
histic pergelic cryaquepts	20
fluvagentic cryofibrists	21
pergelic cryofibrists	22
lithic haplocryands	55
pergelic cryumbrepts	60
rough mountainous land	73
pergelic cryaquepts	80
andic cryochrepts	100
humic cryorthods	110
pergelic cryoboroll	120
typic haplocryands	130
typic haplocryods	131
typic humicryods	132

Surfgeo (Surfgeo.shp) Karlstrom et al. 1974

Category	*Arcinfo code*
glacio-lacustrine and glacio-fluvial deposits	20
floodplain	30
eolian sands	40
bedrock and coarse rubble (mountain alluvial and colluvial)	50
coarse and fine rubble (mountain alluvial and colluvial)	60
volcanic (mountain alluvial and colluvial)	69
fine rubble (mountain alluvial and colluvial)	70
coastal delta	80
undifferentiated coastal deposits	90
alluvial fan and terrace (fluvial)	100
lake	270
ocean	275
glacier	280

Plant functional type from USFWS MSS veg maps

Category	*Arcinfo code*
non-vascular (mosses & lichens	1
non-woody (graminoid)	2
woody (shrubs)	3

Bioclimate subzone

The CAVM divides the Arctic into five bioclimate subzones based on a combination of summer temperature and vegetation. Subzone A is the coldest, most barren subzone, and Subzone E is the warmest and lushest.

Comparison with other zonation approaches

Different geobotanical traditions have divided the Arctic into bioclimatic regions using a variety of terminologies (see Table 1 CAVM). The origins of these different terms and approaches have been reviewed for the Panarctic Flora (PAF) initiative. The PAF and CAVM have accepted the five-subzone approach used here (Elvebakk et al. 1999).

Description of Arctic bioclimate subzone categories A-E

As one moves from north to south across the Arctic, the amount of warmth available for plant growth increases. The mean July temperatures are near 0˚C on the northernmost islands. At these temperatures, plants are at their metabolic limits, and small differences in the total amount of summer warmth make large differences in the amount of energy available for maintenance, growth, and reproduction. Warmer summer temperatures cause the size, horizontal cover, abundance, productivity and variety of plants to increase (see Table 2 CAVM). Woody plants and sedges are absent in Subzone A, where mean July temperatures are less than 3˚C. Woody plants first occur in Subzone B (mean July temperatures about 3-5˚ C) as prostrate (creeping) dwarf shrubs, and increase in stature to hemiprostrate dwarf shrubs (<15 cm tall) in Subzone C (mean July temperatures about 5-7˚C, erect dwarf shrubs (<40 cm tall) in Subzone D (mean July temperature about 7-9˚C), and low shrubs (40-200 cm tall) in Subzone E (mean July temperature about 9-12˚C. At treeline, where the mean July temperatures are between 10 and 12˚C, woody shrubs up to 2 meters tall are abundant. The number of plants in local floras available to form plant communities increases from fewer than 50 species in the coldest parts of the Arctic to as many as 500 species near treeline.

Mapping process

Initial bioclimate subzone boundaries were taken from the Panarctic Flora (PAF) initiative (Elvebakk et al. 1999, see CAVM for additional references). The boundaries were adjusted by the mappers for individual countries, and then moved to follow existing vegetation polygon boundaries. The vegetation polygons are drawn at a much finer resolution than the bioclimate subzone boundaries, so little information was lost in this process. Most areas are mapped with broad bands of bioclimate subzones, but Svalbard subzones were mapped in more detail, showing the changes that occur from the coast inland, and so that section of the map contains many small subzone polygons. *Canada* - PAF boundaries adjusted by W.A. Gould to match data from Edlund (pers.comm.) and personal knowledge.

Greenland - Boundaries drawn by F.J.A. Daniëls. *Iceland* - all subzone E. *Norway* - Boundaries drawn by A. Elvebakk. *Russia* - PAF boundaries modified by B.A. Yurtsev, especially Yakutia and Chukotka. The data from Russia included a sixth subzone (*stlanik* areas), and subdivided the subzones into mountainous and non-mountainous areas. There are a number of boreal inclusion areas mapped within Chukotka. The boundaries of these polygons are much more detailed than the generalized zonal boundaries in the rest of Russia. *United States* - PAF boundaries modified in details by D.A. Walker and M.K. Raynolds, mostly along southern edge of Subzone E (see tree line metadata).

Elvebakk, A., R. Elven and V. Y. Razzhivin. 1999. Delimitation, zonal and sectoral subdivision of the Arctic for the Panarctic Flora Project. Pages 375-386 *in* I. Nordal and V. Y. Razzhivin (eds.) *The Species Concept in the High North - A Panarctic Flora Initiative*. The Norwegian Academy of Science and Letters, Oslo, Norway.

Floristic province

The Arctic has a relatively consistent core of plant species that occur around the circumpolar region, but there is also considerable east to west variation in the regional floras, particularly in the more southern subzones (C, D, and E). This variation is due to a number of factors, including different histories related to glaciations, land bridges, and north-south trending mountain ranges, primarily in Asia. These influences have restricted the exchange of species between parts of the Arctic. Russian geobotanists have described subdivisions based primarily on these floristic differences. Floristic provinces were mapped from the Panarctic Flora Initiative (Elvebakk et al. 1999), based largely on Yurtsev (1994). The boundaries were then adjusted to follow vegetation polygon boundaries. The vegetation polygons are drawn at a much finer resolution than the floristic province boundaries, so little information was lost in this process.

Elvebakk, A. 1999. Bioclimatic delimitation and subdivision of the Arctic. Pages 81-112 *in* I. Nordal and V. Y. Razzhivin (eds.) *The Species Concept in the High North - A Panarctic Flora Initiative*. The Norwegian Academy of Science and Letters, Oslo, Norway.

Yurtsev, B. A. 1994. Floristic division of the Arctic. *Journal of Vegetation Science* 5:765-776.

Substrate pH

Differences in substrate chemistry have important effects on dominant plant communities. Some of the most important effects are related to soil pH, which governs the availability of essential plant nutrients. Soils in the circumneutral range (pH 5.5-7.2) are generally mineral rich, whereas the full suite of essential nutrients are often unavailable in acidic soils (pH < 5.5) or in soils associated with calcareous bedrock (pH > 7.2). The latter often have unique assemblages of endemic plant species. There are no common base maps that show this essential difference in substrate chemistry, so the CAVM substrate map was derived from a wide variety of available sources including soil, surficial geology, and bedrock geology maps, and from spectral patterns that could be recognized on the AVHRR base image. The pH values of the three categories were based on the field experience and hundreds of Arctic vegetation relevé plots sampled by D.A. Walker on the North Slope and Seward Peninsula of Alaska, in consultation with F.J.A. Daniëls (Greenland) and N.G. Moskalenko (Yamal and Gydan Peninsulas, Russia).

There is a saline category in the ARC/INFO database (Table 4). This was used in Canada and Alaska to map low-lying coastal wetlands. In Russia, this code was initially used for large areas of the Yamal Peninsula, where there are saline sub-surface deposits. After further consultation with N.G. Moskalenko, G.V. Ananjeva and D.S. Drozdov, the saline codes were changed to reflect the surface soil chemistry that directly controls plant growth, rather than the chemistry of underlying deposits. The remaining saline areas are mostly coastal and estuarine areas that are too small to show up at the scale at which the Substrate pH map was printed, and so were combined with the circumneutral areas.

Table 4. CAVM substrate legend categories

ARC/INFO code	Substrate type
2	acidic
3	circum neutral
4	carbonate
5	saline

Canada: The substrate code was based largely on Charles Tarnocai's Soil Landscapes of Canada web site with Agriculture and Agri-Food Canada (http://sis.agr.gc.ca/cansis/nsdb/slc/). This site includes maps of "Parent Material Calcareous Class". In addition, surface geology maps which showed the occurrence of limestones and dolomites were used for areas which were too rocky to have soils data (see Appendix C for references). These categories were compared with existing vegetation maps (and areas where known vegetation types conflicted with the mapped substrate were changed to match the substrate type indicated by the vegetation.

Greenland: The Greenland substrate types were based on the ILUM types, as mapped by F.J.A. Daniels and M. Wilhelm (see Greenland vegetation mapping).

Iceland: The Iceland polygons were all mapped as circumneutral by E. Einarsson.

Norway: The Norway substrate types were based on the description of the vegetation type assigned to each polygon by A. Elvebakk (se Norway vegetation mapping).

Russia: The mapping of substrate chemistry in Russia was based mostly on the description of the vegetation types, which were described as acidic or non-acidic (circumneutral). There was also a substrate category which distinguished saline polygons (see Russia vegetatio mapping). In addition, the lithology of the polygons, based on maps of surface geology (Ganeshin et al. 1976) and bedrock geology (Nalivkin et al. 1966), was used. The bedrock geology map was used to distinguish regions with karst-able rocks, especially in areas without a thick cover of loose Quaternary sediment. Karst areas were classified as circumneutral. The substrate mapping was closely proofed by the Russian mappers in during M. Raynolds' visit to Moscow in October 2002.

Ganeschin G.S. (ed.), Adamenko O.M. et al. (1976). The map of the Quarternary (surface) Geology at scale 1:2 500 000. Moscow. GUGK *(in Russian).*
Nalivkin D.S. (ed.) et al. (1966). Bedrock geology map at scale 1:5 000 000. Moscow. GUGK *(in Russian).*

United States: Substrate chemistry from the United States was based on surface and bedrock geology maps of Alaska (Beikman 1980, Karlstrom 1964, Williams et al. 1977), and experience based on years of field work by D.A. Walker, C.J. Markon, and M.T. Jorgenson.

Beikman, H.M. 1980. Geologic Map of Alaska. Miscellaneous Geologic Investigations Map I-357 1 US Geological Survey (Scale 1:1,584,00).

Karlstrom, T.N.V. et al. 1964. Surficial Geology of Alaska. Misccellaneous Geologic Investigations, Map I-357. US Geological Survey.

Williams, J. R., W.E. Yend, L.D. Carter, TD. Hamilton. 1977. Preliminary Surfiial Deposits map of National Petroleum Reserve, Alaska, Open File Report 77-868 U.S. Geological Survey (Sclae 1:60,000).

Percent lake cover

Lake cover strongly affects the albedo, or reflectance, of the land surface over large areas of the Arctic, and is useful for delineating extensive wetlands. Initially lake cover was derived from the AVHRR imagery in several different ways, producing maps that were used to help define vegetation polygons. For Russia, the Map of the World hydrology cover was converted to lake polygons, and then a grid cell analysis (20x20 km cell size) was used to calculate percent lake cover. For Canada, a similar procedure was used, with a 7.5x7.5 km cell size. For Alaska, visual estimates from 1:63,360 topography maps were used to classify percent lakes. For Greenland, visual estimates of percent lakes were made based on the AVHRR false-CIR imagery, as well as from topography maps.

The final lake cover map was based on the number of AVHRR water pixels in each mapped CAVM polygon, divided by the total number of pixels in the polygon. Since the imagery has a pixel size of 1 km^2, lake cover is underestimated for areas with many small lakes. No pixels were sampled within 2 pixels (2 km) of the coastline to avoid including ocean pixels. The percent cover data were grouped into six categories: < 2%, 2-10%, 10-25%, 25-50%, 50-75%, and 75-100%. Since the sum of the last three categories was only 1.5%, (the 75-100% category covered 1% of the map), they were combined for the map into one category, >25%.

Landscape

The landscape map was derived from topographic data, regional physiographic maps, and visual interpretation of the AVHRR false-CIR image. Landscape codes were assigned to each of the vegetation polygons. For Greenland, Russia and the United States, detailed landscape maps formed the basis of the vegetation polygons (see vegetation mapping section). However, these landscape maps did not have a uniform legend, and could not be easily combined. These detailed landscape categories were combined into the ten general categories most useful in creating the vegetation map (Table 5), which were further combined into five categories for the final map (plains, hills, mountains, glaciers (including nunataks), and water (including lakes, lagoons, and ocean)). The plateau category was merged with the either the hill category (<500 m elevation) or the mountain category (>500 m elevation), because it was interpreted differently in different portions of the map. Riparian areas were also not consistently defined in different parts of the map. Many riparian areas, though of great ecological importance, were also too narrow to map (less than 8km width). For these reasons, the riparian landscape category (and the riparian vegetation category) were mapped as linear features, not polygons.

Canada and United States: Landscape codes were derived from the "integrated landscape unit map" (ILUM) code (see metadata for vegetation mapping).

Greenland: Landscape codes were derived from the "integrated landscape unit map" (ILUM) code (see metadata for vegetation mapping).

Iceland: The landscape categories for Iceland were interpreted by M.K. Raynolds, using the AVHRR false-color CIR image and the elevation map.

Norway: The landscape categories were determined based on the vegetation code (see metadata for vegetation mapping).

Russia: The Russian mappers provided "landschaft" (landscape) codes for each of their polygons. These were based largely on existing landscape maps (Gudilin 1980). The polygons were grouped into landscape units for the CAVM based on the description of the "landschaft" codes. Riparian areas were not mapped separately under the Russian "landschaft" approach, so polygons with riparian vegetation codes ("veget-id") were coded as riparian landscape. This proved to be ineffective - the definition of riparian area was too inconsistent across Russia, and between Russia and other areas of the Arctic.

Gudilin I.S. (ed.) et al., (1980). Landscape map of USSR at scale 1:2 500 000. Moscow. GUGK.

Table 5. Cross-walk of CAVM landscape mapping

Landscape	*ARC/INFO code*	*Canada and United States*	*Greenland*	*Iceland*	*Norway*	*Russia*
ARC/INFO item name:		"ilum"	"ilum_nr"		"veg"	"landschaft"
ocean	0	null	null	null	null	null
glaciers	1	280	42		A	20
lakes	2	270	41		N/A	30, ilum = 270
riparian	3	260	N/A		N/A	veget-id = 16,17,36,37,38,68,69,70,98,102
plains	4	170-255, 265	4,5,9,10,14,15,16, 20,21,22		E,F,G,H,L,M,N	1,2,3
plateaus	5	50-95	11,12,13,17,18,19 ,23,24,25,28,29		N/A	4,5,6,7,8
hills	6	100-160, 290	1,2,3,6,7,8,26,27	based on interpretation of AVHRR CIR image & elevation map	C,D,I	9,10,11,12,13

mountains	7	10,20,30,40	30,31,32,33,34,35 ,36,37,38	I,J,K	14,15
nunataks	8	285	39,40	B	N/A
lagoons	9	275	N/A	N/A	30, illum = 275

Appendix A: Map Generalization

1) Coastline and glacier polygons that had an area < 49,000,000 square meters were deleted from the dataset by the ELIMINATE command.

```
Arc: eliminate coast_old coast_new nokeepedge poly # area
Eliminating polygons in coast_old to create coast_new
Enter a logical expression. (Enter a blank line when finished)
>: res area > 0 and area < 49000000
>:
Do you wish to re-enter expression (Y/N)? n
Do you wish to enter another expression (Y/N)? n
 10601 features out of 11432 selected.
Number of Polygons (Input,Output) =      11432        831
Number of Arcs     (Input,Output) =      38736      26987
 Creating coast_new.PAT...
```

2) Coastlines were simplified to a weed tolerance of 5000 m using the bendsimplify option.

```
Arc: generalize coast_el coast_3b5k 5000 bendsimplify
Generalized coverage coast_3b5k
From: 487907 Vertices and 26987 Arcs
To  : 192759 Vertices and 26987 Arcs
Removing Topology...
```

3) Cleaned simplified coastline with a fuzzy tolerance of 500 m.

```
Arc: clean COAST_3B5K COAST_3B5K 500 500 poly
Cleaning /GEODATA/CIRCUMPLR/CAVM_WORKING/COAST_3B5K
 Sorting...
 Intersecting...
 Assembling polygons...
```

4) Repeated step 1 to remove any small polygons that may have been created during the clean process.

Appendix B: AVHRR Composites

Circumpolar AVHRR image was derived from 1993 and 1995 10 day composite images (**REF**). This image was created to replace the less than satisfactory 1992 composite received from the USGS. These images were generated in house from USGS provided 10day composites with the exception of the reprojection of the data from a Goode Homolosine to the Lambert Azimuthal Equal Area projection. Composites from July and August were used. The maximum pixel value was selected from all of the 10 day composites. NDVI was calculated from bands 1 and 2.

The following composite scenes were used:
July 11-20, 1993
July 21-31, 1993
August 1-10, 1993
August 11-20, 1993
August 21-30, 1993

July 11-20, 1995
July 21-31, 1995
August 1-10, 1995
August 11-20, 1995
August 21-30, 1995

Appendix C: Canadian mapping references

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Appendix D - Russian vegetation legend

Legend of Russian Arctic

Map unit	Description	***Community 1***	***Community 2***
Zone 1			
1	Dry acidic and nonacidic lichen-forb tundra	**Cetraria cucullata-Papaver polare [E]**	**Pertusaria-Ochrolechia [E]**
2	Moist acidic lichen-forb tundra and grass-moss barrens	**Stereocaulon rivulorum-Stellaria edwardsii [E]**	Phippsia algida- Racomitrium lanuginosum+Ditrichum flexicaule [T]
3	Moist nonacidic grass-moss tundra	**Deschampsia borealis-Alopecurus alpinus-Aulacomnium turgidum[T]**	
4	Mountain acidic lichen-moss and forb-grass-moss tundra	**Umbilicaria proboscidea-Racomitrium lanuginosum [EY]**	**Saxifraga hyperborea+ Papaver polare+Phippsia algida-Dicranoweisia crispula +Hygrohypnum polare +Polytrichum alpinum [T]**

Zone 2			
5	Dry acidic lichen-rush tundra	**Cladina mitis-Luzula confusa [E]**	
6	Dry acidic moss-lichen tundra	**Racomitrium lanuginosum-Cetraria nivalis [E]**	
7	Dry acidic grass barrens	**Deschampsia brevifolia-Poa alpigena [Y]**	
8	Dry nonacidic prostrate dwarf shrub-lichen tundra	**Dryas subincisa-Cetraria nivalis [E]**	
9	Moist acidic moss-sedge tundra	**Aulacomnium turgidum-Carex arctisibirica [W]**	
10	Moist acidic prostrate dwarf shrub-grass-forb-moss tundra	**Salix reptans+S.polaris-Alopecurus alpinus-Saxifraga nelsoniana-Tomentypnum nitens + Aulacomnium turgidum [C]**	
11	Moist acidic and nonacidic sedge-prostrate dwarf shrub-moss tundra	**Carex lugens+Salix reptans-Tomenthypnum nitens+ Aulacomnium turgidum [C]**	**Dryas integrifolia+Salix rotundifolia-Schistidium strictum+Tortula ruralis [C]**
12	Moist nonacidic moss-grass tundra	Tomentypnum nitens-Deschampsia brevifolia [E]	
13	Moist nonacidic prostrate dwarf shrub-sedge-grass-moss tundra	**Dryas punctata-Carex arctisibirica-Hylocomium splendens + Tomentypnum nitens [T]**	**Salix polaris+S. arctica-Alopecurus alpinus+ Hylocomium splendens [T]**
14	Moist acidic grass-prostrate dwarf shrub-moss tundra and wet sedge mire	**Alopecurus alpinus-Salix polaris-Aulacomnium turgidum [Y]**	**Carex stans+Eriophorum polystachion [Y]**
15	Wet acidic moss-sedge mire	**Calliergon sarmentosum-Carex stans+Eriophorum polystachion [W]**	
16	Riparian acidic sedge-grass-moss mire and prostrate dwarf shrub-sedge-moss tundra	**Carex stans- Dupontia fisheri-Poa arctica-Calliergon sarmentosum [T]**	**Dryas punctata-Carex arctisibirica+Luzula confusa-Hylocomium splendens [T]**
17	Riparian acidic grass-prostrate dwarf shrub-moss tundra and sedge-moss bog	**Alopecurus alpinus-Salix polaris-Aulacomnium turgidum [Y]**	**Carex stans-Eriophorum polystachion-Sphagnum balticum [Y]**
18	Mountain dry acidic lichen-moss-forb barrens	**Pertusaria-Ditrichum flexicaule-Papaver polare [T]**	Rhizocarpon geographicum-Haematomma ventosum [Y]
19	Mountain moist acidic grass-prostrate dwarf shrub-moss tundra	**Alopecurus alpinus-Salix polaris-Ditrichum flexicaule [Y]**	
20	Mountain moist acidic prostrate dwarf shrub-forb-grass-moss-lichen tundra	**Dryas punctata+Saxifraga nelsoniana+Oxyria digyna-Polytrichum alpinum+Cetraria cucullata+Nephroma expallidum [C]**	**Salix pulchra-Arctagrostis latifolia+Petasites frigidus-Tomentypnum nitens +Aulacomnium palustre [C]**
21	Mountain moist acidic prostrate dwarf shrub-sedge-forb-moss-lichen tundra	**Salix arctica+Dryas punctata-Aulacomnium turgidum +Racomitrium uliginosum +Cetraria cucullata+C.nivalis [TC]**	**Carex saxatilis+C.lugens-Salix polaris+S.reptans+ Saxifraga hirculus-Aulacomnium palustre+Oncophorus wahlenbergii [C]**
22	Mountain dry nonacidic forb-moss barrens	**Potentilla hyparctica-Polytrichum alpinum [E]**	

23	Mountain nonacidic sedge-prostrate dwarf shrub-shrub-grass-forb-moss tundra	**Carex lugens+Dryas integrifolia+ Salix reptans-Tomentypnum nitens+Aulacomnium turgidum [C]**	Salix richardsonii-Dryas integrifolia+Salix rotundifolia- Arctagrostis arundinacea+ Saxifraga hirculis-Distichium capillaceum+Myurella julacea [C]
Zone 3			
24	Dry acidic prostrate dwarf shrub-sedge-lichen tundra	**Salix nummularia-Carex arctisibirica-Alectoria ochroleuca [W]**	**Cetraria cucullata-Dicranum elongatum-Hierochloe alpina [W]**
25	Dry and moist saline grass-sedge-forb meadow	**Leymus villosissimus-Mertensia maritima [C]**	**Carex glareosa+Puccinellia phryganodes+Stellaria humifusa [C]**
26	Moist acidic prostrate dwarf shrub-grass-moss tundra	**Salix polaris-Deschampsia brevifolia-Hylocomium splendens [E]**	**Salix polaris-Aulacomnium turgidum [Y]**
27	Moist acidic sedge-moss tundra	**Carex arctisibirica-Aulacomnium turgidum [W]**	
28	Moist acidic low shrub-prostrate dwarf shrub-sedge-moss tundra	**Dryas punctata-Carex arctisibirica-Hylocomium splendens [T]**	**Salix reptans-Carex stans-Saxifraga nelsoniana-Aulacomnium turgidum [T]**
29	Moist acidic prostrate dwarf shrub-sedge-moss-lichen tundra	**Salix polaris-Aulacomnium turgidum-Cetraria cucullata [Y]**	**Carex stans-Aulacomnium turgidum [Y]**
30	Moist acidic prostrate dwarf shrub-forb-lichen and moist prostrate dwarf shrub-sedge-moss tundra	**Dryas punctata-Oxytropis czukotica-Bryocaulon divergens [C]**	**Salix polaris-Carex lugens-Tomentypnum nitens [C]**
31	Moist acidic moss-lichen-dwarf shrub-forb tundra	**Racomitrium lanuginosum+ Cladina rangiferina-Cassiope tetragona+Diapensia obovata+Claytonia acutifolia [C]**	
32	Moist nonacidic and acidic prostrate dwarf shrub-sedge-moss tundra	**Dryas subincisa+Salix polaris-Carex arctisibirica-Dicranum elongatum (W)**	**Dryas punctata-Carex arctisibirica-Rhytidium rugosum+Hylocomium splendens [T]**
33	Wet acidic sedge-grass-moss mire	**Carex stans-Calliergon sarmentosum+Drepanocladus exannulatus [EW]**	**Dupontia fisheri-Calliergon sarmentosum [E]**
34	Wet acidic sedge-moss bog and saline grass-sedge meadow	**Carex stans-Aulacomnium turgidum [Y]**	**Puccinellia phryganodes-Carex subspathacea [Y]**
35	Wet saline grass-sedge meadows	**Puccinellia phryganodes-Carex subspathacea [WY]**	
36	Riparian acidic prostrate dwarf shrub-low shrub-sedge-moss tundra	**Salix polaris-Carex stans-Tomentypnum nitens+ Drepanocladus uncinatus [T]**	**Salix reptans-Carex stans+Eriophorum polystachion-Tomentypnum nitens [T]**
37	Riparian acidic prostrate dwarf shrub-moss tundra and sedge mires	**Salix polaris-Aulaconium turgidum [Y]**	**Eriophorim scheuchzeri-Carex stans Y]**
38	Riparian acidic sedge-moss bogs and willow-forb shrublands	**Carex stans+Eriophorum polystachion-Calliergon sarmentosum [W]**	**Salix glauca-Pedicularis sudetica [W]**

40	Mountain acidic lichen-prostrate dwarf shrub tundra	**Alectoria ochroleuca-Bryocaulon divergens [Y]**	Dryas punctata-Cassiope tetragona [Y]
41	Mountain acidic lichen-moss-forb barrens and prostrate dwarf shrub tundra	**Ochrolechia frigida+Ditrichum flexicaule-Papaver polare [T]**	**Dryas punctata+Novosieversia glacialis-Racomitrium uliginosum [T]**
Zone 4			
42	Dry acidic prostrate dwarf shrub-grass-lichen-moss tundra	**Cladina stellaris-Dicranum fuscescens-Festuca ovina-Salix herbacea [E]**	Empetrum hermaphroditum-Cladina mitis-Polytrichum alpinum [E]
43	Dry acidic dwarf shrub-lichen-moss tundra	**Salix nummularia+Dryas subincisa -Cetraria cucullata [W]**	Cassiope tetragona+Diapensia obovata-Cladina arbuscula-Aulacomnium turgidum [Y]
44	Dry acidic dwarf shrub-grass-moss-lichen tundra	**Betula nana-Empetrum hermaphroditum+Vaccinium minus-Festuca ovina-Dicranum elongatum+Cetraria cucullata [E]**	**Ledum decumbens-Vaccinium minus-Cetraria cucullata-Racomitrium lanuginosum [W]**
45	Dry nonacidic prostrate dwarf shrub-lichen-moss tundra	Dryas subincisa-Stereocaulon paschale-Dicranum elongatum [E]	**Dryas punctata+Androsace chamaejasme-Rhytidium rugosum [T]**
46	Dry and moist acidic low shrub-sedge-moss-lichen tundra	**Betula nana-Salix polaris-Polytrichum hyperboreum-Sphaerophorus globosus [E]**	**Betula nana-Carex arctisibirica-Aulacomnium turgidum-Cladonia gracilis [E]**
47	Dry and moist acidic prostrate dwarf shrub-sedge-moss tundra	Dryas punctata-Rhytidium rugosum [T]	**Dryas punctata-Carex arctisibirica-Hylocomium splendens [T]**
48	Moist and dry acidic sedge-prostrate dwarf shrub-moss-lichen tundra	**Carex stans-Aulacomnium turgidum-Cetraria cucullata [Y]**	**Salix nummularia-Racomitrium lanuginosum-Cladina arbuscula [Y]**
49	Dry and moist saline forb-grass-sedge meadow	**Lathyrus japonicus-Leymus villosissimus [C]**	**Carex subspathacea-Calamagrostis deschampsioides-Pohlia sp. [C]**
50	Moist acidic low shrub-sedge-moss tundra	**Betula nana-Carex arctisibirica-Dicranum congestum-Aulacomnium turgidum [EW]**	Eriophorum vaginatum-Sphagnum lenense [W]
51	Moist acidic low shrub-dwarf shrub-cotton grass-moss tundra	Salix glauca-Salix herbacea-Vaccinium minus-Dicranum elongatum [E]	
52	Moist acidic sedge-forb-low shrub-moss tundra	Eriophorum vaginatum+Petasites frigidus-Sphagnum girgensohnii [E]	**Carex arctisibirica-Betula nana-Vaccinium minus-Dicranum congestum [EW]**
53	Moist acidic prostrate dwarf shrub-low shrub-sedge-moss tundra	**Dryas punctata-Carex arctisibirica-Hylocomium splendens+ Tomentypnum nitens [T]**	**Betula nana-Salix reptans-Carex arctisibirica-Tomentypnum nitens [T]**

54	Moist acidic dwarf shrub-sedge-moss tundra	**Salix polaris-Carex stans-Aulacomnium turgidum [Y]**	**Carex stans-Vaccinium minus-Aulacomnium turgidum [Y]**
55	Moist acidic low shrub-erect dwarf shrub-sedge-moss tundra	**Salix pulchra-Vaccinium minus-Carex stans-Aulacomnium turgidum [Y]**	Eriophorum vaginatum-Aulacomnium turgidum [Y]
56	Moist acidic dwarf shrub-sedge-lichen-moss tundra	**Betula exilis+Ledum decumbens+Carex stans-Cetraria islandica+Cladina rangiferina+ Sphenolobus minutus [C]**	**Eriophorum vaginatum+ Ledum decumbens-Dicranum elongatum+Cladina rangiferina+Cetraria cucullata [C]**
57	Moist acidic dwarf shrub-sedge-grass-moss-lichen tundra	**Betula exilis+Ledum decumbens-Diapensia obovata-Carex lugens+ Calamagristis holmii-Dicranum elongatum+Ochrolechia gonatodes+Peltigera aphthosa [C]**	
58	Moist nonacidic prostrate dwarf shrub-low shrub-forb-moss tundra	**Drys punctata-Saxifraga nelsoniana-Dicranum congestum [W]**	**Salix glauca+Salix lanata-Petasites frigidus-Aulacomnium palustre [W]**
59	Moist and wet acidic shrub-prostrate dwarf shrub-moss tundra and sedge-forb-moss mire	**Betula nana-Vaccinium microphyllum-Salix polaris-Dicranum congestum [E]**	**Carex aquatilis+Eriophorum polystachion-Rubus chamaemorus-Sphagnum squarrosum [E]**
60	Moist and wet acidic shrub-dwarf shrub-sedge-moss tundra and mire	**Betula nana-Cassiope tetragona-Carex arctisibirica-Tomentypnum nitens [T]**	**Carex stans-Salix reptans-Meesia triquetra [T]**
61	Moist and wet acidic dwarf shrub-sedge-moss tundra and sedge moss-lichen bog	**Salix pulchra-Carex stans-Aulacomnium turgidum [Y]**	**Carex stans+Eriophorum polystachion-Sphagnum balticum-Cetraria cucullata [Y]**
62	Moist and wet acidic sedge-dwarf shrub-moss tundra and sedge-moss bog	**Eriophorum vaginatum-Vaccinium minus-Aulacomnium turgidum [Y]**	Carex stans+Eriophorum polystachion-Sphagnum balticum [Y]
63	Wet and moist acidic sedge-forb-moss mire and tundra	**Carex aquatilis+Eriophorum polystachion-Rubus chamaemorus-Sphagnum squarrosum [EW]**	Eriophorum vaginatum-Rubus chamaemorus-Sphagnum girgensohnii-Aulacomnium palustre [W]
64	Wet acidic sedge-forb-moss mire	**Eriophorum polystachion-Carex aquatilis-Rubus chamaemorus-Calliergon stramineum [E]**	**Eriophorum polystachion-Carex aquatilis-Rubus chamaemorus-Sphagnum fimbriatum [EY]**
65	Wet acidic sedge-dwarf shrub-moss mire	**Carex aquatilis-Drepanocladus exannulatus+D. fluitans [EW]**	**Ledum decumbens-Carex stans-Sphagnum lenense [W]**
66	Wet saline grass-sedge meadow and acidic prostrate dwarf shrub-sedge-moss bog	**Puccinellia phryganodes-Carex subspathacea [Y]**	**Salix polaris-Carex stans-Aulacomnium turgidum [Y]**

67	Wet saline grass-sedge meadow	**Puccinellia phryganodes-Carex subspathacea [WY]**	
68	Riparian acidic shrub-sedge-dwarf shrub-forb-moss tundra	**Betula nana-Carex arctisibirica-Vaccinium minus-Arctous alpina-Dicranum congestum [E]**	**Salix glauca-Salix lanata-Carex aquatilis-Polemonium acutiflorum-Pleurozium schreberi-Tomentypnum nitens [ET]**
69	Riparian acidic sedge-moss mire and low shrub-sedge-moss tundra	**Carex stans-Drepanocladus revolvens-Calliergon giganteum +Meesia triquetra [WT]**	**Salix lanata+Salix glauca-Calamagrostis neglecta+Carex stans-Aulacomnium turgidum + Tomentypnum nitens [WT]**
70	Riparian acidic sedge-grass mire and shrubland	**Carex stans+Eriophorum polystachion+E.vaginatum+ Arctophila fulva [Y]**	**Salix pulchra-Salix alaxensis +Alnus fruticosa [Y]**
71	Riparian acidic sedge-moss mire	**Carex stans+ Eriophorum polystachion-Sphagnum balticum [Y]**	
72	Mountain dry acidic prostrate dwarf shrub-lichen tundra	**Dryas punctata-Cassiope tetragona [Y]**	**Alectoria ochroleuca-Bryocaulon divergens [Y]**
73	Mountain moist acidic prostrate dwarf shrub-forb-moss-lichen tundra	**Dryas punctata+Salix phlebophylla-Astragalus umbellatus+Petasites frigidus-Dicranum spadiceum-Rhytidium rugosum-Dactylina arctica [C]**	
74	Mountain moist and wet acidic shrub-dwarf shrub-grass-sedge-forb-moss-lichen tundra	**Salix saxatilis+S.pulchra-S.phlebophylla-Dryas punctata+ Hierochloe alpina+Carex lugens+Pyrola grandiflora-Dicranum elongatum+Thamnolia vermicularis [C]**	**Eriophorum vaginatum+Carex stans+Betula exilis+Salix fuscescens-Dicranum elongatum+Drepanocladus revolvens [C]**
Zone 5			
75	Dry acidic dwarf shrub-rush-grass-lichen tundra	**Empetrum nigrum-Cetraria nivalis-Cladina stellaris [E]**	**Luzula confusa-Vaccinium mitis-Festuca ovina-Salix herbacea-Cladina mitis-C.rangiferina [E]**
76	Dry acidic dwarf shrub-sedge-lichen-moss tundra	**Ledum decumbens-Vaccinium vitis-idaea-Empetrum subholarcticum-Cladina mitis [W]**	**Dryas subincisa-Carex arctisibirica-Cladina rangiferina-Racomitrium lanuginosum [W]**
77	Dry acidic low shrub-lichen-moss tundra	**Betula exilis+Salix pulchra-Cetraria cucullata [Y]**	**Salix glauca+Salix lanata-Deschampsia alpina-Hylocomium splendens [E]**
78	Dry nonacidic low shrub-prostrate dwarf shrub-forb-lichen-moss tundra	**Salix glauca-Dryas subincisa-Diapensia lapponica-Pedicularis sudetica-Alectoria ochroleuca-Racomitrium lanuginosum [W]**	
79	Dry and moist acidic dwarf shrub-low shrub-moss tundra	**Dryas punctata-Bistorta elliptica- Racomitrium lanuginosum [T]**	**Betula nana+Alnus fruticosa-Ledum decumbens-Carex arctisibirica-Hylocomium splendens [T]**
80	Moist and dry acidic low shrub-dwarf shrub-moss-lichen tundra	**Betula exilis-Vaccinium vitis-idaea-Aulacomnium turgidum-**	**Betula exilis-Salix pulchra-Cetraria cucullata [Y]**

		Cetraria cucullata [Y]	
81	Moist acidic low shrub-grass-dwarf shrub-moss-lichen tundra	**Betula nana-Festuca ovina-Carex rotundata-Polytrichum strictum-Hylocomium splendens-Cladina stellaris [E]**	**Betula exilis-Salix pulchra-Vaccinium vitis-idaea-Aulacomnium turgidum-Cetraria cucullata [Y]**
82	Moist acidic dwarf shrub-sedge-moss-lichen tundra	**Betula nana+Salix pulchra-Aulacomnium turgidum+Cladina stellaris [W]**	Eriophorum vaginatum-Dicranum elongatum +Sphagnum balticum [W]
83	Moist acidic dwarf shrub-low shrub-forb-moss-lichen tundra	**Betula nana-Dryas punctata-Aulacomnium turgidum+Cladina stellaris [W]**	**Salix lanata-Vaccinium microphyllum-Polemonium acutiflorum-Aulacomnium palustre [W]**
84	Moist acidic low shrub-sedge-forb-grass-moss tundra	**Betula nana+Salix glauca-Carex aquatilis-Stellaria calycantha-Deschampsia alpina-Sphagnum squarrosum [E]**	**Salix glauca+S.lanata-Deschampsia alpina+Bistorta vivipara-Hylocomium splendens [E]**
85	Moist acidic low shrub-dwarf shrub-moss-lichen tundra and dwarf shrub-moss-lichen open woodland	**Betula exilis-Vaccinium vitis-idaea-Aulacomnium turgidum-Cetraria cucullata [Y]**	**Larix gmelini-Vaccinium vitis-idaea-Hylocomium splendens-Cetraria cucullata [Y]**
86	Moist acidic shrub-dwarf shrub-grass-forb-sedge-moss-lichen tundra	**Salix krylovii+S.pulchra-Vaccinium uliginosum+ Arctagrostis arundinacea +Polygonum tripterocarpum +Petasites frigidus-Drepanocladus uncinatus-Peltigera scabrosa [C]**	
87	Moist acidic sedge-dwarf shrub-forb-moss-lichen tundra	Eriophorum vaginatum+Carex stans+Ledum decumbens+Rubus chamaemorus-Dicranum elongatum+Cladina rangiferina+Nephroma expallidum [C]	**Carex rariflora-Salix fuscescens-Sphagnum sp. [C]**
88	Moist nonacidic and acidic sedge-low shrub-dwarf shrub-moss tundra	**Carex ledobouriana-C.gracilis-Dicranum elongatum [W]**	**Carex arctisibirica-Betula nana-Ledum decumbens+ Vaccinium microphyllum-Dryas punctata-Hylocomium splendens [T]**
89	Moist and wet acidic low shrub-dwarf shrub-sedge-moss-lichen tundra and palsa bog	**Betula exilis-Vaccinium vitis-idaea-Aulacomnium turgidum-Cetraria cucullata [Y]**	**Betula exilis-Carex stans-Cetraria cucullata-Aulacomnium turgidum [Y]**
90	Moist and wet acidic low shrub-dwarf shrub-forb-moss-lichen tundra and palsa bog	**Betula nana+Salix glauca-Vaccinium uliginosum-Hylocomium splendens [W]**	**Ledum palustre-Rubus chamaemorus-Cladina stellaris-Sphagnum fuscum [W]**
91	Moist and wet acidic low shrub-sedge-forb-moss tundra and mire	**Betula nana+Salix glauca-Carex rotundata+Polemonium acutiflorum+Pedicularis sudetica+Aulacomnium palustre**	**Betula nana-Carex aquatilis-Carex rotundata-Rubus chamaemorus-Comarum palustre-Sphagnum fuscum+**

		[EW]	**S. lindbergii [EW]**
92	Moist and wet acidic low shrub-sedge-moss tundra and mire	**Betula exilis-Salix pulchra-Eriophorum vaginatum-Aulacomnium turgidum [Y]**	**Betula exilis-Salix pulchra-Eriophorum vaginatum+Carex stans-Polytrichum strictum-Tomentypnum nitens [Y]**
93	Moist and wet acidic shrub-sedge mire and shrublands	**Alnus fruticosa-Salix pulchra-Eriophorum vaginatum+Carex stans [Y]**	**Salix pulchra-Salix alaxensis [Y]**
94	Wet low shrub-dwarf shrub-sedge-forb-moss-lichen mire	**Salix lapponum-Betula nana-Carex aquatilis-Calliergon stramineum+ Sphagnum lindbergii [EW]**	**Ledum palustre+Eriophorum vaginatum-Rubus chamaemorus-Sphagnum fuscum-Cladina stellaris [EW]**
95	Mesic saline prostrate dwarf shrub-forb-grass tundra and wet saline sedge-grass-forb meadow	**Empetrum subholarcticum-Potentilla fragiformis-Leymus villosissimus [C]**	**Carex lyngbyei+Arctophila fulva-Ranunculus tricrenatus [C]**
96	Wet saline sedge-grass-forb meadow	**Carex subspathacea-Potentilla egedii-Triglochin maritimum [E]**	**Leymus arenarius+Agrostis stolonifera-Sonchus humilis [E]**
97	Riparian acidic grass-forb-moss meadow	**Alopecurus pratensis-Achillea millefolium-Brachythecium mildeanum [E]**	
98	Riparian acidic grass-forb shrubland and grass-horsetail-forb fen	**Salix pyrolifolia-Salix glauca-Bromopsis inermis-Galium boreale [E]**	**Arctophila fulva-Equisetum arvense-Caltha palustris [E]**
99	Riparian acidic dwarf shrub-forb shrubland	**Betula nana-Vaccinium microphyllum-Bistorta elliptica [E]**	
100	Riparian acidic shrub-dwarf shrub-sedge-moss tundra	**Alnus fruticosa-Ledum decumbens-Dryas punctata-Carex arctisibirica-Hylocomium splendens [T]**	Eriophorum vaginatum-Betula nana-Sphagnum fimbriatum [T]
101	Riparian acidic sedge-moss mire and grass-forb-sedge-moss shrublands	**Carex aquatilis+Eriophorum polystachion-Calliergon stramineum [WT]**	**Salix lanata-Calamagrostis langsdorfii-Pedicularis sudetica-Carex aquatilis-Aulacomnium turgidum-Drepanocladus uncinatus [WT]**
102	Riparian acidic shrub-sedge mire and shrublands	**Alnus fruticosa-Betula exilis-Eriophorum vaginatum+Carex stans-Polytrichum strictum [Y]**	**Salix pulchra-Salix alaxensis [Y]**
103	Riparian acidic low shrub-sedge-moss bog	**Betula exilis-Salix pulchra-Eriophorum vaginatum-Aulacomnium turgidum [Y]**	**Carex stans+C.chordorriza [Y]**
104	Mountain moist acidic sedge-shrub-grass-forb-moss-lichen tundra	**Carex lugens-Salix pulchra-Dicranum elongatum+ D.scoparium+Dactylina arctica [C]**	**Salix pulchra+Alnus fruticosus-Calamagrostis purpurea+Polygonum tripterocarpum+Petasites frigidus-Dicranum sp.+ Polytrichum juniperinum [C]**
105	Mountain moist acidic shrub-dwarf shrub-grass-forb-moss tundra	**Alnus fruticosa+Ribes triste-Empetrum**	

		subholarcticum+Festuca altaica+Rubus arcticus-Tortula ruralis [C]	
106	Mountain dry nonacidic lichen-moss barrens and prostrate dwarf shrub-forb-lichen-moss tundra	Rhizocarpon geographicum-Racomitrium lanuginosum [EY]	**Dryas subincisa+Dryas punctata-Thalictrum alpinum-Alectoria ochroleuca-Rhytidium rugosum [EY]**
107	Mountain dry nonacidic sedge-prostrate dwarf shrub-moss tundra	**Carex ledobouriana-Dryas subincisa-Racomitrium lanuginosum [W]**	
108	Mountain dry nonacidic lichen-moss barrens and moist low shrub-dwarf shrub-moss tundra	Rhizocarpon geographicum-Racomitrium lanuginosum [E]	Juniperus sibirica-Ledum palustre-Dicranum congestum [E]
109	Moist nonacidic shrub-prostrate dwarf shrub-forb-moss tundra	**Alnus fruticosa+Salix richardsonii-Arctous erythrocarpa+Anemone parviflora+Thalictrum alpinum-Drepanocladus uncinatus + Ptilidium ciliare [C]**	**Dryas integrifolia-Saxifraga oppositifolia-Carex scirpoidea [C]**
110	Moist acidic stlanic shrub-low shrub-dwarf shrub-grass-sedge-forb-moss-lichen forest tundra	**Pinus pumila+Alnus fruticosa-Ledum decumbens+Vaccinium uliginosum-Calamagrostis purpurea+Carex globularis-Pleurozium scheberi+Dicranum bergeri+Cladina rangiferina+C.arbuscula+Cladonia elongata [C]**	**Eriophorum vaginatum+Carex soczavaeana-Betula middendorffii-Ledum decumbens+Vaccinium uliginosum-Rubus chamaemorus+Pedicularis lapponica-Drepanocladus revolvens+Calliergon sarmentosum+Aulacomnium turgidum [C]**

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