# Proceedings of the Third International Circumpolar Arctic Vegetation Mapping Workshop

By Carl J. Markon and D.A. Walker

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# PROCEEDINGS OF THE THIRD INTERNATIONAL CIRCUMPOLAR ARCTIC VEGETATION MAPPING WORKSHOP

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## Dedication

This U.S. Geological Survey Open-File Report is dedicated to the memory of Stephen C. Zoltai. Stephen was an outstanding Canadian scientist who contributed greatly to the mapping and understanding of northern boreal and arctic environments, and in particular the wetlands. Stephen had a love of the natural sciences and, impelled by his curiosity, helped pioneer our understanding of the soils and permafrost in northern forests. Most recently, he had worked to help clarify the effects of past global climate change that are recorded in Canadian wetlands and had helped produce the Circumpolar Arctic Vegetation Map. Through his career, he published more than 70 publications, numerous reports, and a variety of maps; he also found time to mentor many graduate students. Stephen was a true "field ecologist," and through his dedication and hard work, he quickly became recognized as a distinguished and respected scientist. Stephen's quiet and helpful nature will be missed by all who had the pleasure of knowing him.

## Welcome, History, and Goals of the Third International Cirumpolar Arctic Vegetation Mapping Workshop

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Welcome

I would like to welcome everyone to the Third International Circumpolar Arctic Vegetation Mapping Workshop. I am especially happy that we can hold this meeting at the USGS EROS Alaska Field Office. This office has been the source of various remote sensing products that we will use in making the circumpolar arctic vegetation map (CAVM). It is the home of Carl Markon and Mike Fleming who have made major contributions to the project. I'd like to thank Carl and Mark Shasby, Director of the facility, who have made this meeting possible. I'd also like to thank Steve Talbot, who helped organize the workshop and was able to obtain partial funding for the workshop from the US Fish and Wildlife Service and the Bureau of Land Management. In Colorado, Andy Lillie and Shannon Murphy have worked very hard putting together the schedule, compiling the abstracts, and communicating with all of you. Shannon is here today, but is leaving tomorrow for field work at Toolik Lake. Most of all I would like to thank everyone here for coming and helping to move the CAVM project forward.

For those who were not at the first two international workshops in St. Petersburg, Russia and Arendal, Norway, or the 1997 North American Workshop in Anchorage, I will first give a brief review of the history of the project and where we have been. I will then present the goals of the workshop.

History of the CAVM project

The idea for the CAVM project came at the 1992 International Workshop on Classification of Circumpolar Vegetation, in Boulder, Colo., United States (Walker and others, 1994). The Boulder workshop created the first synthesis of vegetation classification in the Arctic. One of the resolutions of the workshop was to obtain funding and develop the organization for a new vegetation map of the circumpolar tundra region.

In 1994, the Komarov Botanical Institute hosted the First International CAVM workshop in Lakta on the outskirts of St. Petersburg, Russia (Walker, et al., 1995; Walker and Markon, 1996). During the workshop, we proposed to make several types of map products, including an accurate base map of the circumpolar region derived from a mosaic of AVHRR satellite images, a variety of products derived from the AVHRR normalized difference vegetation index (NDVI), and the final CAVM database, which will produce a variety of vegetation maps.

The 2$^{nd}$ International CAVM, in Arendal, Norway in 1996, laid the foundation for a three-level legend system and an integrated vegetation map, and at the 1997 North American CAVM workshop in Anchorage, a preliminary method for making an integrated vegetation database was presented (Walker and Lillie, 1997). The participants at the 1997 Anchorage meeting agreed to apply the method to several prototype map areas in North America. I think at the present workshop, we will see a variety of interpretations of the method. While this variety is good at this initial stage, we have to settle on a clearly defined method that can be applied equally in each country. Furthermore, we need input from our Scandinavian and Russian colleagues regarding the feasibility of this method in Europe and Asia.

The CAVM project has received the endorsement of the International Arctic Science Committee (IASC) and the U.S. Polar Research Board (PRB) and it has been recognized as a priority task of the Conservation of Arctic Flora and Fauna Project. It recently received a considerable boost with funding from the U.S. National Science Foundation (NSF) as part of the new Arctic System Science project called Arctic Transitions in the Land-Atmosphere System (ATLAS). Our goal is to produce a circumpolar map by the year 2001. The funding from NSF will see us a long way toward this goal, and I see this workshop as the launching pad for the effort. Everything up to now has been preparation for the launch.

There is already considerable interest and immediate needs for the results of our endeavor. There are many needs related to education and the practical aspects of land use planning in the Arctic. There also are many purely scientific needs. For example, at a recent BIOME 6000 workshop in Potsdam, Germany, modelers made objectively based reconstructions of biome distributions at 6000 y BP and the last glacial maximum on the basis of plant physiology, plant dominance, soils, and climate. They used a modified version of the map of arctic subzones (figure 1; Yurtsev, 1994) to help validate the output of the BIOME model (Prentice, et al., 1992). The AVHRR databases (Fleming, 1997) are also finding wide applications as researchers across a broad spectrum of disciplines are looking for consistent databases of the entire circumarctic region. Another example comes from the ATLAS project which is focusing on extrapolating detailed energy and trace-gas flux measurements to regional and circumpolar scales. Recently we reported major differences in energy and trace-gas fluxes and a wide variety of ecosystem properties across a pH boundary in northern Alaska (Walker, et al., in press). This boundary is probably equivalent to the boundary that separates hypoarctic from arctic tundra system across much of the Arctic. The nonacidic vegetation north of the boundary are also very important to a wide variety of wildlife species, such as caribou, and may be a useful analogue for steppe tundra ecosystems during the last glacial maximum (Walker, et al., in press). In order to assess the importance of this boundary globally, we need to know the worldwide distribution of acidic and nonacidic tundra.

## Goals of the workshop

We have 3.5 years to complete the map, so it is essential that we agree and are clear on a method from the start. Within the next year we need to have draft maps of each region in the Arctic. Toward this longer-term objective, there are three specific goals for this workshop:

Review progress: Since the Arendal meeting, we have been working at various levels of intensity on the project. The Scandinavians and Russians have not been able to progress because of the lack of base maps for their regions. This problem has been solved to some extent, although there are still problems with snow cover in parts of the High Arctic and Greenland. On the first day, we will hear short presentations from each section of the Arctic. I will present an overview of the integrated vegetation mapping technique used for the prototype map of northern

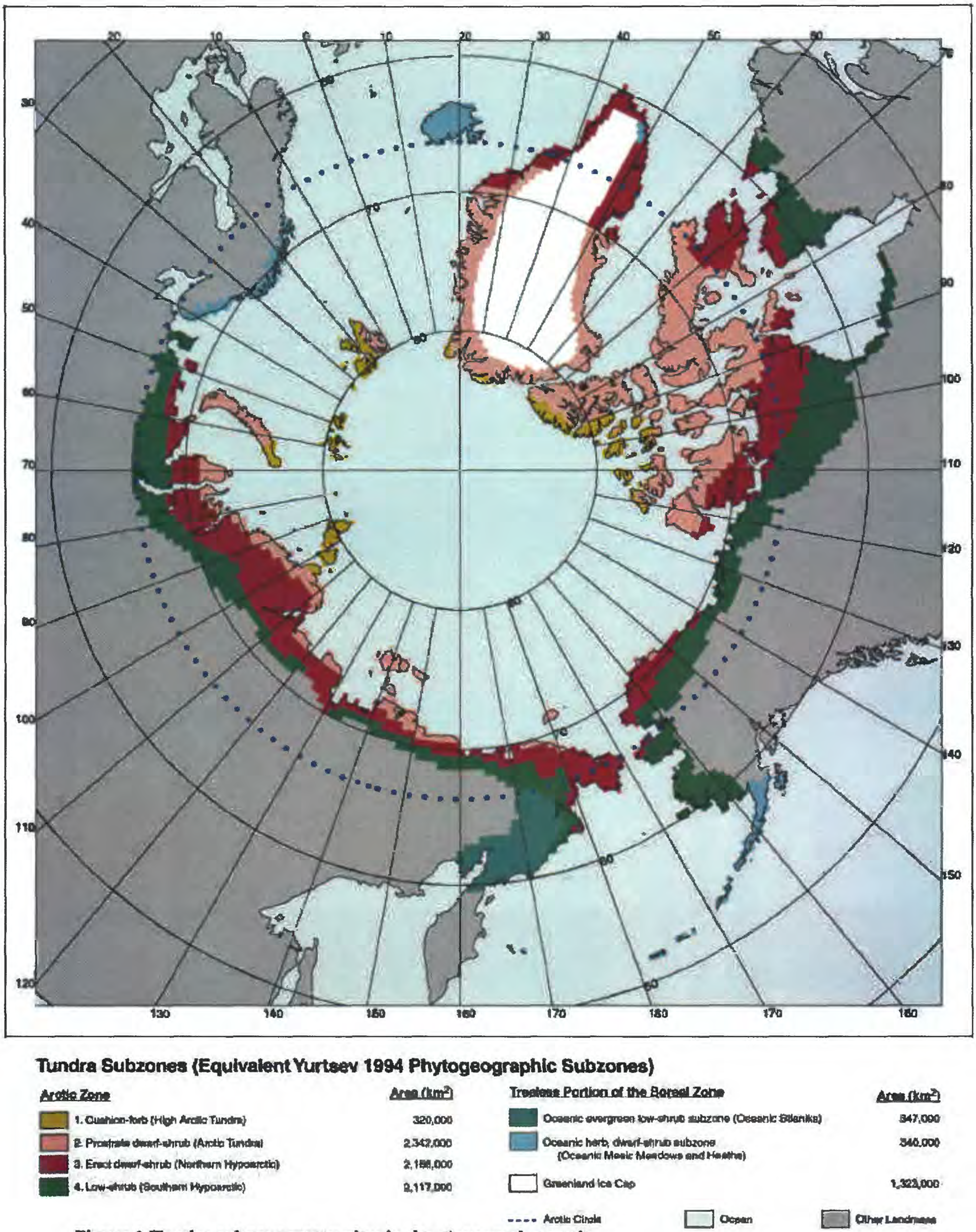


Figure 1 Tundra subzones occurring in the circumpolar arctic.

Alaska. Other presentations will present results from the Yukon-Kuskoqwim River Delta (Carl Markon and Steve Talbot), Banks Island and other sites in Canada (Bill Gould and Larry Bliss), and Greenland (Christian Bay and Fred Daniels). Helmut Epp will give the keynote talk on the status of remote sensing programs that are relevant to the CAVM in the Canadian Arctic. Participants from Scandinavia and Russia will present their latest thoughts on the mapping procedures and classification. We will also review the funding situation and a schedule for the final map by 2001. In the evening of the first day, at the request of Fred Daniels, we will have a slide show presenting our concepts of the zonal vegetation for parts of the Arctic with which we are most familiar. This could be most revealing, and I hope everyone has brought slides of their favorite sections of the Arctic.

Mapping workshop: On days 2 and 3 we will go through the integrated vegetation mapping methods. Everyone should have maps and literature sources for a small section of the Arctic that you are thoroughly familiar. Tomorrow we will refine the integrated vegetation mapping procedures. The Alaska Field Office (AFO) has provided the light tables and facilities for this activity. On the following day, we will go through the procedures for creating the look-up tables. The method we have developed allows us to start drawing the maps without finalizing the legend. In fact, the process allows us to see the variety of map units and we can use the experience to derive a unified true vegetation legend toward the end of the project. Our goal has to be a simple true vegetation map that can be understood by a wide variety of users.

Field Trip and Banquet: On day 4, we will visit the alpine of the Chugach Mountains and afterwards have a banquet. The site we will visit is on the Fort Richardson Army Base; it is a fairly pristine alpine area that is rarely visited by the public, but is easily accessible from here.

Future plans: On day 5, we will review the organization and schedule for the project and the plans for international funding. Although the United States is providing a major contribution toward the map, this will not be sufficient to complete the map. We still need significant contributions from the other countries. We need to find ways to increase the visibility of the project and encourage the participation of international funding agencies. Bill Gould will lead a discussion regarding the possibility of trans-Arctic field trips in 1999 and 2000 to examine the vegetation along treeline-to-polar-desert gradients in Canada and Russia.

So, we have 5 days to share our ideas and establish a firm foundation for the coming year of mapping. Again, welcome to everyone. In the spirit of our past workshops, I'm sure we will work very hard, but at the same time have fun.

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**Progress of the CAVM Project in Greenland and the Feasibility of the Integrated Geobotanical Mapping Approach for Greenland**

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The following new botanical initiatives in Greenland of relevance to the CAVM project have taken place since the last CAVM workshop in Arendal, Norway:

The Greenland Institute of Natural Resources has started a 3-year project focusing on mapping caribou habitats on the basis of remote sensing of important ranges in West and South Greenland. Data from the first season have been published (Bay, 1998a). On the east coast at Zackenberg, a research station has been established and is, since last summer, fully operational. The monitoring area in the vicinity was mapped last summer as well (Bay, 1998b).

A major paper on the vegetation in central East Greenland will be published this year (Fredskild, 1998). It fills a gap in our knowledge on plant communities from this part of middle arctic Greenland. In 1997, the Institute of Plant Ecology in Muenster started a 3-year project dealing with classification, surveying, and mapping of the vegetation of middle arctic Northwest Greenland (69-72), which is a poorly known region. Fieldwork was carried out in 1993 and 1997 and will be intensified in 1998. This high-priority project is mainly sponsored by the German Research Foundation. Also, a survey by Daniëls of plant communities in eastern North Greenland is in preparation (Alstrup and others, 1999).

The soil associations of Greenland have recently been classified as part of a contribution to an International Permafrost Association soil-mapping project. A map showing the distribution of the soil types has been presented (Jacobsen, 1997) and will be integrated into the CAVM.

The feasibility of the geobotanical mapping approach of Walker (1997) was tested in Greenland. Three prototype mapping areas in the three vegetation zones proposed by Bay (1997) have been selected as we have sufficient data for them and the areas represent different biomes in respect to climate, substrate, and vegetation: Ammassalik, Jameson Land, and eastern North Greenland. Tables 1 and 2 show mapping results for the landscape units and vegetation complexes of Ammassalik and Jameson Land, respectively. The availability of good false color composite and Normalized Difference Vegetation Index (NDVI) images as base-maps is very important. An integrated terrain unit map should mainly be on the basis of landscape units, vegetation complexes, and bedrock/soil types. The production of the Polygon-ID-Number map is very time-consuming in patchy regions. We conclude that in general the proposed CAVM mapping approach by Walker (1997) can be successfully applied to the prototype areas and other botanically well-known areas. Areas of limited information can be mapped by extrapolations from areas with detailed information as well as from our general botanical knowledge of all the vegetation zones. Thus, the proposed CAVM mapping approach can be applied to the entirety of Greenland.

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Table 1. Landscape Units and Vegetation Complexes for Ammassalik, Southeast Greenland (66 degrees North Latitude)

**Landscape Units**

| Code | Landscape Unit |
|---|---|
| 1 | Lake |
| 2 | Ocean |
| 3 | Hills and low mountain without altitudinal belts |
| 4 | Mountains with altitudinal belts |
| 5 | Glacier |
| 6 | Mountain valley |

**Vegetation Complexes**

| Code | Vegetation Complex |
|---|---|
| 1 | Fellfield vegetation (mostly on mountains > 400 m): most dominant are *Juncetea trifidi* communities; on basic soils are communities of *Carici-Kobresietea*; on more wet soils *Thlaspietea* communities; in snowbeds vegetation from the *Salicetalia* herbaceae. |
| 2 | Dwarf shrub heathland: communities from the *Loiseleurio-Vaccinietea* as zonal vegetation; communities of the *Caricetalia fuscae* and *Glauco-Puccinelietatia* as azonal vegetation in mires, bogs, deltas and salt marshes and *Festuco-Salicetum* as an extrazonal association. |
| 3 | Rich fen vegetation with *Tofieldietalia* communities |
| 4 | Water vegetation: *Potametea, Caricion curto-nigrae* communities |
| 5 | No vegetation (glaciers) |

Table 2. Landscape Units and Vegetation Complexes for Jameson Land, Northeast Greenland (70 degrees North Latitude)

**Landscape Units**

| Code | Landscape |
|---|---|
| 1 | Ocean/Fjord |
| 2 | Rolling lowlands |
| 3 | Uplands |
| 4 | Mountains |
| 5 | Glaciers |

**Vegetation Complexes**

| Code | Vegetation Type | Plant Community |
|---|---|---|
| 1 | Dwarf shrub/moss | *Vaccinium uliginosum - Salix arctica* |
| 2 | Dwarf shrub | *Cassiope tetragona - Betula nana* |
| | Graminoid/moss | *Eriophorum scheuchzeri - Carex saxatilis* |
| 3 | Dwarf shrub | *Cassiope tetragona - Salix arctica - Betula nana* |
| 4 | Dwarf shrub | *Dryas octopetala - Salix arctica* |
| | Graminoid/organic crust | *Carex lachenalii - Phippsia algida* |
| 5 | Herbs | *Papaver radicatum - Cerastium arcticum* |

**Is it Possible to Prepare a Remote Sensing Based Bioclimatic Zone Map of Svalbard?**

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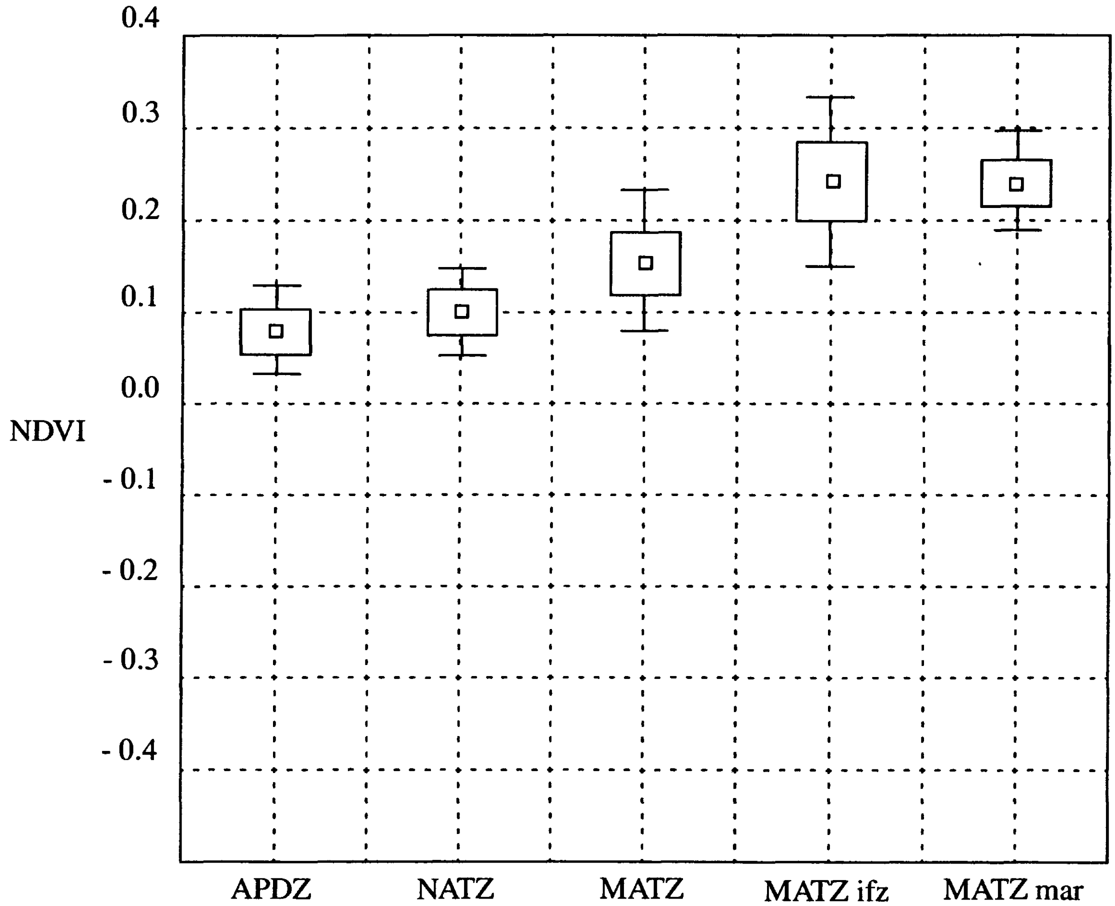
Uneven snow distribution in the nonforested Arctic makes the vegetation more mosaic-like than in areas with a similar topography but different climate. It is a challenging task to compress this heterogeneity into generalized maps covering large areas. The most common approach for areas of Northern Europe and Greenland has been to produce vegetation zone maps. In Russia the tradition has been focused on both vegetation maps and vegetation zone maps, whereas the study by Edlund and Alt (1989) is an example of the vegetation zone approach adopted in arctic Canada.

Most of these vegetation maps can probably better be called 'climatic-phytogeographic' maps (Tuhkanen, 1984), or more succinctly, 'bioclimatic' maps. The object of these classifications is to unite botanic (vegetation types, vegetation physiognomy, and floristics) and climatic (including climatic soil processes) criteria to form units. These zonal units then represent a range of climate, and within this climatic regime different sets of vegetation types can be realized on different habitats, like ridges, mesic plains/slopes, snowbeds, and so on, and on acidic versus. alkaline substrates. On a circumpolar scale, such types also change according to the historical factors reflected in the floristic composition of the different phytogeographic provinces. Thus a mapped polygon of a certain vegetation zone or bioclimatic zone represents an abstraction of what vegetation types can be realized within the climatic regime in question and not areas where habitats are over- represented (for example, mires or dry ridges).

The most detailed bioclimatic map of any arctic area is the one of Svalbard , on the basis of a map by Brattbakk (1986), but with important revisions mainly following Elvebakk (1997). An AVHRR NDVI map of Svalbard from the peak of the growing season produced a different pattern, which can be expected, as biomass is not only dependent on temperature, but also on landscape forms, substrate type and, often more locally, on erosion processes, glacial history, or manuring by birds and animals.

Berge (1998) recently focused on the possibility of making a satellite-based bioclimatic map which applied a multitemporal analysis. The integration of several scenes throughout spring, summer, and autumn produced an average NDVI map where values in areas with long snow-free periods and earlier visible green biomass are increased in comparison with colder areas. The effect of this multitemporal analysis is especially evident on the island Edgeøya where the NDVI values of the eastern parts are significantly lower compared with values from the peak season. A comparison of average NDVI values computed for the five bioclimatic mapping units shows a very clear and positive trend, although there is overlap between some of the units (figure 1).

The next step was to incorporate other factors, and a GIS terrain model was applied to compensate for areas with flat or concave topographic relief, which accumulates water and




APDZ: arctic polar desert zone
NATZ: northern arctic tundra zone
MATZ: middle arctic tundra zone
MATZ ifz: middle arctic tundra zone, inner fjord zone
MATZ mar: middle arctic tundra zone, maritime zone

□ Mean

+/- Standard Error

+/- Standard Deviation

Figure 1. A comparison of Greenland zonal mapping units with growing season mean NDVI values

produces a higher biomass than gently sloping areas. A model was developed on the basis of areas where sufficiently large areas of gently sloping terrain and weakly concave/flat terrains coexist. This modified the map by increasing the vegetation cover of the presumably warm Wijdefjorden area where the topography prevents the formation of mires, as well as the Roosflya area as compared with the definitely cooler area further north at Reinsdyrflya.

A last modification was to compensate for manuring from bird cliffs, and for a exceptionally low vegetation cover in valleys known to have especially large erosion areas.

The final map product showed a much higher similarity with the bioclimatic zone map than with the original NDVI map. However, two areas deviate: the lowlands along the west coast where there are no large bird cliffs and the gently sloping terrain of Edgeøya. The major reasons for this are explained by three factors:

1. The availability of cloud-free scenes is minimum for this type of analysis, and no scenes were evailable for mid-June when the snow cover and phenological differences between the west coast and central parts are greatest.

2. The long-term manuring effects of both reindeer and geese and other birds concentrated on wetlands is practically unknown but is definitively much greater than normally realized. At Edgeøya, a disproportionately high portion of the Svalbard reindeer population (now about 20%) is present and has probably modified the vegetation by increasing the moss cover during most of the Holocene. A similar development can be suggested when comparing the three neighboring peninsulas in the warmest central Isfjorden area. Bünsow Land has extremely steep mountain sides and practically no available winter grazing areas for reindeer (Spjelkavik and Elvebakk, 1989), whereas the two neighboring peninsulas have gentle slopes and large mountain plateaus. These plateaus, at about 500 m in elevation, have a similar moss cover (especially of *Tomentypnum nitens*) like the areas of Edgeøya. Both are in climatically unfavourable zones (northern arctic tundra zone and partly in the arctic polar desert zone) but have an anomalously higher vegetation cover over large areas than can be expected for temperature reasons alone. A similar interpretation can be given for the coastal lowlands, where the density of lowland birds evidently is much higher than in central valleys, although we lack figures in this respect.

3. Humidity favors the production of biomass. Eastern Edgeøya probably has the highest amount of precipitation of any area in the Arctic with a polar desert climate. Values are supposed to be in the range 0f 600-800 mm, which is about the same as along the western coast but definitively higher than the central valley areas.

As a conclusion, a model involving multitemporal analysis and compensation for other factors involving the GIS produces a map approaching those showing traditional bioclimatic zones. However, it is difficult to obtain satisfactory multitemporal cloud-free coverage and to quantify several other factors, especially long-term biotic effects. Therefore, it is difficult to verify or to control traditional bioclimatic maps using a satellite-based model.

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**Progress in Mapping the Vegetation of Iceland Since the CAVM Aredal Workshop**

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At the Second Circumpolar Arctic Vegetation Mapping Workshop in Arendal in 1996 the work on Mapping the Natural Vegetation of Europe, which started several years ago, was represented by Dr. Udo Bohn. Among the material shown was a draft vegetation map of Iceland, with many errors, as well as descriptions of the vegetation types used for Iceland as legends, both needing a thorough revision. The Icelandic Institute of Natural History in Reykjavìk took on the revision work which is now nearly finished. The map itself, which will be published as part of Europe at a scale of 1: 2,500,000, is finished together with two thirds of the vegetation descriptions, whereas the remaining ones will be completed this summer. As dealt with at the Circumpolar Arctic Vegetation Mapping Workshop in St. Petersburg in 1994 (Einarsson 1995), vegetation mapping in Iceland started relatively late and was for the first 40 years or so carried out at the Agricultural Research Institute. The first map was published in 1957 showing the actual vegetation of Gnupverjaafrettur in the highlands of South Iceland. The mapping work went on until around 1990, with periodic lapses due to sparse funding. At present, maps covering about 60% of the total area of Iceland have been published, mainly at the scale 1: 40,000, covering most of the uninhabited central highlands and some parts of the inhabited lowlands; the publication of maps has not been concurrent with the field work. The last maps published were made with the help of digital computers. The work to digitize all material not yet published and store it in a database has been started.

No reliable map of the actual vegetation of Iceland as a whole has been available but considered to be badly needed. Therefore the Icelandic Institute of Natural History decided to make such a map at a scale of 1:500,000, even if the legends had to be simplified owing to lack of exact data from large areas, which would have taken a lot of work and many more years to collect. Data compilation has been going on for the last couple of years, carried out by Gudmundur Gudjonsson and Einar Gislason (1998), directed by the former, and the map has now been published. The legends are divided into two categories similar earlier vegetation maps of the Agricultural Research Institute that were used for land use purposes: vegetation complexes or types where the total cover is more than 50% of the surface, and vegetation types where the cover is less than 50% of the surface; altogether 7 different complexes. In the former category the legends include the complexes: moss heath, heath, grassland and cultivated land, birch forest and shrub, and wetland, while the legends of the latter category do include the complexes: sand vegetation, lava vegetation, and sparse vegetation of mountains and gravel flats. These new maps will no doubt be of valuable help in the completion of a vegetation map of Iceland for the Circumpolar Arctic Vegetation Map.

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# The Zonal Concept in the Arctic: Its Difference from Vegetation Mapping and its Demands for Criteria

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The zones of the Arctic as described by numerous botanists can be characterized as 'integrated phytogeography'. As much botanical knowledge as possible has been used to make schemes that reflect a climatic zonation dividing the Arctic or parts of the Arctic into a few major units. Thus, criteria involving plants from different habitats have been used, and the approach has not been to map physical habitats. This is a fundamental difference from vegetation mapping, which maps the spatial occurrence of vegetation which varies a lot depending on the local occurrences of poor- drained depressions forming mires, well-drained limestone landscapes, etc. The zonal concept does not include geographic positioning of mires, etc. Instead a unit represents a climate range which permits the development of certain types of mire vegetation, ridge vegetation, etc., in most cases different from those of the neighbouring units.

The integrated nature and the wide scope of possibilities probably accounts for the variation in systems that have been used, in addition to different developments in different political parts of the Arctic.

A major criterion has been set to be the most advanced growth form of the zonal habitat because this is very sensitive to climate. This growth form can then be accompanied in a matrix by information on vegetation type (descriptive or in a Braun-Blanquet system if available), floristics, soil type, and temperature range as was done at the previous Arendal CAVM Workshop. However, this can also be done for the other major habitats like ridges, snowbeds, and mires. Figure 1 shows a simplified topographic gradient both for the five arctic zones and the two neighbouring stlanik and oceanic boreal zones, provisionally named A-F, at Arendal, in addition to a typical boreal situation. This figure illustrates that there are important transitions at the other three habitats although this is not expressed so clearly as a shift in growth forms in the zonal habitat.

In zones F and G forests occur, but in restricted sites; in one or both of the habitats that were called zonal and snowbed habitats. The existence of forests, a criterion sufficient to exclude most of these units from the Arctic, is notably accompanied by two important shifts in the other habitats: a) the disappearence of snowbed vegetation and, b) the disappearance of a distinct ridge vegetation, at least in zone G.

This has two important implications related to climate gradients. Snowbed vegetation disappears because in continental areas, summer temperature sum is so high that the snowbed syndrome is not suppressing the vegetation and in oceanic areas the snow cover is too thin and ephemeral. In the latter area humidity and a very long growing season that may include parts of the winter for some growth forms, does not lead to a distinct open and drought-stressed ridge vegetation.

Thus the existence of a ridge-snowbed gradient in the vegetation pattern is an additional criterion to the existence of delimited forests for delimiting zones F and G from the Arctic.

The demands for nomenclature are proposed here as follows:

(1) Simplicity: This means that names like 'Southern variant of the arctic tundra subzone' (in addition to too much hierarchy in the nomenclature system), and 'Enriched prostrate shrub zone' as used about unit C are not appropriate.

(2) Exclusivity: The use of only growth form names is not exclusive, as 'herb zone', or 'dwarf shrub zone' is focusing on a botanical aspect that is so much distributed also outside the Arctic.

(3) Precision: For this reason 'subarctic' should be avoided, as it has been used so widely and in different meanings, and encompassing areas far into the boreal zone. The same can be applied to 'high arctic', as this has different meanings whether or not 'middle arctic' is used, and it can be confusing when used in a nonhierarchic system which also uses the concept 'polar desert'. The use of the names 'high arctic tundra subzone' and 'arctic tundra subzone' at the same level in a hierarchic system is also not consistent.

(4) Internationality: Some names are used more often than others in the different national systems, but words like 'hemiarctic' and 'hypoarctic' are virtually unknown outside Fennoscandia and Russia, respectively, and have small chances to be widely adopted by an international non-expert audience.

For these reasons I have no better proposals than the following:

| | | |
|---|---|---|
| (A) | Arctic polar desert | High Arctic |
| (B) | Northern arctic tundra | High Arctic |
| (C) | Middle arctic tundra | High Arctic |
| (D) | Southern arctic tundra | Low Arctic |
| (E) | Arctic shrub-tundra | Low Arctic |

To harmonize it with the widespread High-Low Arctic system this can be added as a hierarchical dimension. If units F and G will be treated by us, names like the following can be suggested:

(F) Northern boreal stlanik shrublands

(G) Northern boreal coastal heathlands

This system seems to be consistent with the set of criteria listed above. It also emphasizes the physiognomy of the Arctic, with the three central zones centered around the core of the most widespread concept of the word 'tundra' - low vegetation cover - as opposed to the barren, desert-like aspect to the north and the taller vegetation, but still not forested, shrub tundra furthest to the south. The system also allows for an approximately equal sectioning of the Arctic with zones, each encompassing 2° C of mean July temeperatures. It also ties nomenclaturally to the early Soviet maps and the publications of Gorodkov and others where 'arctic deserts,' 'arctic tundra,' and 'shrub-tundra' are keywords.

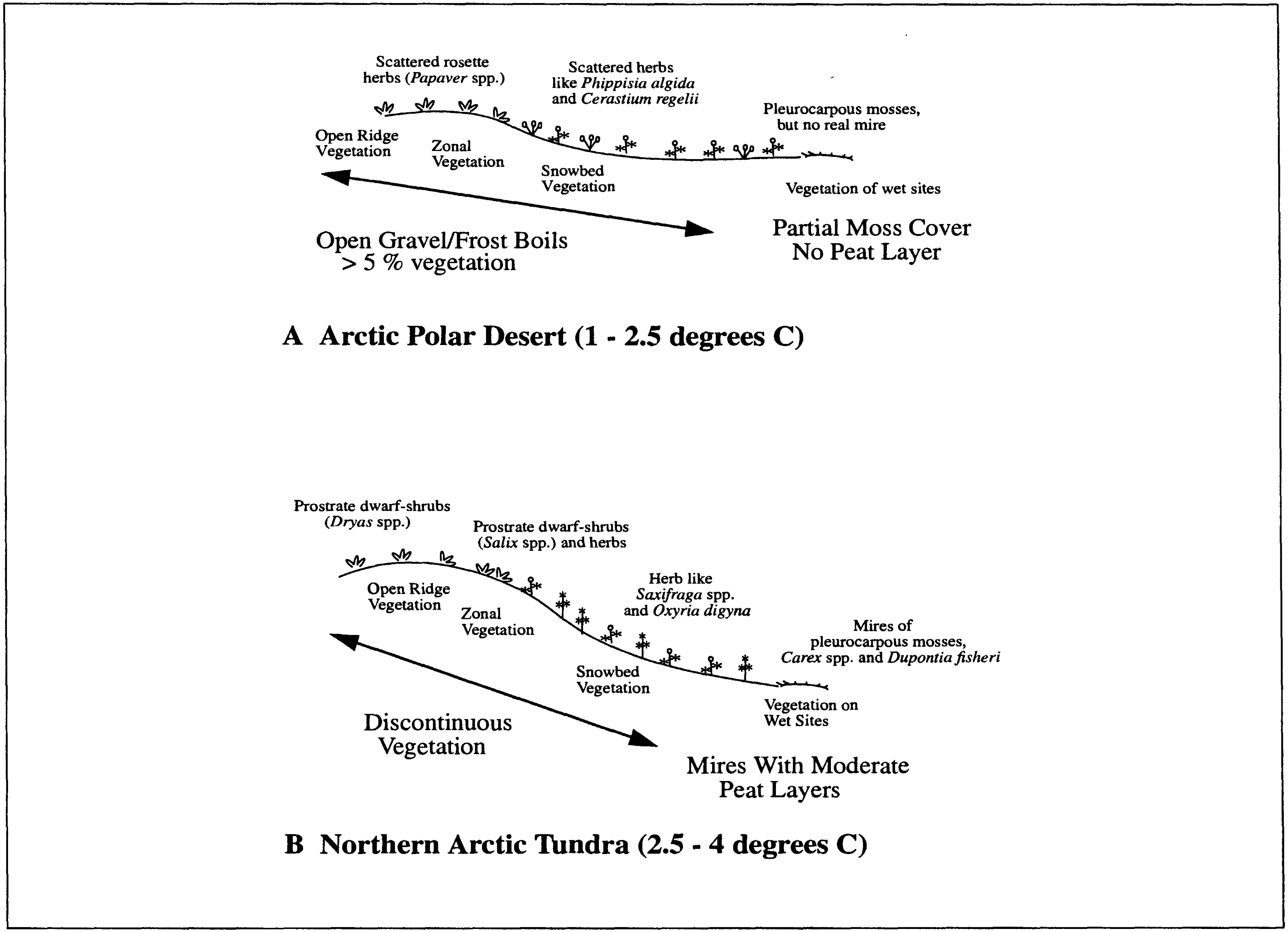


Figure 1a. Simplified topographic gradients of arctic zones A and B.

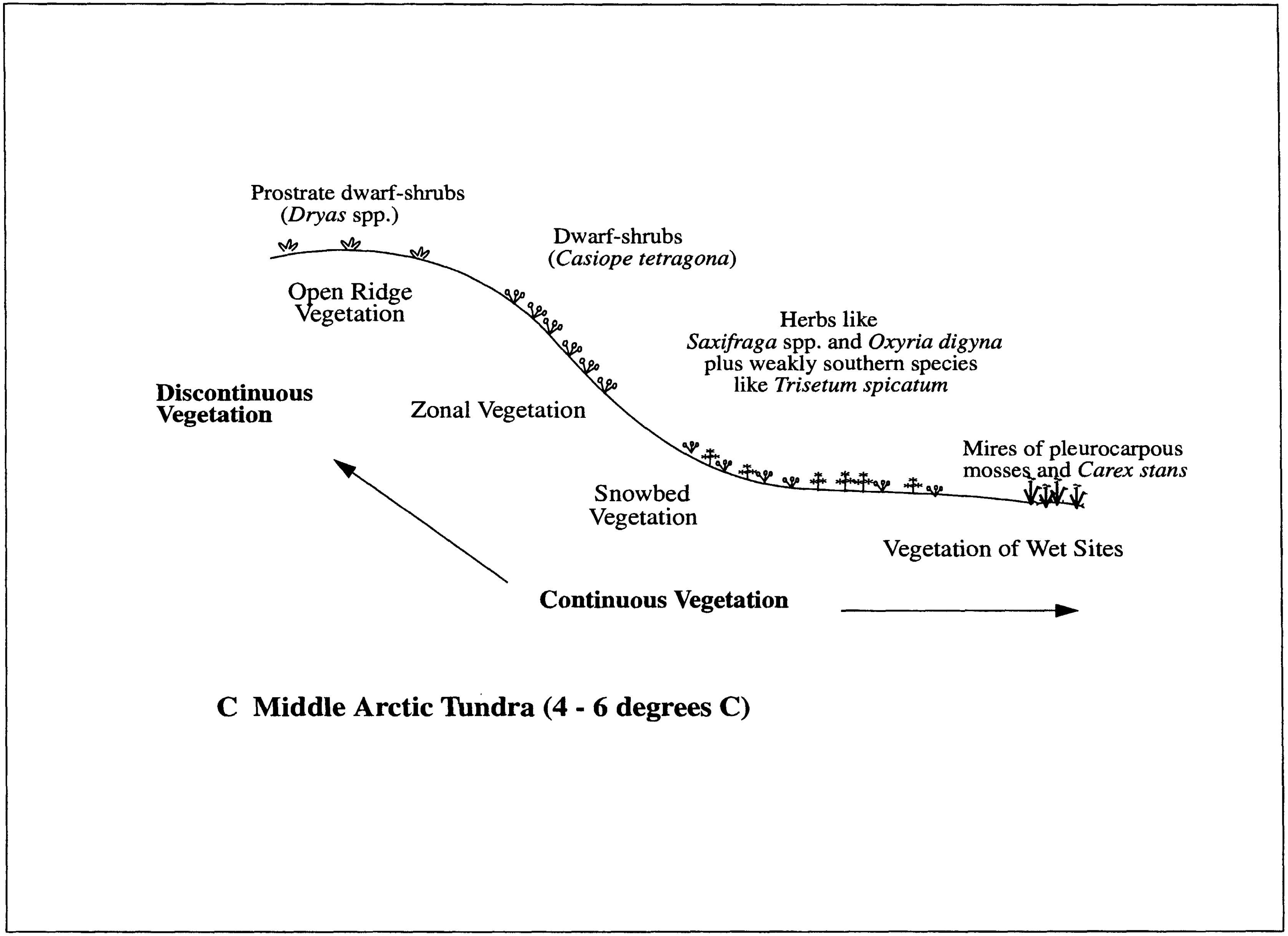


Figure 1b. Simplified topographic gradient of arctic zone C.

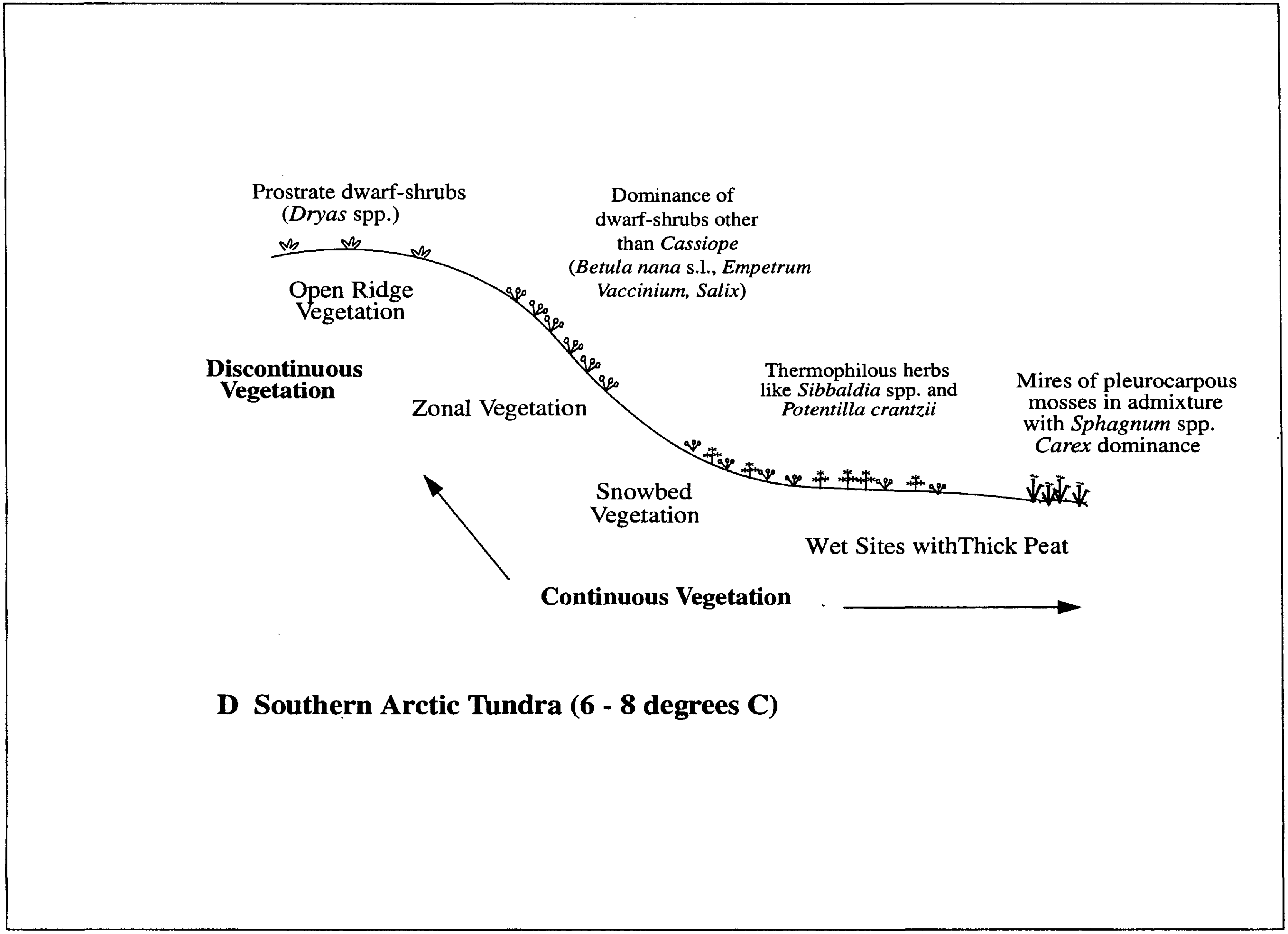


Figure 1c. Simplified topographic gradient of arctic zone D.

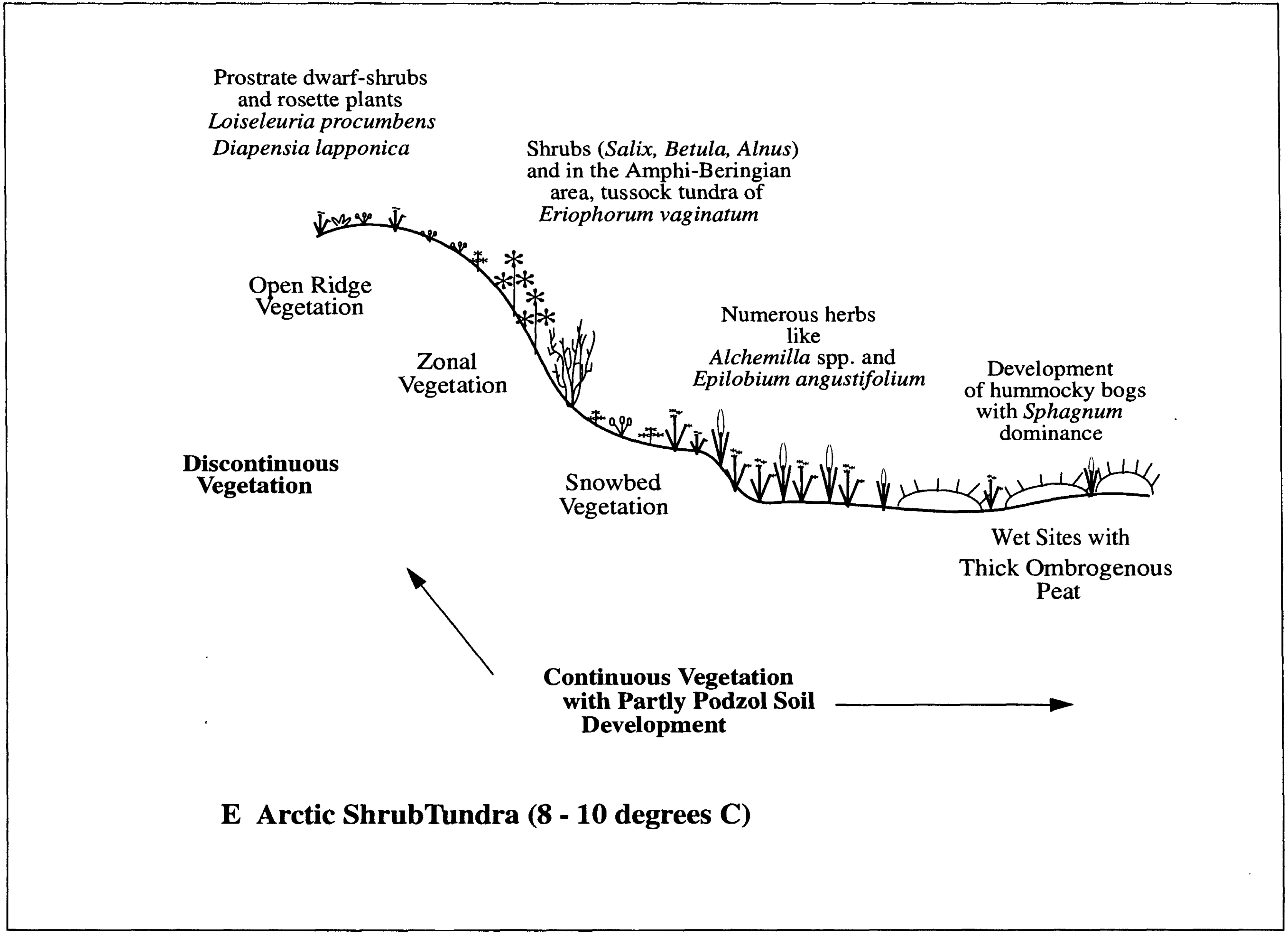


Figure 1d. Simplified topographic gradient of arctic zone E.

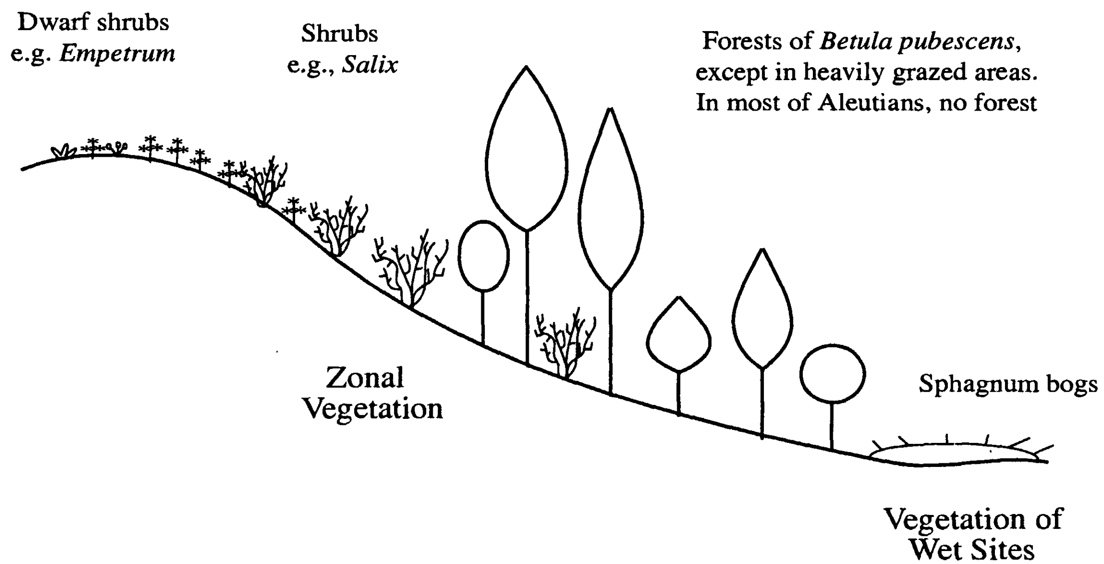


Figure 1e. Simplified topographic gradient of arctic zone F.

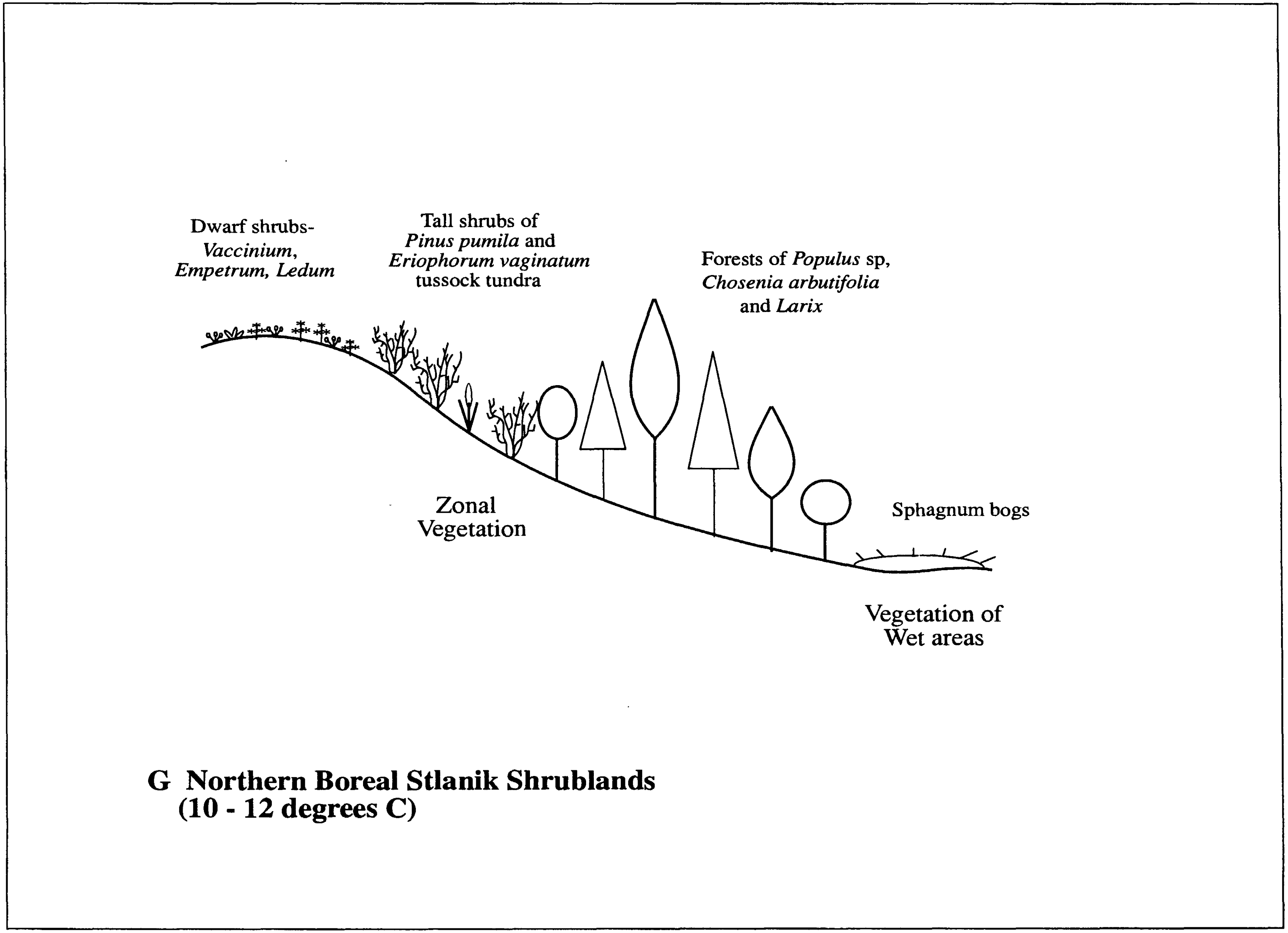


Figure 1f. Simplified topographic graident of arctic zone G.

**Canadian Arctic Remote Sensing Programs and Their Possible Relvance to the CAVM Project**

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The Canadian Arctic covers an area of approximately 3.76 million square kilometers, over one-third of Canada, with a great diversity of plant and animal species and covered by a wide variety of natural regions. It is an area with very few roads, a small population, and large areas of almost unexplored wilderness.

As development in the form of mining and forestry increases there is a greater demand for information on vegetation and wildlife. Due to the excessive area of the Canadian Arctic no systematic vegetation mapping program has ever been initiated. Mapping has been done on a project-by-project basis for a variety of reasons and using a variety of legends.

Early mapping was done using aerial photographs, but over the past ten years mostly satellite images, especially Landsat Thematic Mapper (TM) data, have been used. This has been due to the high cost of obtaining the aerial photographs, the length of time required to do the interpretation, and the more recent requirement of digital data as a direct input into geographic information systems.

At the small-scale level, the Arctic has been covered through the National Ecological Framework for Canada by ecozones, ecoregions, and ecodistricts on the basis of a discrete system resulting from the interplay of geologic, landform, soil, vegetative, climatic, wildlife, water, and human factors. The use of NOAA AVHRR data has also increased over the past ten years to provide general vegetation maps on the basis of 10- or 20-day composites but with little ground verification. The USGS provided a vegetation map for North America in 1994 with approximately 18 vegetation classes covering the Arctic. The Canada Centre For Remote Sensing made a first attempt at a vegetation classification of all of Canada using 20-day composites. No ground verification took place. A second classification is in the process of being verified by ground data being provided by agencies within each province and territory. Again data was used from a 20-day composite taken during the summer of 1995.

The AVHRR classification of the Canadian Arctic is contains 19 different classes. These classifications should be used at the 1:1,000,000 scale or smaller. If more detailed vegetation information is required aerial photography or Landsat TM data should be analyzed. Approximately 50% of the Yukon has been mapped. In the northern part, most of the mapping has been done through the analysis of TM data covering the coastal plain, the Richardson Mountains, the Eagle Plains, and parts of the southeast Yukon. The southern Yukon and some smaller areas in the west were done through the interpretation of aerial photography. Most of the work was done by the Department of Renewable Resources and the Canadian Wildlife Service. In the Northwest Territories almost all of the vegetation mapping has been done in the western part by the Department of Resources Wildlife and Economic Development, the Canadian Wildlife Service and Parks Canada.

This mapping is due partly to a viable forestry industry and the associated threat of forest fires, and a greater demand for habitat data by biologists because of the increasing development of mines (especially gold and diamond). In the forestry sector a combination of aerial photography and Landsat TM data is used to provide forest inventory data as well as for an ecological land classification. TM data provides an initial general vegetation classification to identify potential merchantable timber areas. These are then flown over and aerially photographed for detailed forest inventory interpretation.

Vegetation/habitat classifications have been done in a number of areas with the number of classes ranging from 10 to 16. Some of the areas were classified specifically for a particular species, such as grizzly bear or moose but most areas were classified on a more general basis and such classifications could be used by biologists working on different animal species or for park management. In a number of areas there are ongoing projects, and within the next two to three years the area classified into vegetation types will have increased by five to ten percent. All of the data could have a direct input to the Circumpolar Arctic Vegetation Mapping Project.

# AVHRR Images for Developing a Circumpolar Arctic Vegetation Map

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During the next few decades, the Arctic will continue to be strongly affected by many forces from within and outside the region, including global climate change and the cumulative impacts of resource development, population increases, and tourists. A new vegetation map of the entire Arctic is needed for a wide variety of purposes related to anticipated global changes, landuse planing, and education. A new circumpolar arctic vegetation map (CAVM) and geographic information system (GIS) database are being drafted by participants from all of the arctic countries. The data will provide a framework for generalization and extrapolation of results for numerous ongoing international arctic research programs. Mapped vegetation and terrain information for the arctic tundra and polar desert regions is based on our most recent scientific understanding. A plan for making the map involves the close coordination of mapping teams in North America, Europe, and Russia, using the same base data set for the entire region.

Obtaining sufficient data to describe the characteristics of vegetation over large geographic areas has traditionally been difficult. However, during the last decade, substantial progress has been made by using Advanced Very High Resolution Radiometer (AVHRR) satellite data for land cover characterization on a global scale. The procedures used to collect the AVHRR data and generate the Normalized Difference Vegetation Index (NDVI) composites are described by Eidenshink and Faundeen (1994). The NDVI values are derived from a ratio of the visible and near-infrared spectral channels of the AVHRR sensor. A maximum is calculated from daily observations for a series of periods extending through an entire growing season. The data are summarized over a period of time instead of using the daily values in order to remove, or at least minimize, the occurrance of clouds in the data. The data sets are currently being developed on a global scale and composited in ten day periods. The global database begins on April 1, 1992 and continues through September 30, 1993. A new dataset has recently been completed for February 1 through December 30 1995.

At the beginning of this project, the only data available were from the 1992 growing season. The initial set of circumpolar products was generated using the data collected during thirteen periods between May 11, 1992 and September 20, 1992, covering the relatively short growing season of the arctic region. The data were projected into a Lambert Azimuthal Equal Area projection, maintaining the 1-km resolution. From this data set, two important baseline products of the circumpolar region were generated: (1) cloud-free and snow minimized false-color infrared (CIR) imagemap and (2) imagemap of maximum NDVI that occurred during the growing season.

Evaluation of the initial NDVI and CIR circumpolar products generated using the 1992 data indicated a year of low reflectance values and corresponding NDVI values, particularly on Greenland and nearby northeastern Canada. This indicates either a cold, snowy, and (or) cloudy summer for several areas of the arctic region. For this region, data from 1993 was processed and used to generate 1:4,000,000-scale working maps. The circumpolar data sets were mosaicked a second time to correct several problems in the initial version, mainly lines at the seams between sections of the global data set.

The second major data set assembled was a DEM mosaic of the circumpolar arctic region. From this data set shaded relief elevation imagemaps were generated and overlaid with a lake and stream hydrology network to show the landscape features and aid in the interpretation of the vegetation.

Two scales of products have been generated to aid in the development of a circumpolar arctic vegetation map for each of the three data sets; CIR, maximum NDVI, and DEM. Circumpolar products for the entire region were generated at 1:12,000,000-scale. Regional products were generated by partitioning the circumpolar data sets into 11 politically defined working/analysis blocks and producing 1:4,000,000-scale baseline mapping products. The blocks varied from page size (8.5" x 11") to approximately 25"x25".

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**Prototype Map of Southwestern Alaska for the Circumpolar Arctic Vegetation Map**

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As part of an international effort to produce a new circumpolar arctic vegetation map (1:4,000,000-scale), we prepared a prototype map of the Yukon Delta National Wildlife Refuge on the basis of D.A. Walker's integrated vegetation mapping approach. This site in southwestern Alaska is one a several sites selected from Alaska, Canada, and Greenland for examining the feasibility of Walker's method in widely different landscapes. The landscape-guided method consists of making several separate maps portraying different themes (for example, landscape units, soils, bedrock geology, percentage of lake cover, and vegetation complexes). Rather than producing a single vegetation map, the goal of the integrated vegetation mapping approach aims to create a database that can he used to derive a wide variety of map products and spatial analyses of the arctic region. Polygon unit boundaries on several of the separate thematic maps, or layers, are integrated onto a single map sheet, the integrated terrain unit map (ITUM), which contains all the polygon boundaries. These data are stored in a geographic information system (GIS) database.

The GIS database consists of two principal files, one containing topology information for the ITUM polygons and the other containing the geobotanical attributes for each polygon. Separate 'look-up' tables are linked to the attribute file. These tables contain additional information regarding principal plant communities and vegetation properties of each vegetation complex for each fioristic subprovince/phytogeographic zone combination. All map products will be at a scale of 1:7,500,000. Final products of the project will include (1) an enhanced false-color infrared image (CIR) derived from a mosaic of cloud-free Advanced Very High Resolution Radiometer (AVHRR) images, (2) a relative-greenness image derived from a time series mosaic of maximum-NDVI pixels from the AVHRR image, (3) a topography and hydrology map derived from the digital chart of the world (DCW) information, and (4) a circumpolar arctic vegetation map derived from image interpretation of the AVHRR C1R image in conjunction with a wide variety of ancillary map data. We also indicate locations of major study sites and ancillary map data on which the integrated components of the vegetation map and geobotanical database for North America will be based. These ancillary data will encompass our most recent understanding of large-scale patterns in vegetation, satellite imagery, surficial and bedrock geology, soil geochemistry, topography, and hydrology of the region.

We conclude that Walker's method can be effectively used in southwestern Alaska. This international effort to produce a new vegetation map of the circumpolar Arctic is recognized by the Conservation of Arctic Flora and Fauna (CAFF) program and U.S. National Science Foundation and the International Arctic Science Committee (IASC) as a priority research item.

**Prototype Vegetation Maps for the Canadian Arctic**

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The vegetation and landscape characteristics of several prototype areas of the Canadian Arctic were mapped at 1:4,000,000 scale using initial iterations of the integrated vegetation mapping approach developed for the Circumpolar Arctic Vegetation Mapping Project (CAVM, Walker and Lillie, 1997). Initial mapping areas include Ellesmere Island, Devon Island, and Axel Heiberg mapped by L. Bliss (unpublished), and Banks Island, the Melville Hills area, Southampton and Coates Islands, Somerset Island, Victoria Island, and the southern boundary of the Canadian Arctic (treeline) mapped by S. Zoltai (unpublished). Areas previously mapped at a larger scale will be the focus of additional prototype mapping, and these include the central Queen Elizabeth Islands and the area east of Chantrey Inlet mapped by Edlund (1976, 1990) and the area west of Bathurst Inlet mapped by Gould (1998).

Banks Island was remapped following recent modifications of the integrated vegetation mapping approach (Walker, this issue). The prototype map of Banks Island is on the basis of interpretation of AVHRR false-color-infrared (CIR) imagery. Ancillary information was used to define landscape units with boundaries recognizable on the AVHRR image. An integrated landscape-unit map (ILUM) was created, with boundaries relevant to the vegetation derived from source maps of bedrock and surficial geology, topography, hydrology, and soils. An integrated vegetation complex map (IVCM) was created using the ILUM, AVHRR CIR imagery, and a maximum NDVI map. Phytogeographic subzones and floristic subprovinces mapped by Yurtsev (1994) were adjusted to the AVHRR imagery for the prototype area. Information from published literature, expert knowledge, and vegetation complex characteristics within each phytogeographic and floristic area were used to determine dominant plant community types and vegetation characteristics within each mapped vegetation complex. Look-up tables were developed from this information to create derived maps of vegetation and vegetation characteristics, such as dominant plant communities, horizontal structure of vegetation, plant functional types, biomass, and net primary production.

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## Progress in Elaboration of the Vegetation Map of the East Siberian Arctic

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The creation of the Circumpolar Arctic Vegetation Map is attractive to many Russian scientists, however, they do not have enough funds in order to develop this project successfully. Therefore, present research is being done at a very slow pace. This year Yakutia (using materials by V.N. Andreev, V.N. Perfiljeva and others) and Taymir (using materials by R. Schelkunova) have been mapped digitally in PC ARC/INFO format. These maps were joined with the Chukotka vegetation map. As a result, the map of the East Siberian Arctic was produced. The following zonal vegetation was shown on this map: Arctic deserts, Arctic tundra (5 subdivisions), subarctic tundra (10 subdivisions), tundra bogs and tundra wetland complexes (5 subdivisions), near-tundra open forests (5 subdivisions), mountain vegetation (4 subdivisions), coast vegetation (3 subdivisions). A disadvantage of this map is the differing levels of vegetation details shown on separate parts of the map. For example, Taymir territory is still superfluously detailed and needs generalization. Meanwhile Korjakia vegetation is too general and needs more details. Unfortunately, we did not receive a topographic base map for the project in order to show vegetation at necessary scales.

We increased the information of digital maps in 1997-98. The maps of survey scales contain less information about concrete plots of area than large-scale maps. Therefore we decided to join these maps in one project. Now the Magadan region vegetation map and Chukotka vegetation map project is developing in the following manner: a survey map created at a 1:2,500,000-scale in ArcView is overlaid by a grid. Each square of this grid corresponds to a sheet of the map at 1:200,000-scale. By selecting a square, it is possible to overview the vegetation of a needed plot of area in more detail. The program provides for the possibility of overviewing the database using parameters for each map polygon.

For completion of the work on the East Siberian part of the project we need a general topographic base map and additional funds for the purchase of large-scale vegetation maps of Korjakia, for generalization of Taymir vegetation maps, and for a pedologist's contribution of soil information to the database.

**An Integrated Vegetation Map for Northern Alaska: A Prototype for Circumpolar Arctic Vegetation Mapping**

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A six-step process for making a 1:4,000,000-scale integrated vegetation map and derived map products for northern Alaska is presented. The method uses two primary maps. A phytogeographic subzones and floristic subprovinces map (PFM) portrays the boundaries of Yurtsev's (1994) maps adjusted to Advanced Very High Resolution Radiometer (AVHRR) imagery, and an Integrated Vegetation Complex Map (IVCM) portrays vegetation complexes whereby the map-polygon boundaries are guided by terrain, surficial-geology, soil, lake-cover, and vegetation features. The IVCM is created from a variety of remote sensing data (AVHRR imagery, maximum greenness maps, and classified images) and hard-copy source maps (surficial geology, bedrock geology, soils, percentage of water cover). The map-polygon boundaries are integrated so that polygon boundaries conform to terrain features on the AVHRR CIR imagery as much as possible and to eliminate repetitious boundaries and unnecessary polygons. The PFM and IVCM are then overlaid in a geographic information system (GIS) to produce a series of derived maps, including maps of dominant plant communities, horizontal structure, plant functional types, biomass, and net primary productivity. The derived maps are produced by reference to a series of look-up tables that contain plant community names and other vegetation information from the literature. The method can be modified to any region of the Arctic on the basis of available information, and is it suggested as a standard method for making the Circumpolar Arctic Vegetation Map (CAVM; see complete paper, page 47).

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**Approach to Compiling the Russian Portion of the Circumpolar Arctic Vegetation Map**

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Application of the recommended method for creating an Integrated Terrain Unit Map (ITUM, Walker and Lillie, 1997) to mapping the vegetation of the Russian Arctic (RA) is quite difficult. The application of the method also means replacing the original aim of the collective work - to create a vegetation map and its legend -- along with the creation of a multidisciplinary GIS database, including, in addition to the vegetation map, the maps of soils, lithology, and so on. Our opinion is that the work should be focused on the vegetation map, and the other layers may be added as auxiliary ones in a simplified form to the extent that they help to differentiate the vegetation.

The situation involved in mapping the RA vegetation is as follows (Walker and Talbot, 1995). We have the survey maps of vegetation (1:2,500,000 to 1:5,000,000 scale), not entirely uniform in their principles, for each sector of the RA, in contrast with the North American Arctic for which such maps are lacking. But we have to deal with typologically generalized polygons that lack individual features; very often we do not have access to original materials (including relevés). The data concerning the environmental parameters (pH, the depth of the organic layer, and so on) for most of the polygons are absent. In contrast, our North American colleagues do not have such survey maps. They do, however, have recent data on environmental parameters and productivity obtained in the course of intense complex studies, and large-scale maps for selected areas, though the extent to which the data may be extrapolated to enormous unvisited territories of the Arctic is yet to be determined.

The difference in the strategies suggested by the North American group and the Russian group is as follows. The North American participants are planning to perform geobotanical identification of landscape units, including the data on soils, lithology, and hydrology. Whereas we have to use the available "vegetation complexes" polygons which portray, first of all, the structure of latitudinal (rarely also altitudinal) zonation and sectoral features of vegetation (depending on the flora history and the degree of continental-oceanic influence of climate), and, far from always, the landscape combinations ("complexes") of plant communities. The boundaries of "landscape units" do not always correspond to the available geobotanical polygons. In addition, the situation may be complicated by the contrasting lithology within a vegetation polygon.

In practice we will have to transfer the boundaries of the vegetation polygons on the landscape units base map and try to bring them into conformity (where we find the material for this). The second task would be to try and decipher the vegetation in areas of contrasting geochemical influence: carbonate, acidic, basic siliceous, ultramaphic, or various combination, within a single landscape. The data on edaphic-differential plant species could be, in part, extracted from their distribution maps (Yurtsev, 1997). Nonacidic combinations of plant communities include both the lithologically determined ones (with contrasting bedrock) and climatically determined ones (the increase of pH on the same bedrock as one proceeds northward). Legends of the auxiliary maps (soils, lithology) should be essentially generalized to demarcate major bedrock-edaphic variants of "vegetation complexes" and to avoid controversy in terminology associated with national traditions in soil nomenclature. Though the minimal number of the variants should be more than four (mentioned in bedrock classification in Walker and Lillie, 1997), the acidic sedimentary rocks may be united with the acidic siliceous, but the ultramaphic ones should be separated from the basic siliceous. In addition, loose sedimentary beds on plains, lowlands, and in large valleys may also be geochemically contrasting depending on the source of the accumulation; saline (salt-enriched) coastal areas should also be distinguished.

Thus, while compiling the RA vegetation map, we will have, in many cases, to work with already available (established previously) polygons on the survey vegetation maps of scales from 1:2.500,000 to 1:5,000,000 (for different sectors) and with their legends to coordinate the distinguished units in various sectors and then to try to correct them, bringing them into accordance with landscape and edaphic units and AVHRR CIR and maximum NDVI images. So, the polygons will be initially generalized, which cannot prevent each of them from receiving its own number. After that, all the other layers could be created and digitized for an ITUM. The "vegetation complexes" layer would take priority.

One should realize that any polygon in a small-scale vegetation map covers extensive areas with a significant variability of environmental conditions, soils, and vegetation. Ascribing strict ecological parameters to polygons (certain values of pH, soil temperature, humus horizon depth), as well as strict values of primary production and biomass using the data of complex studies in a concrete polygon (which is justified at a large-scale mapping) means inadequate extrapolation ("false accuracy") leading to possible mistakes. For many extensive territories in the RA such data are lacking. Our opinion is that such data may be included in look-up tables only as illustrating examples along with concrete relevés with the respective references. In addition to the dominant plant communities, some characteristic ones should be listed - in particular those differing the given subzone and sector from the neighboring ones. It is rational to enumerate in a look-up table, for each dominant and characteristic plant community, the set of main biomorphs (growth forms) in accordance with the vertical layers' sequences, as well as dominant and differential species and the principal elements of the horizontal structure. The community name of only two species names may prove to be insufficient. One should discuss the possibility of using the Russian-American tradition of designating the arctic plant communities through a combination of main biomorphs; for example tussock (*Eriophorum vaginatum*) - dwarf shrub (*Ledum decumbens*) - moss (*Hylocomium, Sphagnum*) tundra (or bog).

The real multidisciplinary GIS database could be created only after completing the vegetation map - on the basis of collaboration of geobotanists with soil scientists, cryolithologists, geologists and climatologists - by means of comparison of their more-or-less independently created products. In addition, after the creation of the vegetation map the layers for its separate characteristics can be produced (floristic, structural and ecological ones, such as: dominant species, growth forms, vegetation type, base-saturation of the soil, and so on).

To cope with difficulties in the nomenclature of (sub) zones, the most neutral way is to accept the system of letter indices, proposed by Arve Elvebakk, with a number of synonyms, according to different traditions.

In any case, different regional (sectoral) fragments of the vegetation complexes map, produced with the use of different traditions, should be comparable in terms both the characteristics of units and the degree of generalization.

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**Possibilities of Applying a Small-Scale Russian Arctic Landscape Map to Circumpolar Vegetation Mapping**

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The landscape map (scale of 1:7,500,000) legend for the Russian Arctic has been produced at the Earth Cryosphere Institude (Melnikov and others, 1997). It includes zonal, subzonal, and altitudinal-longitudinal landscape types and subtypes, morphogenetic groups, and landscape varieties for platform and mountain regions.

Three morphogenetic groups of landscapes are allocated for platform regions of hypsometric postion: landscapes of low plains created mainly by most recent submergence, landscapes of high plains and plateaus with a predominance of gently sloping terrain created by most recent emergence and plateau and tableland landscapes with prevalence of most recent upwarping and block ermergence.

Morphogenetic varieties of landscapes (marine and icy marine, alluvial, lacustrine, and lucustrine-alluvial, glacial, fluvio-glacial and accumulative undifferentiated) are distinguished among landscape groups of platform regions by accumulative plains which contain genesis deposits.

For mountain regions two morphogenetic groups of landscapes are unique from landscapes of intermontane and intermountian depressions, foothill plains, and foothills and mountain structures.

Morphogenetic varieties of landscapes (marine, alluvial, lacustrine and lacustrine-alluvial, glacial and fluvio-glacial, deluvial, alluvial-proluvial, solifluction, and accumulative undifferentiated) are distinguished among accumulative plains of intermontane and intermountian depressions and superimposed foothill plains on genesis deposits composing them. In all, there are 15 unique mophogenetic landscape varieties including erosion-denudation relief forms.

The differentiation of landscapes of the Russian Arctic is shown in combination with various types of lithogenic bases, from them four for loose rocks (peaty, clayey, sandy, and coarse detritus) and two for rocky and semi-rocky deposits (soluable and insoluable rocks), as well as combinations of these types. The display of the lithogenic base makes possible an appropriate generalization of map contours depending on the purpose of landscape base use.

Using the compiled legend, we prepared the electronic landscape map for the Russian Arctic. A fragment of this map is shown in figure 1. The landscape-base was composed with reference to the earlier maps, landscape maps (1:2,500,000 scale and 1:4,000,000 scale edited by I.S. Gudilin and A.G. Isachenko), maps of quaternary sediments (1:2,500,000 scale and 1:5,000,000 scale edited by G.S. Ganeshin) and other maps, in relevant reports, being the result of space image interpretation and materials from perennial studies carried out by the Institute VSGINGEO. The main source of the data for compiling a landscape base was the landscape map of the USSR edited by Gudilin (1980). This map, however, does not contain important information on the composition of quaternary deposits. Therefore, this information was entered in the database simultaneously with the generalization of landscape contours.

Attribute layers on engineering geocryological boreholes (Konchenko and Melnikov, 1996, Korostelev and Aleksandrov, 1997) in tabular form supplement the compiled landscape database.

The landscape map was digitized using Lamberts Isometric Azimuthal polar projection with suitable scales varying from 1:2,500,000 to 1:10,000,000-scale. The programe Map Edit was employed to vectorize the map elements. Subsequent processing of data for the final map version was done using the GeoDraw and GeoGraph software packages. These programs allow export of the integral map in DXT format which in turn permits data import into ARC/INFO, the format of the geographical information system (Walker and Walker 1996).

The prepared landscape map reflecting interrelations between the components of cryogenic geosystems (Melnikov, 1988) at a global level, such as lithology, relief, and vegetation, is a good basis for compiling thematic maps of various data layers. A map of permafrost and ground ice conditions at 1:10,000,000 scale (as part of the International Circum-Arctic Permafrost map, Brown and others, 1997), reflecting the properties and extent of permafrost, and a map of cryogenic physio-geological processes at 1:7,500,000-scale (Melnikov and others, 1996) were made with the use of the earler map for territories of Russia and Mongolia. Nowadays the landscape map is used for creating the International Circumpolar Soil map (1:7,500,000 scale). The compiled landscape map can be successfully used for creation of the Circumpolar Arctic vegetation map for Russia. Relief and lithology contours that drive vegetation patterns can be transformed into appropriate contours on a vegetation map. For example, a landscape base map of the vegetation map of the Western Siberian Arctic has been compiled (figure 2).

Use of the same landscape base for different circumpolar maps will ensure their continutiy and will create the best opportunities for their comparison and inclusion in the ecological atlas of the Arctic region.

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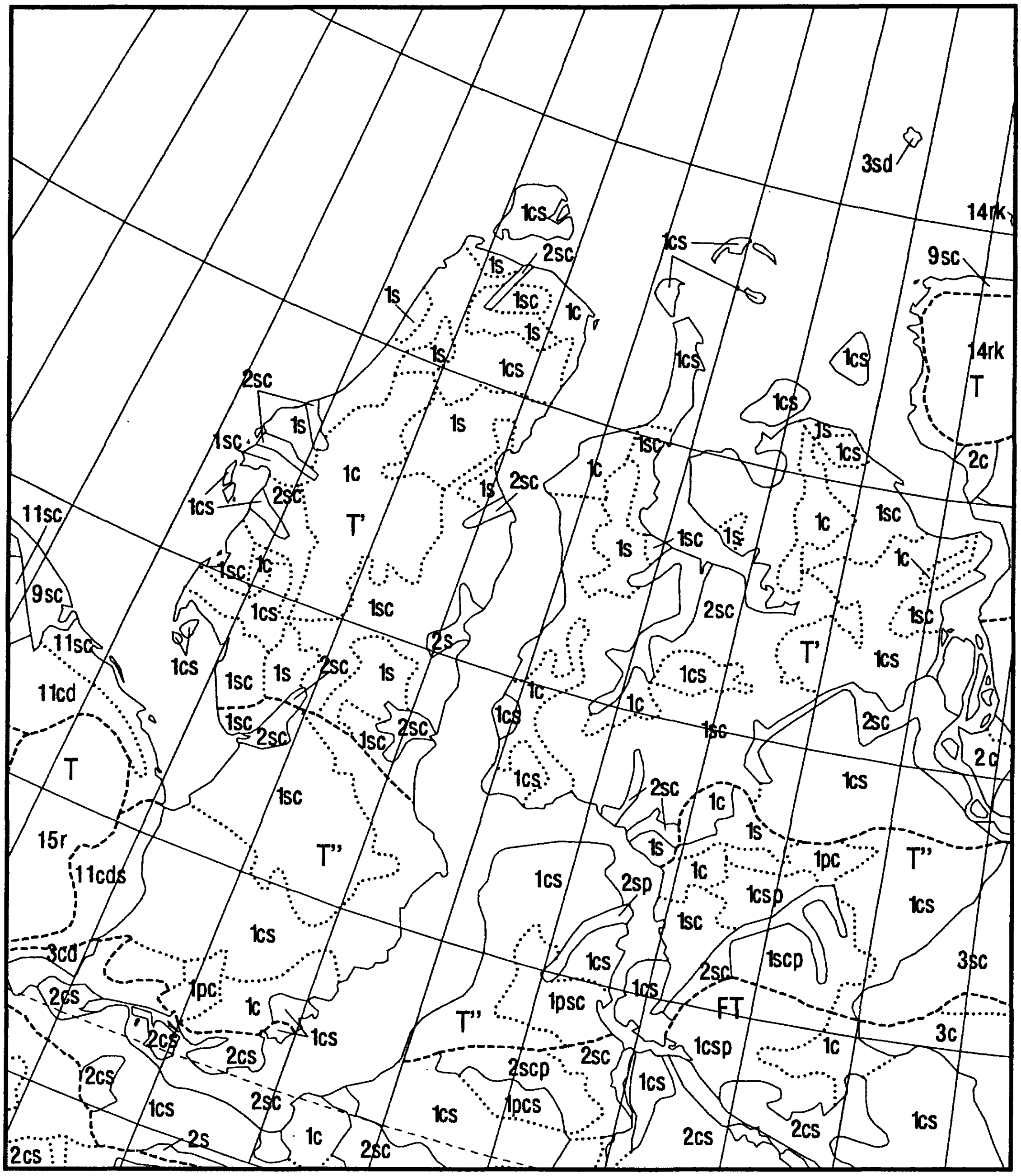


Figure 1. Portion of the landscape map for the Russian Arctic (see text for legend to map)

Legend to Figure 1.

I. Zonal, subzonal and altidue-zoned types and subtypes of landscapes

A. Plains

T' - north and typical tundra

T'' - south tundra

F' - north taiga

FT - forest tundra

B. Mountains

T - mountain tundra

II. Morphogenetic groups and varieties of landscapes

A. Platform regions

1 - marine

2 - alluvial, lacustrine-alluvial and lacustrine

3 - glacial and fluviao-glacial

B. Mountain regions - basins and piedmonts

9 - marine

11 - glacial and fluvio-glacial

14 - erosional-denudational

15 - mountains (low, middle, and high

III. Types of lithogenic base of landscapes

p - peat

c - clay and silt

l - loess

s - sand

d - coarse clastic deposits (debris)

r - insoluble rocks

k - soluble rocks (karst rocks)

IV. Boundaries

--------- zonal, subzonal, and altitude-zoned types and subtypes of landscapes

———— morphogenetic varieties of landscapes

............ types of lithogenic bases of landscapes

Note: Combinations of letters indicate mixed composition of soils, listed in order of predominance, (for example, cs), or layered compositions of soils over rocks (for example, c/r). Saline ground is indicated by a bar above the letter.

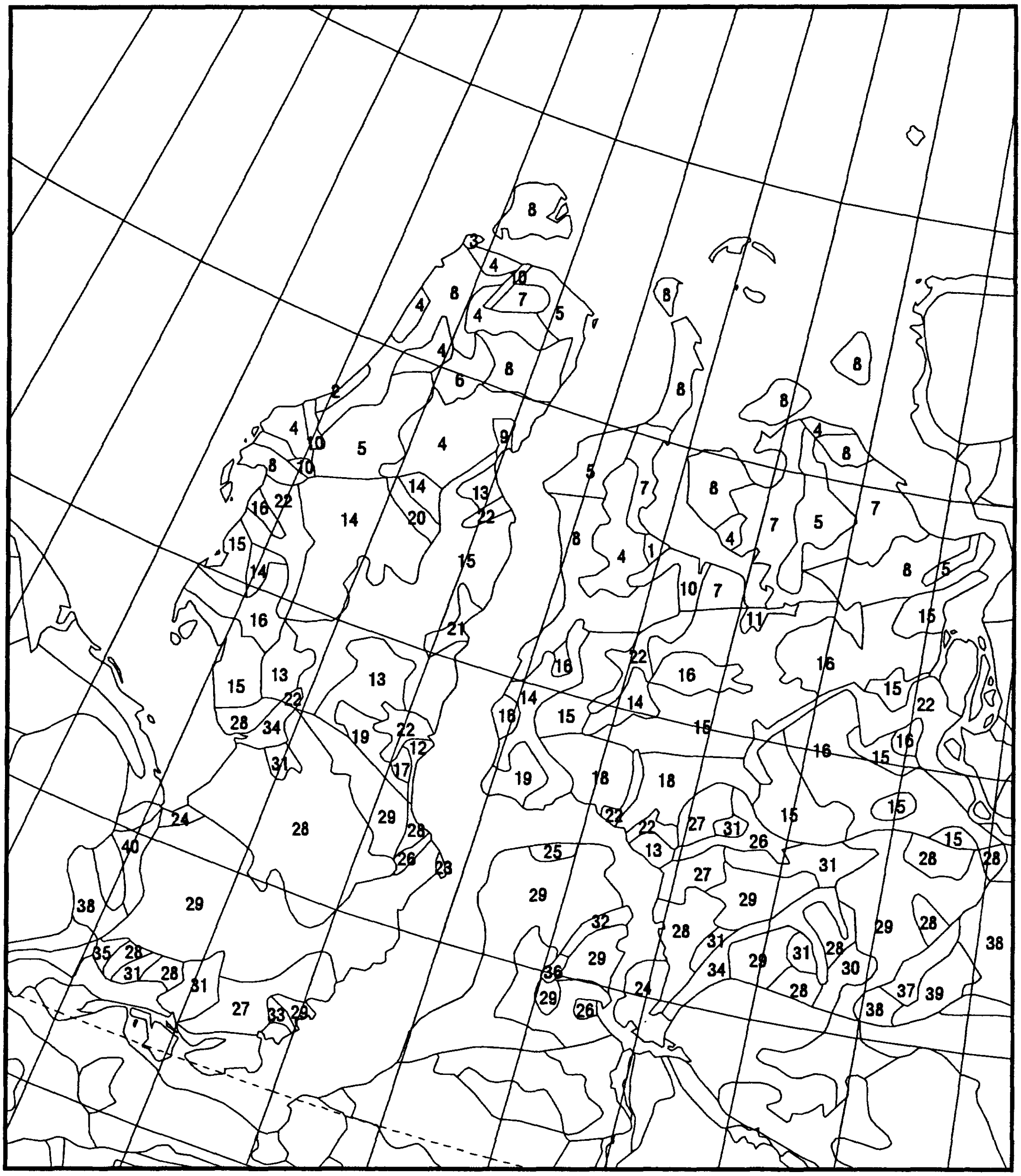

Figure 2. Vegetation map of tundra region, western Siberian arctic (legend follows).

Legend to figure 2, Vegetation Map of Tundra Region,Western Siberian Arctic

| | Characteristic of Vegetation Cover | | | | Ecological Conditions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Soil Properties | | |
| | Dominant and subdominant communities | Dominant growth forms | Horizontal structure | Biomass g/m2 | Landscape | Lake Extent % | Moisture conditions | Org-anic hori-zon cm | Mechanical composition | Chemical properties |
| | | | | **Arctic Tundras** | | | | | | |
| 1 | Sedge-*Hypnum* bogs, sedge-*Dupontia* meadows | Graminoids, mosses | Low centre polygons with tussocks | 110 -130 | Marine floodplain | 20 - 30 | Boggy | >5 | Sands, loams | Salted in some places |
| 2 | Sedge-*Hypnum* bogs, cotton grass tundras | Graminoids, mosses | Low centre polygons, with tussocks | 120 - 140 | Marine floodplain | 20 - 30 | Boggy | >5 | Loams, sands | Seldom salted |
| 3 | Sedge-*Dupontia* meadows, cotton grass tundras | Graminoids | Tussocks | 130 - 140 | Marine floodplain | 10 - 20 | Wet | 2 - 5 | Sands | Often sandy |
| 4 | Willow-lichen tundras, sedge-cotton grass-moss tundras | Dwarf shrubs, lichens | Flat centre polygons, with tussocks | 70-90 | Marine plain | < 5 | Dry, wet | < 2 | Sands | Acid |
| 5 | Willow-sedge-cotton grass-moss tundras, *Hypnum* bogs | Dwarf shrubs, graminoids, mosses | Hummocks tussocks, Low centre polygons | 100 - 120 | Marine plain | 5 - 10 | Wet, boggy | 2 - 5 | Loams | Acid |
| 6 | Sedge-*Hypnum* bogs, willow-sedge - cotton grass - moss tundras | Graminoids, dwarf shrubs, mosses | Low centre polygons, tussocks, hummocks | 100 -130 | Marine plain | 20 - 30 | Boggy, wet | > 5 | Sands, loams | Acid |
| 7 | Lichen tundras, moss tundras | Lichens, mosses | Flat centre polygons, hummocks | 50 - 70 | Marine plain | < 5 | Dry, wet | 2 - 5 | Sands, loams | Acid |
| 8 | Moss tundras, *Hypnum* bogs | Mosses | Hummocks, low centre polygons | 80 - 100 | Marine plain | 5 - 10 | Wet, boggy | > 5 | Loams, sands | Acid |
| 9 | Sedge-*Hypnum* bogs, willow-lichen tundras | Graminoids, dwarf shrub, mosses, lichens | Low centre polygons | 100 - 120 | Floodplain | 20 -30 | Boggy, dry | 2 - 5 | Sands | Acid |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Sedge/*Hypnum* bogs, willow stands | Graminoids, low shrubs, mosses | Low centre polygons, with tussocks | 120 - 140 | Floodplain | 20 -30 | Boggy, wet | > 5 | Sands, loams | Acid |
| **Northern Hypoarctic Tundras** | | | | | | | | | | |
| 11 | Sedge/*Hypnum* bogs, sedge/*Dupontia* meadows | Graminoids, mosses | Low centre polygons with tussocks | 130 -140 | Marine floodplain | 20 - 30 | Boggy | > 5 | Sands, loams | Salted in some places |
| 12 | Sedge/*Hypnum* bogs, Willow stands | Graminoids, low shrubs, mosses | Low centre polygons with tussocks | 130 - 150 | Marine floodplain | 20 -30 | Boggy, wet | 2 - 5 | Loams | Seldom salted |
| 13 | Graminoids/ Labrador tea/ lichen tundras, willow/lichen/ moss tundras | Graminoids, ericaceous shrubs, dwarf shrubs, lichens | Flat centre polygons, sandy patches | 70 - 90 | Marine plain | < 5 | Dry | < 2 | Sands | Acid |
| 14 | Labrador tea /willow/ sedge/moss tundras, forb/sedge/ moss willow stands | Ericaceous shrubs, low shrubs, graminoids, mosses | Hummocks | 110 - 130 | Marine plain | 5 - 10 | Wet | 2 -5 | Loams | Acid |
| 15 | Labrador tea/ lichen tundras, sedge/crowberry/moss/lichen tundras | Ericaceous shrubs, graminoids, lichens, mosses | Flat centre polygons | 70 -90 | Marine plain | 10 - 20 | Dry, wet | < 2 | Sands, loams | Acid |
| 16 | Labrador tea/willow/ sedge/ moss tundras, birch and willow stands | Ericaceous shrubs, graminoids, lichens, mosses | Hummocks | 110 - 130 | Marine plain | 10 -20 | Wet | 2 - 5 | Loams, sands | Acid |
| 17 | Labrador tea/cloudberry/lichen/moss bogs, sedge/cottongrass /moss bogs | Ericaceous shrubs, graminoids, lichens, mosses | High centre polygons, tussocks | 90 - 110 | Marine plain | 10 -20 | Boggy | > 5 | Sands, loams | Acid |
| 18 | Birch/sedge/lichen tundras, cottongrass tundras | Low shrubs, graminoids, lichens | Hummocks, tussocks | 70 - 90 | Marine plain | < 5 | Dry, wet | 2 - 5 | Sands, loam | Acid |
| 19 | Birch/sedge/ moss tundras, labrador tea lichen tundras | Low shrubs, ericaceous shrubs, graminoids, mosses | Hummocks, flat centre plolygons | 70 - 80 | Marine plain | 5 - 10 | Wet, dry | 2 - 5 | Loams, sands | Acid |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | Willow/cottongrass/ moss tundras, labrador tea/sedge/moss tundras | Low shrubs, ericaceous, graminoids, mosses | Tussocks, hummocks | 100 - 120 | Marine plain | 5 - 10 | Wet | 2 - 5 | Loams | Acid |
| 21 | Sedge/*Hypnum* bogs, forbs/ moss/willow stands | Graminoids, low shrubs, mosses | Low centre polygons, tussocks | 130 - 150 | Floodplain | 10 -20 | Boggy, wet | > 5 | Sands | Acid |
| 22 | Sedge/*Hypnum* bogs, sedge/forb/willow stands | Graminoids, low shrub, mosses | Low centre polygons, tussocks | 130 - 150 | Floodplain | 10 - 20 | Boggy | > 5 | Sands, loams | Acid |
| **Southern Hypoarctic Tundras** | | | | | | | | | | |
| 23 | Sedge/shrub/peat moss bogs, sedge/forb/willow stands | Graminoids, low shrubs, mosses | Low centre polygons, tussocks | 140 - 150 | Marine floodplain | 10 -20 | Boggy | > 5 | Sands | Seldom salted |
| 24 | Sedge/graminoid meadows sedge/ *Hypnum* bogs | Graminoids, mosses | Tussocks, low centre polygons | 130 - 140 | Marine floodplain | 5 - 10 | Wet, boggy | 2 - 5 | Loams, sands | Salted in some places |
| 25 | Sedge/graminoid meadows labrador tea/ birch/sedge/moss bogs | Graminoids, ericaceous shrubs, mosses | Tussocks, high centre polygons | 110 - 130 | Marine floodplain | 10 -20 | Wet, boggy | > 5 | Peat, loams | Salted in some places |
| 26 | Labrador tea/birch/ lichen tundras, labrador tea /lichen/moss tundras | Ericaceous shrubs, lichens, mosses | Flat centre polygons, hummocks | 80 - 100 | Marine plain | < 5 | Dry, wet | < 2 | Sands | Acid |
| 27 | Labrador tea/birch/ willow/sedge lichen/ moss tundras, willow/ birch/ moss/lichen stands | Ericaceous shrubs, low shrubs, lichens, mosses | Hummocks | 110 - 130 | Marine plain | 5 - 10 | Wet | 2 5 | Loams | Acid |
| 28 | Labrador tea/birch/ willow/sedge lichen/ moss tundras, willow/ birch moss/lichen stands | Ericaceous shrubs, low shrubs, lichens, mosses | Sand patches, hummocks | 90 - 110 | Marine plain | 5 - 10 | Wet, dry | < 2 | Sands, loams | Acid |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 29 | Labrador tea/willow/ birch/sedge/ lichen/ moss tundras, willow birch stands | Ericaceous shrubs, low shrubs, lichens, mosses | Hummocks tus-socks | 120 - 140 | Marine plain | 5 - 10 | Wet | 2 - 5 | Loams, sands | Acid |
| 30 | Labrador tea/*Androm-eda*/sedge/lichen/ moss bogs, cottongrass/ labrador tea/moss/ lichen tundras | Ericaceous shrubs, graminoids, lichens, mosses | High centre poly-gons, tussocks | 110 - 130 | Marine plain | 10 -20 | Boggy, wet | > 5 | Peat, sands | Acid |
| 31 | Labrador tea/*Anrom-eda*/sedge/lichen/ moss bogs, cottongrass/ labrador tea/moss/ lichen tundras | Ericaceous shrubs, low shrubs, lichens, mosses | Flat centre poly-gons, sandy patches | 110 - 130 | Marine plain | 20 - 30 | Boggy, wet | > 5 | Peat, sands, loams | Acid |
| 32 | Labrador tea/ birch/ graminoid/lichen tun-dras, willow/birch stands | Ericaceous shrubs, low shrubs, graminoids, lichens | Flat centre poly-gons, sandy defla-tions | 100 -120 | Floodplain | 5 - 10 | Dry, wet | < 2 | Sands | Acid |
| 33 | Birch/willow/ moss/ lichen stands, cotton-grass /sedge/willow/ peat moss bogs | Low shrubs, gram-noids, mosses, lichens | Tussocks | 140 - 160 | Floodplain | 10 -20 | Wet, boggy | 2 - 5 | Loams | Acid |
| 34 | Labrador tea/birch/ graminoid/lichen tun-dras, birch/willow moss/lichen stands | Ericaceous shrubs, low shrubs, lichens, mosses | Flat centre poly-gons | 120 - 140 | Floodplain | 5 - 10 | Dry, wet | < 2 | Sands, loams | Acid |
| 35 | Birch/willow/moss/ lichen stands, cotton-grass/ sedge/willow/ peat moss bogs | Low shrubs, grami-noids, mosses, lichens | Tussocks | 140 - 160 | Floodplain | 5 - 10 | Wet, boggy | 2 - 5 | Loams, sands | Acid |
| 36 | Labrador tea/cloud-berry/ lichen/ moss bogs, sedge/cotton-grass/moss bogs | Ericaceous shrubs, graminoids, lichens, mosses | High centre poly-gons, tussocks | 120 - 140 | Lacustrine - allu-vial plain | 20 - 30 | Boggy | > 5 | Peat, sands | Acid |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Alder grove shrub/ forbs/ moss, cotton-grass /sedge/ willow/ moss tundras | Tall shrubs, forbs graminoids, mosses | Tussocks, hummocks | 160 - 180 | Glacial plain | 5 - 10 | Wet | 2 - 5 | Loams | Acid |
| 38 | Birch/*Empetrum*/ lichen/moss tundras, alder grove/ forbs/ mosses | Tall and low shrubs, lichens, mosses | Sandy patches, hummocks | 160 - 180 | Glacial plain | 5 - 10 | Wet | 2 - 5 | Loams, sands | Acid |
| 39 | Alder grove shrubs/ forbs/ moss, birch/ *Empetrum*/ lichen/ moss tundras | Low shrubs, forbs, graminoids, mosses | Hummocks, patches | 80 -100 | Glacial plain | 5 -10 | Wet | 2 -5 | Loams, sands | Acid |
| 40 | Shrub/forb tundra, sedge/shrub/ moss tundras | Low shrubs, forbs, graminoids, mosses | Hummocks, patches | 80 - 100 | High glacial plain | 5 - 10 | Dry, wet | < 2 | Loams, cobble | Calcareous in some places |

# An integrated vegetation mapping approach for the Circumpolar Arctic Vegetation Map

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## ABSTRACT

A six-step process of making a 1:4 million-scale integrated vegetation map and derived map products for northern Alaska is presented. The method uses two primary maps. A Phytogeographic subzones and Floristic subprovinces Map (PFM) portrays the boundaries of Yurtsev's (1994) maps adjusted to AVHRR (Advanced Very High Resolution Radiometer) imagery, and an Integrated Vegetation-Complex Map (IVCM) portrays vegetation complexes whereby the map-polygon boundaries are guided by terrain, surficial-geology, soil, lake-cover, and vegetation features. The IVCM is created from a variety of remote-sensing data (AVHRR imagery, maximum greenness maps, and classified images) and hard-copy source maps (surficial geology, bedrock geology, soils, percent water cover). The map-polygon boundaries are integrated so that polygon boundaries conform to terrain features on the AVHRR false-color-infrared (CIR) imagery as much as possible and to eliminate repetitious boundaries and unnecessary polygons. The PFM and IVCM are then overlaid in a geographic information system (GIS) to produce a series of derived maps, including maps of dominant plant communities, horizontal structure, plant functional types, biomass, and net primary production. The derived maps are produced by reference to a series of look-up tables that contain plant community names and other vegetation information from the literature. The method can be modified to any region of the Arctic based on available information, and is recommended as a standard method for making the Circumpolar Arctic Vegetation Map (CAVM).

## INTRODUCTION

This paper presents a vegetation mapping approach that was developed for a small-scale (1:4 million) map of northern Alaska. It includes six steps with technical details and legends used for each step of the process. The method could be modified and adapted to any region of the Arctic based on available information.

Like many areas of the Arctic, northern Alaska has a small-scale vegetation map (Fig. 1), but the map is based on information collected before the vegetation was as well known as it is presently. The map units portray very broad categories of vegetation that are difficult to reconcile with modern vegetation maps based on satellite imagery (Jorgenson, 1994; Muller, 1998 in press; Bureau of Land Management, in press). Some of the map unit boundaries are overly general and do not follow physiographic boundaries. For example, "high brush" in Figure 1 covers a much larger area than in reality. The existing map also does not portray vegetation associated with different substrates that are clearly evident on small-scale satellite imagery. Such differences are important to a wide variety of ecosystem studies, including estimates of energy and trace-gas flux fluxes, habitat evaluation, and modeling studies that link climate to vegetation. It would be

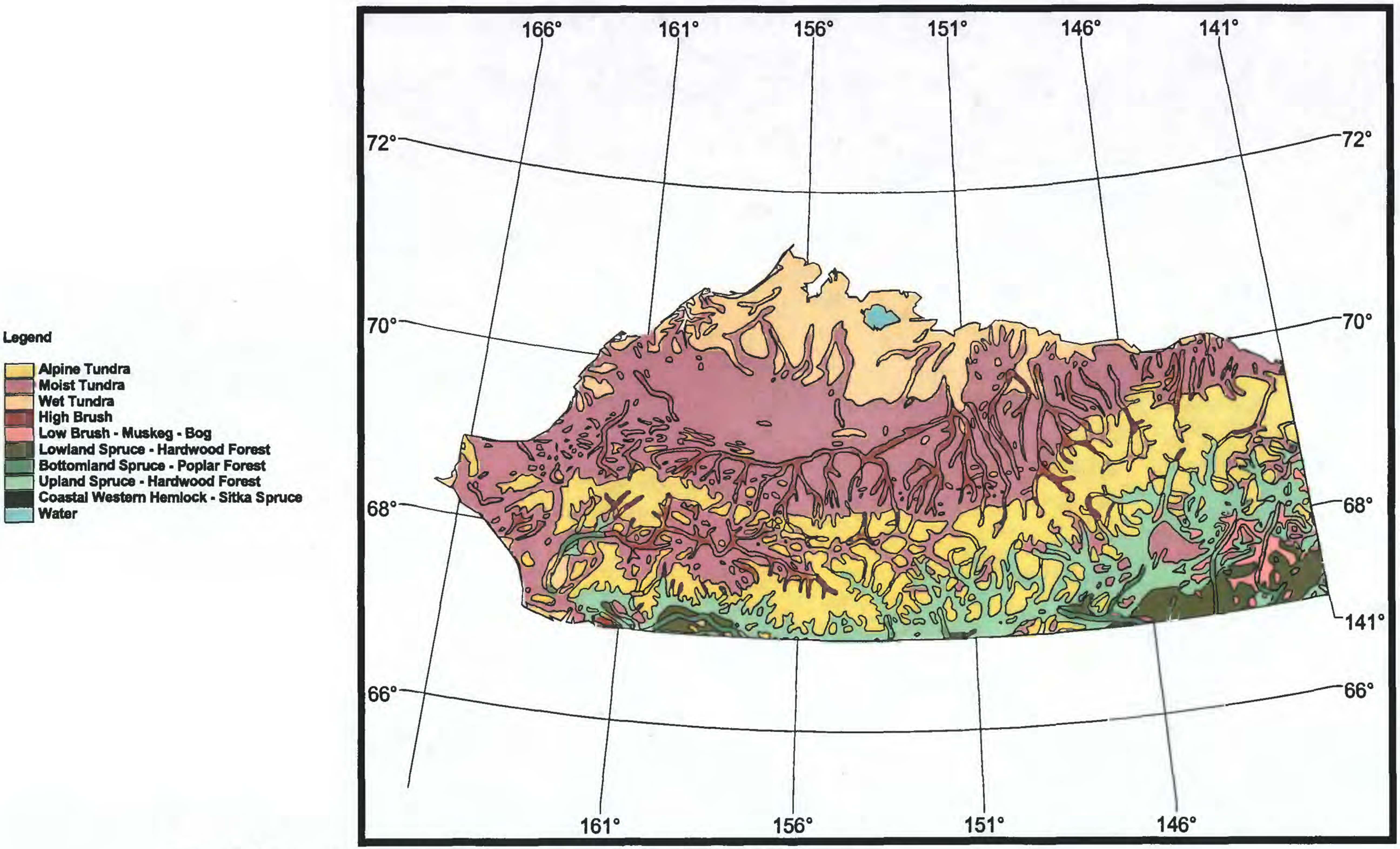


Figure 1. Existing vegetation map of northern Alaska (Spetzman, 1959)

highly desirable to produce a vegetation map that utilizes all the available mapped information as well as satellite-derived information.

Rather than aiming toward a single vegetation map, the goal of the integrated vegetation mapping approach described here is a vegetation database for deriving a variety of vegetation-related products and spatial information. The integrated vegetation mapping approach is based on landscape-guided mapping espoused by the International Training Centre for Aerial Survey (ITC, now called the Institute for Aerospace Survey and Earth Sciences) in the Netherlands (Zonneveld 1988). The application of this approach to GIS technology has been described as the Integrated Terrain Unit Mapping (ITUM) approach (Dangermond and Harnden, 1990). The approach uses the philosophy that soil and vegetation boundaries on maps are controlled principally by physiographic landscape features. In the Arctic North America, this philosophy has also been well demonstrated (Everett *et al.* 1978; Walker *et al.* 1980, Zoltai and Johnson 1977, Zoltai and Pettapiece 1973). The integrated method described here requires that vegetation complexes first be defined and mapped based on a wide variety of sources, including remotely sensed images and hard-copy geology, soil, vegetation maps, and maps of vegetation greenness and satellite-derived land-cover classifications. Phytogeographic subzones and floristic subprovinces (Yurtsev, 1994) are on a separate overlay in the CAVM GIS. Reference to detailed vegetation information in a series of look-up tables is then used to derive a map of common plant communities in subzone/subprovince/vegetation-complex combinations. A wide variety of other vegetation map products can also be derived.

## METHODS

The method consists of six steps: (1) collect and reproduce source maps at 1:4 million scale, (2) simplify source maps and adjust boundaries to the AVHRR CIR image, (3) make an Integrated Landscape-Unit Map, (4) make an Integrated Vegetation-Complex Map (IVCM), (5) make look-up tables to relate the vegetation complexes to information from the literature, and (6) make the final vegetation map and other derived maps. Each step is outlined below with technical information and legends used for making the map of northern Alaska.

### Step 1, collect and reproduce source maps at 1:4 million scale.

The first step is to collect and evaluate all the available maps and literature for the region and then reproduce the source maps to a common 1:4 million scale. Map sources include remote-sensing imagery (AVHRR CIR, maximum NDVI, and classified time series data) (Fig. 2, maps 1-3; Fleming 1997), a topography/ hydrology map produced from the Digital Chart of the World (DCW; Fig. 2, map 4) and maps from literature sources (vegetation, surficial geology, bedrock geology, soils, percent water cover, and phytogeographic subzones and floristic subprovinces; Fig. 2, maps 5-10). All the hard-copy maps are photographically reproduced to 1:4 million scale to match the CIR image.

**Summary of remote-sensing and DCW products.** Note: Consecutive numbers of paragraphs describing products and legends below refer to layer numbers in Figures 2 through 7.

**1. AVHRR CIR composite (1:4,000,000 scale) (Fleming, 1997 unpublished).** This layer provides basic boundaries for the landscape units. This is the base image to which all boundaries conform. It is the northern Alaska piece of an AVHRR false color-infrared composite of the circumpolar region at 1:4,000,000-scale. It displays the maximum reflectance of the vegetation for each 1x1-km pixel during the summer of 1992.

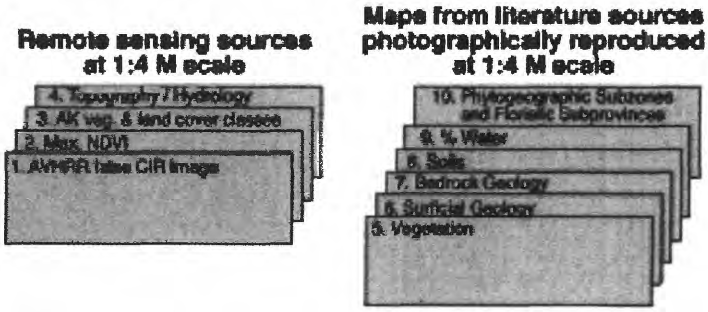


*Figure 2. Source maps for the Alaskan portion of the CAVM.*

**2. Maximum NDVI (Fleming, 1997 unpublished).** This layer is derived from the AVHRR data. NDVI has been shown to be a good surrogate of vegetation greenness. Generally, the NDVI values are highest in vegetation with greater biomass. In tundra, the NDVI can be useful to define areas of sparse vegetation, such as barrens, or areas with high biomass such as shrublands. This layer portrays the maximum NDVI for each pixel during the summer of 1992 in Alaska. It was particularly useful for defining the boundaries of shrublands.

**3. Alaska Vegetation/ Landcover classes (Fleming, 1997).** This layer was prepared from a 1992 time series of AVHRR images. The classification contains 54 classes and is useful for helping to define boundaries on some vegetation classes.

**4. Topography/ hydrology map (Fleming, 1997).** This layer is composed of data from the Alaska digital elevation model and the hydrological information in the Digital Chart of the World. This layer provides the coastal boundaries for the map and helps guide landscape-unit boundaries along rivers and major lakes and in the mountains.

| Map Code | Elevation (m) |
|---|---|
| *Green 1* | 1-10 |
| *Green 2* | 11-50 |
| *Green 3* | 51-100 |
| *Green 4* | 101-200 |
| *Green 5* | 201-300 |
| *Green 6* | 301-400 |
| *Tan* | 401-500 |
| *Yellow* | 501-1000 |
| *Orange 1* | 1001-1500 |
| *Orange 2* | 1501-2000 |
| *Orange 3* | 2001-3000 |

**4a. Shorelines and river systems.** This is the shorelines and river systems without the topography. It helps better define the drainage systems

## Step 2, simplify source maps and adjust boundaries to the AVHRR CIR image

In Step 2 the source maps *are simplified to reflect only information that is relevant to the vegetation*, and the map polygon boundaries are adjusted to conform to the AVHRR CIR base map (Fig. 3, maps 5a-10a). Polygon boundaries are drawn on mylar overlays of the hard-copy source maps. Landsat or other finer-scale satellite images are also used to help delineate boundaries. Minimum polygon size is 3.5 mm except for river valleys and linear features, where a 2-mm minimum width is used. Map legends are also simplified to retain only information with known relevance to the vegetation (Legends 1-10.). The southern boundary for the map area on all overlays conforms to the treeline on the vegetation overlay (map 5a).

## TECHNICAL NOTES REGARDING MYLAR OVERLAYS

(1) The AVHRR base image (Layer 1) should have 3 or 4 registration marks that are aligned with registration marks on Layer 12 (the IVCM). This is necessary to register the ITUM to the base-map/image during the digitizing process. (2) The process of making the various overlays is greatly aided by special registration tabs and pins that allow the layers to be added or removed easily while maintaining perfect registration. The pins eliminate the need for registration marks on all the overlays. The pins we use are base 3 "p3", and the tabs are stripping tabs with oval ends, distributed by Echo Blueprint, Hudson, Florida, USA (phone 1-800-875-3246). (3) Coding the polygons appearing on each layer should be done such that a dot is placed

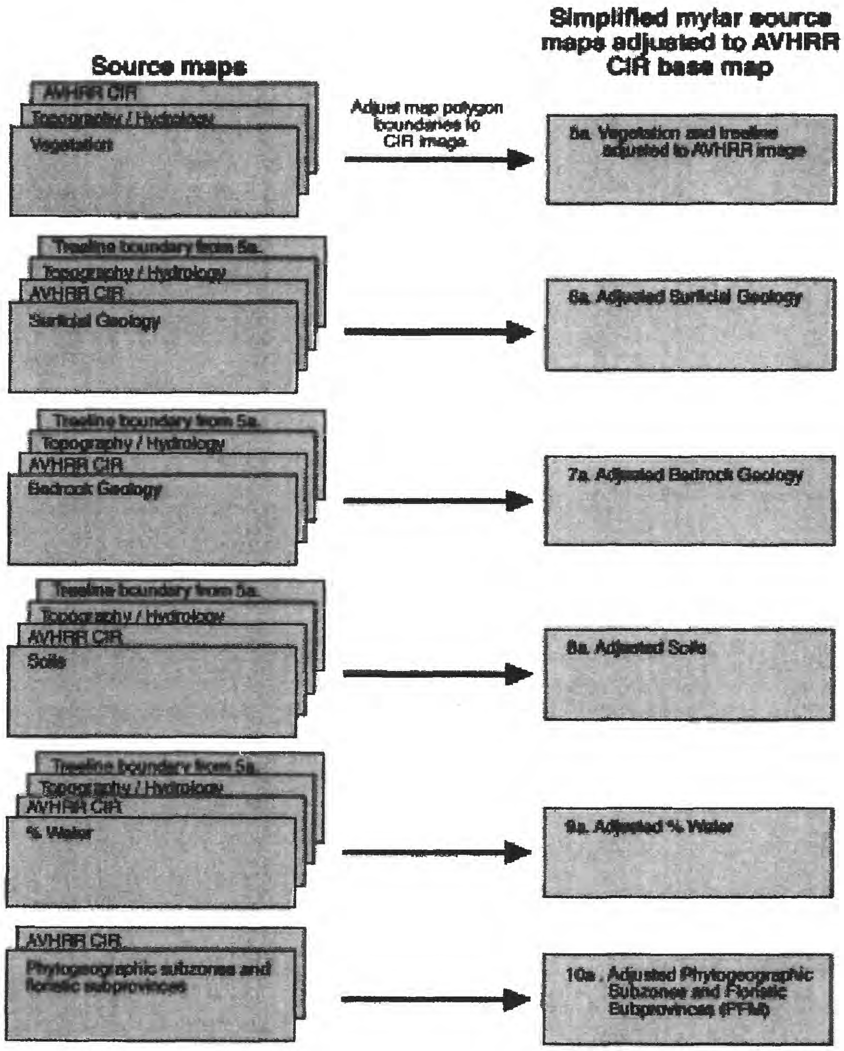


*Figure 3. Creation of simplified source maps with boundaries adjusted to the AVHRR CIR base.*

in the center of the polygon and leader line drawn from the dot to the respective code. Wherever possible the code should be contained in the polygon that it describes. For very complex maps it may be desirable to use different colored pencils for the polygon boundaries and the codes and leader lines to avoid confusion between the leader lines and the polygon boundaries. (4) It is important that all polygons are closed and that the line work is as neat as possible with no overshoots or gaps where boundary lines meet. Polygon boundaries should be rounded with no narrow "peninsulas" that could become closed and create false polygons.

## Summary of simplified legends for mylar overlays at 1:4 million scale

**5a. Vegetation.** The map is used primarily for defining the treeline (southern boundary of the study area), and for some areas of alpine vegetation. This layer is derived from the vegetation map of the Arctic Slope of Alaska. (Spetzman, 1959).

| *Map code* | *Vegetation* |
|---|---|
| 1 | Alpine tundra |
| 2 | Moist tundra |
| 3 | Wet tundra |
| 4 | Shrublands |
| 5 | Bottomland spruce - poplar forest |
| 6 | Upland spruce - hardwood forest |

**6a. Surficial geology.** The differences in the vegetation on acidic and nonacidic substrates have not been previously mapped in northern Alaska, and is necessary to use a combination of spectral information, soil, and geological information to infer the location of these tundra types. This layer is derived from the Surficial Geology of Alaska (1:1,584,000 scale) (Karlstrom and al., 1964) and Surficial Geology Map of National Petroleum Reserve Alaska [Williams, 1978 #4591

| Map Code | *Surficial geology units (Karlstrom et al. 1964)* | *Description* |
|---|---|---|
| | Qi, Qm4, Qm3, Qm2, Qm1 | Glacial moraines and associated drift |
| | Qg, Qw2, Qw1 | Glacio-lacustrine and glacio-fluvial deposits |
| | Qfp | Fluvial deposits |
| | Qed, Qe, Qes | Eolian silt deposits |
| | Qra | Undifferentiated slope deposits in mountainous areas, predominantly coarse rubbly deposits regions |
| | Qrb | Undifferentiated slope deposits in hilly areas with steeper hills and bedrock exposures largely restricted to the upper slopes and crestlines |
| | Qrc | Undifferentiated slope deposits, dominantly fine-grained deposits associated with gently sloping hills and rare bedrock exposures. |
| | Qcd | Coastal delta deposits |
| | Qcc, Qcb | Undifferentiated coastal deposits |
| | Qat, Qaf | Older fluvial terrace deposits and alluvial fan deposits |
| | Qu | Undifferentiated valley deposits |
| | Qes | Eolian sand deposits |
| | Qmsi | Marine silt deposits |
| | Qms | Marine sand deposits |

**7a. Generalized bedrock geology.** Bedrock composition is particularly important to plant communities in areas where bedrock is near the surface and not overlain by deep unconsolidated deposits. This layer is greatly generalized from the Geologic map of Alaska. Scale 1:2,500,000 (Beikman, 1980). Units are generalized into groups that weather into acidic or nonacidic soils.

| *Map Code* | *Geologic units (Beikman 1980)* | *Bedrock category* |
|---|---|---|
| 1 | uT, Uk, KJ, J, J Tr, Tr P, JP, Mz Pz, P, JM, MD, C, I Tc, I Kc, | Primarily acidic sedimentary rocks, including siltstone, sandstone, conglomerate and shale. |
| 2 | Kif, Mz Pzif | Primarily acidic igneous and metamorphic rocks, mostly felsic instrusives, granite to granodiorite, syenite to diorite. |

| | | |
|---|---|---|
| 3 | lPM, DS, lPz, lPzpC, | Primarily nonacidic sedimentary rocks, including limestone, dolomite, marble, conglomerate, and shales. |
| 4 | J Ppvm, Cvm, J Pu, | Primarily nonacidic igneous and metamorphic rocks, volcanics and ultramafic rocks, including rhyolite to dacite, trachyte to andesite, basalt, olivine, gabbro, and serpentine. |

**8a. Soil associations.** Soil maps can help in defining the location of vegetation complexes associated with soils of different pH and texture. This is particularly useful in the foothills and coastal plain, where distinctive plant community complexes are associated with acidic sandy substrates, or nonacidic loamy substrates. Based on photointerpretation of AVHRR false CIR composite and several sources (Gryc, 1985; Hamilton, 1986; Hamilton and Porter, 1975; Rieger, et al., 1979; USDI, 1982), and personal unpublished data from numerous surveys.

| *Map Code* | *Soil code* | *Soil Association (See Rieger et al. 1979 for full description)* |
|---|---|---|
| 1 | IQ2 | Histic Pergelic Cryaquepts, loamy, nearly level to rolling association |
| 1a | IQ3 | Histic Pergelic Cryaquepts–Typic Cryofluvents, gravelly, nearly level association |
| 2 | IQ6 | Histic Pergelic Cryaquepts, loamy nearly level to rolling–Pergelic Cryofibrist, nearly level association |
| 3 | IQ7 | Histic Pergelic Cryaquepts, loamy nearly level to rolling–Pergelic Cryaquepts, gravelly, nearly level to rolling association |
| 4 | IQ8 | Histic Pergelic Cryaquepts, loamy, nearly level to rolling–Pergelic Cryaquepts, very gravelly, hilly to steep association |
| 4a | IQ11 | Histic Pergelic Cryaquepts, loamy, nearly level to rolling–Pergelic Cryumbrepts, very gravelly, hilly to steep association |
| 5 | IQ20 | Pergelic Cryaquepts–Pergelic Ruptic-Histic Cryaquepts, loamy nearly level to rolling association |
| 6 | IQ21 | Pergelic Cryaquepts–Pergelic Cryopsamments, nearly level to rolling association |
| 7 | IQ22 | Pergelic Cryaquepts, very gravelly, nearly level to rolling association |
| 8 | IQ24 | Pergelic Cryaquepts–Pergelic Cryorthents, very gravelly, hilly to steep association |
| 9 | IQ25 | Pergelic Cryaquepts–Pergelic Cryochrepts, very gravelly, hilly to steep association |
| 10 | IU2 | Pergelic Cryumbrepts–Histic Pergelic Cryaquepts, very gravelly, hilly to steep association |
| 11 | MA1 | Pergelic Cryaquolls–Histic Pergelic Cryaquepts, loamy, nearly flat to rolling association |
| 12 | MA2 | Pergelic Cryaquolls, very gravelly, nearly level to rolling association |
| 13 | MA3 | Pergelic Cryaquolls, very gravelly, nearly level to rolling–Pergelic Cryoborolls, very gravelly, hilly to steep association |
| 14 | MB2 | Pergelic Cryoborolls–Pergelic Cryaquolls, very gravelly, hilly to steep association |
| 15 | RM1 | Rough mountainous land |
| 16 | RM2 | Rough mountainous land–Lithic Cryorthents, very gravelly, hilly to steep association |
| 17 | none | Water |

**9a. Percentage land cover by lakes.** Spectral variation within wetland complexes at the AVHRR scale is mainly a function of lake size and density. In most cases, lakes have subpixel dimensions at the AVHRR scale (1x1-km pixels). The map boundaries were interpreted by reference to the more detailed Landsat images of the North Slope (USGS 1978, USGS EROS Data Center) and maps of the percent cover of water on the Arctic Slope (Sellmann, et al., 1975). Percentages reflect only lakes and do not include marshes and drained lake basins.

| *Map code* | *Percent of lakes* |
|---|---|
| 1 | <2 |
| 2 | 2-10 |
| 3 | 10-25 |
| 4 | 25-50 |
| 5 | 50-100 |

**10a. Phytogeographic subzones and floristic subprovinces.** This map modified from Yurtsev's (1994) maps, based on expert knowledge and interpretation of the AVHRR CIR image.

| *Map code* | *Floristic subprovince and phytogeographic subzone* |
|---|---|
| 11 | Arctic Tundra subzone, Northern Alaska subprovince |
| 21 | Northern Hypoarctic subzone, Northern Alaska subprovince |
| 22 | Northern Hypoarctic subzone, Beringian Alaska subprovince |
| 31 | Southern Hypoarctic subzone, Northern Alaska subprovince |
| 32 | Southern Hypoarctic subzone, Beringian Alaska subprovince |

## Step 3, Integrated Landscape-Unit Map (ILUM)

The landscape unit layer includes all the geologic and terrain information relevant to the vegetation. The boundaries on this map guide the boundaries on the Integrated Vegetation-

Complex Map (IVCM). Landscape-unit boundaries are drawn on a mylar overlay of maps 6a-9a (surficial geology, bedrock geology, soils, and percent water) to create the ILUM (map 11). Boundaries are reconciled to eliminate all unnecessary polygons. Overlays are continuously shuffled to use boundaries from the best source in different parts of the map and to minimize sliver polygons (narrow polygons that result from mismatched lines from different source maps). All boundaries are also reconciled to the AVHRR CIR base (Fig. 2, map 1). *Hard boundaries* are those associated with water boundaries, river corridors, and major physiographic features, and are laid down first. *Soft boundaries* are those associated with features varying across gradients, such as soils or percent water cover, and are laid down secondly. The legend for the ILUM is in Legend 11.

A full explanation of integrated mapping approach is contained in "Map data standardization: a methodology for integrating thematic cartographic data before automation" (Dangermond and Harnden 1990). The method has been applied to terrain mapping at a wide variety of scales including entire continents. The advantages include: (a) use of common boundaries wherever possible for various geobotanical themes, (b) minimizing the total number of polygons stored in the GIS, (c) resolution of boundary inconsistencies between the various themes, and (d) smoothing of boundaries to eliminate unnecessary crenulations and very small polygons. It allows information from a wide variety of sources to be compiled at a common scale with the same level of accuracy and registered to the same photo base. Many very small polygons of minimal value to the final map (sliver polygons) can be eliminated by following the landscape-unit boundaries wherever possible.

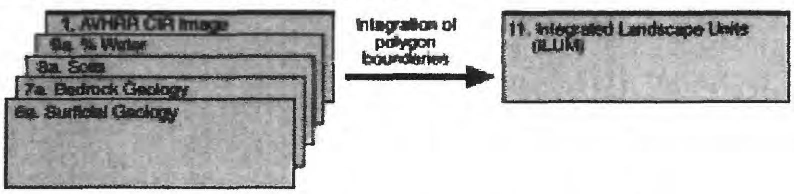


*Figure 4. Procedure for making the Integrated Landscape-Unit Map (ILUM).*

## LEGEND FOR ILUM

**11. Landscape units on example map.** This legend includes the units that were mapped for the demonstration example, a modified legend recommended for future mapping is in 11a. The map displays basic landscape units that can be recognized on the AVHRR-derived base map with reference to a variety of literature sources. The map is based on photo interpretation of AVHRR CIR composite image 1:4,000,000 (Fleming, this volume) and maps 6a-9a (surficial geology, bedrock geology, soils, and percentage cover of water). In some cases the locations of mountain valleys and floodplains were difficult to delineate on the AVHRR image, and the position of landscape unit boundaries was aided by reference to mosaics of Landsat images of northern Alaska with reference to standard false-color controlled Landsat mosaic of mainland Alaska, Scale 1:1,000,000 (USGS, 1978) and other source maps.

| *Map code* | *Landscape Unit* |
|---|---|
| 1 | Lakes |
| 2 | Oceans |
| 3 | Plains |
| 4 | Plateaus |
| 5 | Mountain valleys |
| 6 | Hills and low mountains without altitudinal belts |
| 7 | Mountains with altitudinal belts |
| 8 | Floodplains, deltas, and outwash plains (active and recently active floodplains with fluvial landforms) |
| 9 | Glaciers and ice caps |

**11a. Suggested landscape units for future mapping.**

| New code | Description |
|---|---|
| ***Mountains*** | |
| 1 | Acidic mountain complex with coarse rubbly deposits, extensive bedrock |
| 2 | Nonacidic mountain complex with coarse rubbly deposits, extensive bedrock |
| 3 | Acidic plateau, basin, or plain complex |
| 4 | Nonacidic plateau, basin, or plain complex |
| 5 | Glaciated valley and moraine complex |
| ***Hills*** | |
| 6 | Acidic hill complex with rare bedrock outcrops |
| 7 | Acidic hill complex with occasional bedrock outcrops |
| 8 | Nonacidic hill complex with rare bedrock outcrops |
| 9 | Nonacidic hill complex with occasional bedrock outcrops, |
| ***Plains*** | |
| 10 | Acidic plains, <25% lakes |
| 11 | Acidic plains, 25-75% lakes |
| 12 | Nonacidic plains, <25% lakes |
| 13 | Nonacidic plains 25-75% lakes |
| 14 | Deltas and coastal wetlands (saline) |
| ***Riparian areas*** | |
| 15 | River floodplain complex |
| ***Water and glaciers*** | |
| 16 | Water or lake complex (>75% water cover) |
| 17 | Glacier complex (>75% glacier cover) |

## Step 4, Integrated Vegetation-Complex Map (IVCM)

The IVCM contains all the terrain information from the ILUM plus vegetation information from a variety of sources (map 12). At very small scales, it is not possible to map the details of vegetation communities, and it is necessary to map vegetation complexes related to terrain features, similar to the approach used for the European vegetation map (Bohn, 1994) and several Russian vegetation maps (Perfilieva, 1997). Vegetation complexes are created by adding vegetation information to the boundaries of the ILUM. For example, in northern Alaska, additional polygons were added from the vegetation map (map 5a, for some areas of alpine vegetation), maximum NDVI map (map 2, for areas of shrub tundra), and the classified AVHRR image (map 3, for better defining the boundary between moist acidic and moist nonacidic tundra). The legend for the IVCM is in Legend 12.

An uncoded version of the IVCM, showing only the map polygon boundaries, is prepared for scan digitizing (map 12a). This results in a raster-format file, that is then converted to a vector (or line) format using GIS software. Unique consecutive polygon identification (ID) labels are added to each polygon either automatically using GIS software or by manually creating centroids (dot in the center) in each polygon and attaching the polygon ID number. A final polygon ID map is then produced that shows the polygon boundaries, centroids, and polygon ID numbers.

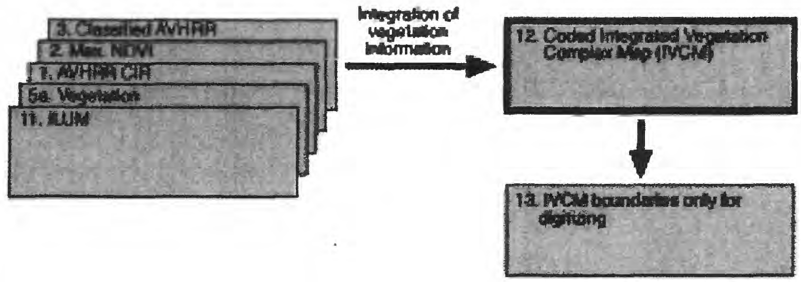


*Figure 5. Procedure for making the Integrated Vegetation-Complex Map (IVCM) and version for digitizing.*

## LEGEND FOR IVCM

**12. Vegetation complexes on example map.** This legend includes the units that were mapped for the demonstration example, a modified legend recommended for future mapping is in 12a. The boundaries on this map are based primarily on the landscape-unit boundaries (ILUM) with supplemental information from the Max NDVI map (2), and Alaska Vegetation/ Landcover classes map (3), with reference to Landsat or other images at finer scales

| *Map code* | *Vegetation complex* |
|---|---|
| 1 | Acidic mountain complex with vertical zonation |
| 2 | Circumneutral to alkaline mountain complex with vertical zonation |
| 3 | Circumneutral to alkaline plateau complex |
| 4 | Glaciated valley and moraine complex |
| 5 | Upland scrub complex |
| 6 | Acidic hill complex |
| 7 | Circumneutral hill complex |
| 8 | Glaciated hill complex (>15% dry elements and numerous lakes) |
| 9 | Lowland scrub complex |
| 10 | Riparian complex (including glacial outwash and rivers) |
| 11 | Acidic wetland complex (including poor fens) |
| 12 | Circumneutral wetland complex (including marshes) |
| 13 | Coastal wetland complex (with saline communities) |
| 14 | Bottomland evergreen forest complex |
| 15 | Upland mixed forest complex |
| 16 | Water complex |
| 17 | Glacier complex |

### 12a. Suggested vegetation complexes for future mapping.

| *New Code* | *Description* |
|---|---|
| *Mountains* | |
| 1 | Acidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation |
| 2 | Nonacidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation |
| 3 | Acidic plateau, basin, or plain complex |
| 4 | Nonacidic plateau, basin, or plain complex |
| 5 | Glaciated valley and moraine complex |
| *Hills* | |
| 6 | Acidic hill complex with rare bedrock outcrops, no vertical zonation |

| | |
|---|---|
| 7 | Acidic hill complex with occasional bedrock outcrops, no vertical zonation |
| 8 | Nonacidic hill complex with rare bedrock outcrops, no vertical zonation |
| 9 | Nonacidic hill complex with occasional bedrock outcrops, no vertical zonation |
| 10 | Low- to high-shrub tundra complex on uplands |
| 11 | Subalpine shrubland complex |
| 12 | Mixed evergreen and deciduous forest on uplands (border area with Canada) |
| ***Wetlands*** | |
| 13 | Acidic mire complex, <25% lakes |
| 14 | Acidic mire complex, 25-75% lakes |
| 15 | Nonacidic mire complex, <25% lakes |
| 16 | Nonacidic mire complex 25-75% lakes |
| 17 | Coastal mire complex (saline) |
| ***Riparian areas*** | |
| 18 | River floodplain complex |
| 19 | Bottomland evergreen forest complex |
| 20 | Bottomland deciduous forest complex |
| ***Water and glaciers*** | |
| 21 | Water or lake complex (>75% water cover) |
| 22 | Glacier complex (>75% glacier cover) |

**13. Integrated vegetation-complex boundaries only for digitizing.** This layer is for scan-digitizing the map polygon boundaries. It is identical to 11a except without the codes.

## Step 5, look-up tables

The look-up tables relate the vegetation complexes to common plant communities and other vegetation information. The plant communities within the vegetation complexes vary according to the phytogeographic subzone and the floristic subprovince in which they occur (PFM, map 10). A map showing the locations of all vegetation study locations (map 13), is overlaid on the PFM to find the relevant literature sources for each vegetation complex/subzone/subprovince combination. Plant communities and their characteristics (Braun-Blanquet class, community name, habitat, literature sources, dominant plant functional types (PFTs), horizontal structure, total biomass, net primary production (NPP)) within each subzone and subprovince are determined from the literature and expert knowledge. Codes giving the names and characteristics of the plant communities are listed in Look-up Tables 1 and 2. Look-up Table 3 lists the dominant plant community codes for each vegetation complex/subzone/subprovince combination.

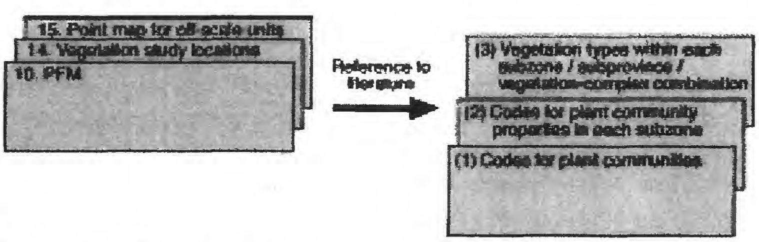


*Figure 6. Derivation of look-up tables.*

## Legends and references for study-site locations and off-scale points

**14. Locations of intensive vegetation and soil studies.** This information is used to determine the dominant communities described in the literature for each vegetation complex/subzone/subprovince combination. These sites generally have detailed vegetation descriptions with complete species lists and/or good vegetation maps derived from photointerpretation. Information from these studies help to create the information in the look-up tables.

| *Map code* | *Location* | *References* |
|---|---|---|
| 1 | Barrow | (Elias, et al., 1995; Gersper, et al., 1980; Webber, 1978; Webber, et al., 1980) |
| 2 | Fish Creek | (Lawson, et al., 1978) |
| 3 | Kuparuk Oil Field | (Everett and Walker, 1982) |
| 4 | Prudhoe Bay Oil Field | (Everett and Parkinson, 1977; Walker, 1985; Walker and Acevedo, 1987 Walker, 1991 #6532) |
| 5 | Barter Island | (Elias, et al., 1995) |
| 6 | Meade River | (Everett, 1980; Komárková and Webber, 1980) |
| 7 | West Oumalik | (Ebersole, 1985) |
| 8 | Umiat | (Bliss and Cantlon, 1957; Churchill, 1955) |
| 9 | Sagwon Upland | (Walker, et al., 1998) |
| 10 | Happy Valley | (Walker, 1994 unpublished). |
| 11 | Arctic National Wildlife Refuge | (Hettinger and Janz, 1974; Jorgenson, et al., 1994; Walker, et al., 1982) |
| 12 | Cape Thompson | (Holowaychuk, et al., 1966; Johnson, et al., 1966) |
| 13 | Arrigetch Mountains | (Cooper, 1986) |
| 14 | Toolik Lake | (Walker, et al., 1994) |
| 15 | Imnavait Creek | (Walker, et al., 1989; Walker and Walker, 1996) |
| 16 | Kobuk River Valley | (Racine, 1976) |
| 17 | Lake Peters | (Batten, 1977) |
| 18 | Noatak River | (Young, 1973) |
| 19 | Killik River | (Murray, 1974) |

**15. Point map for off-scale units (not shown in example).** This map is not shown in the examples, but it should be included to show locations of important vegetation features that are too small to map at the 1:4,000,000 scale.

| *Map Code* | *Characteristic* |
|---|---|
| 1 | Polar oases |
| 2 | Poplar groves |
| 3 | Major springs |

## LOOK-UP TABLE 1. CODES FOR PLANT COMMUNITIES.

**Column 1, plant-community codes.** The plant-community names and codes are standardized according to the following rules: Each plant community is given a 5-digit code with the first two numbers corresponding to the Braun-Blanquet class (bold numbers and names). The third and fourth numbers refer to the association or plant community, and fifth number corresponds to the subassociation.

**Column 2, Braun-Blanquet Class and plant community name.** The plant communities are grouped according to Braun-Blanquet classes. If a published Braun-Blanquet association name is available, it takes precedence over all other descriptions because this name is readily recognized by vegetation scientists and contains a great deal of inherent information regarding species composition, geographic location, and habitat. If no Braun-Blanquet reference is available, the best available plant-community description is selected as the reference plant community. The preferred information should contain a complete species list for the community (vascular plants and cryptogams), preferably with a table showing the abundance of the species in multiple relevés or samples. The plant community names should contain two species, the dominant plant species and a characteristic plant species, preferably one that is characteristic of the floristic subregion in which the community occurs. For subassociations, a third plant species characteristic of the subassociation is included in the name. The plant names are italicized and separated by a dash

**Column 3, habitat.** Habitat information is given emphasizing site moisture, pH conditions, special habitat conditions, and distribution of the plant community if it is restricted to a certain region.

**Column 4, literature source.** The author(s) of the article in which the community is described and the date of publication. A bibliography containing all the literature citations is also included.

### Look-up table 1.

| Veg Code | B-B Class and Plant community | Habitat | Source |
|---|---|---|---|
| **01000** | **Rhizocarpetea geographici** | **Acidic rock lichen communities** | |
| 01010 | Cetraria nigricans-Rhizocarpon geographicum comm. | Xeric, acidic, sandstone and conglomerate rocks | Walker et al. 1994 |
| **02000** | **Carici rupestris-Kobresietea bellardii** | **Dry, often calcareous, tundra swards** | |
| 02010 | Selaginello sibiricae-Dryadetum octopetalae | Xeric, exposed, acidic, rocky slopes, mountains, | Walker et al. 1994 |

| | | | |
|---|---|---|---|
| | | foothills | |
| 02011 | Oxtropis bryophila ssp. pygmaeus-Dryas octopetala comm. | Xeric, exposed, acidic, rocky slopes, Cape Thompson | Johnson et al. 1966 |
| 02012 | Dyas integrifolia-Oxytropis nigrescens comm. | Xeric, exposed, calcareous sites, coastal plain | Walker and Everett 1991 |
| 02020 | Dyas integrifolia-Cassiope tetragona comm. | Subxeric, well-drained, nonacidic, shallow snowbeds | Walker et al. 1994 |
| **03000** | **Cetrario-Loiseleurietea** | **Dry acidic tundra** | |
| 03010 | Salici phlebophyllae-Arctoetum alpinae | Subxeric, moderately exposed, acidic, rocky sites, glacial till, foothills, sandstone | Walker et al. 1994 |
| 03020 | Hierochloë alpina-Betula nana comm. | Subxeric, somewhat protected, acidic sites | Walker et al. 1994 |
| 03030 | Carici microchaetae-Cassiopetum tetragonae | Subxeric, well drained, acidic shallow snowbeds | Walker et al. 1994 |
| **04000** | **Salicetea herbaceae** | **Snow patch communities** | |
| 04010 | Salix rotundifolia comm. | Mesic, nonacidic, deep snowbeds | Walker et al. 1994 |
| **05000** | **Oxycocco-Sphagnetea** | **Raised bogs, acidic tussock tundra** | |
| 05010 | Sphagno-Eriophoretum vaginati typicum | Mesic to subhygric, acidic, uplands, moderate snow | Walker et al. 1994; Churchhill 1955; Bliss 1956, Johnson 1966, |
| 05011 | Sphagno-Eriophoretum vaginati Cassiope tetragona comm | Coastal plain tussock tundra with short tussocks and few shrubs | Walker and Everett 1980; Komarkova and Webber 1980 |
| 05020 | Sphagno-Eriophoretum vaginati betuletosum nanae subass. prov. | Dwarf-birch dominated, mesic margins of water tracks, high-centered polygons | Walker et al. 1994 |
| 05030 | Sphagnum lense-Salix fuscenscens comm | Subhygric, acidic fens | Walker et al. 1994 |
| **06000** | **Scheuchzerio-Caricetea nigrae** | **Small sedge nonacidic mires and moist tundra** | |
| 06010 | Dryado integrifoliae-Caricetum bigelowii | Mesic to subhygric, nonacidic, uplands foothills | Walker et al. 1994 |
| 06011 | Eriophorum triste-Dryas integrifolia comm. | Mesic to subhygric, nonacidic, uplands coastal plain | Walker 1985 |
| 06012 | Trichophorum caespitosum-Tomentypnum nitens comm. | Subhygric hummocks in fens | Walker pers. comm. |
| 06020 | Sphagnum orientale-Eriophorum scheuchzeri comm | Hygric, acidic, poor fens | Walker et al. 1994 |
| 06030 | Eriophorum angustifolium-Carex aquatilis comm | Hygric, non-acidic fens | Walker et al. 1994 |
| 06031 | Carex aquatilis-Saxifraga cernua | Mesic to subhygric acidic coastal uplands, Barrow | Elias et al. 1996 |
| 06032 | Eriophorum angustifolium-Carex aquatilis-Calliergon sarmentosum comm. | Hygric, acidic, poor fens, coastal areas, Barrow | Elias et al. 1996 |
| 06033 | Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius comm | Hygric, non-acidic fens, coastal plain, Prudhoe Bay | Walker 1985, Elias et al. 1995 |
| 06040 | Carex aquatilis-Carex chordorrhiza comm. | Subhygric to hygric, nonacidic fens | Walker et al. 1994 |
| 06050 | Hippuris vulgaris-Arctophila fulva comm. | Hydric, marshes, pond margins | Walker et al. 1994 |
| **07000** | **Potametea** | **Rooted water-plant communities** | |
| 07010 | Hippuris vulgaris-Sparganium hyperboreum comm. | Hydric, ponds and lake margins | Walker et al. 1994 |
| **08000** | **Juncetea maritimi** | **Coastal shore shallow water communities** | |
| 08010 | Caricetum subspathacea | Hygric, saline, tidal areas | Hadac 1946, Walker et al. 1980 |
| **09000** | **Betulo-Adenostyletea** | **Tall perrenial herb and shrub communities** | |
| 09010 | Salix alaxensis-Salix lanata comm. | Riparian, calcareous shrublands | Walker et al. 1994 |
| 09011 | Epilobium latifolium-Artemisia arctica comm | Riparian, coastal, depauperate | Walker 1985 |
| 09020 | Eriophorum angustifolium-Salix planifolia ssp. pulchra comm. | Riparian, noncalcareous shrublands | Walker et al. 1994 |
| 09030 | Alnus crispa- | Subalpine alder thickets, Kobuk Valley | Racine 1976 |
| 09031 | Alnus crispa-Carex bigelowii | Alder savannas | Racine 1976 |
| **10000** | **Miscellaaeous communities and other** | | |
| 10010 | Anthelia juratzkana-Juncus biglumis comm. | Acidic nonsorted circles | Walker et al. 1994 |
| 10020 | Saxifraga oppositifolia-Juncus biglumis comm. | Nonacidic nonsorted circles | Walker et al. 1985 |
| 10030 | Picea glauca-Betula papyifera | Upland forests, Canadian border | |
| 10040 | Picea glauca-Betula nana | Noatak River | Young 1973 |
| 11000 | Barren | | |
| 12000 | Water | | |
| 13000 | Ice | | |

## LOOK-UP TABLE 2. PLANT-COMMUNITY PROPERTIES IN EACH SUBZONE.

**Column 1. Plant community codes (from Look-up Table 1).**

**Columns 2-4. Plant functional types (examples).** Dominant secondary and tertiary PFTs are listed if they normally occupy >30% of the plant cover.

01 Evergreen needleleaf tree (*Picea glauca*)
02 Deciduous broadleaf tree (*Populus balsamifera*)
03 Deciduous needleaf tree (*Larix laricina*)
04 Low to tall evergreeen shrub (>50 cm) (*Pinus pumila*)
05 Low to tall deciduous shrub (>50 cm) (*Alnus crispa, Betula , Salix*)
06 Dwarf evergreen shrub (3-50 cm) (*Cassiope, Ledum, Empetrum, Vaccinium vitis-idaea*

07 Dwarf deciduous shrub (3-50 cm) (*V. uliginosum*, many *Salix*, *Artemisia*)
08 Prostrate evergreen shrub (mat forming, <3 cm) (*Dryas*, *Loiseleuria*)
09 Prostrate deciduous shrub (mat forming, <3 cm) (*Salix arctica*, *Arctous alpina*, *S. polaris*, *S. ovalifolia*)
10 Wet graminoids (*Carex aquatilis*, *Eriophorum angustifolium*, *Arctophila*)
11 Dry graminoids (*Hierochloë alpina*, *Carex rupestris*, *Luzula confusa*)
12 Cushion and rosette forbs (*Saxifraga*, *Draba*, *Silene*, *Papaver*)
13 Other forbs (*Pedicularis*, *Astragalus*, *Eutrema*)
14 True mosses and liverworts (*Bryum*, *Dicranum*, *Tomenthypnum*, *Calliergon*, *Ptilidium* )
16 *Sphagnum*
17 Crustose lichens and bryophytes (*Rhizocarpon*, *Lecanora*, *Lecidea*)
18 Foliose and fruticose lichens (*Thamnolia*, *Cladonia*, *Peltigera*)
19 Tussock graminoids (*Eriophorum vaginatum*, *Deschampsia caespitosa*)
20 Aquatic forbs (*Sparganium*, *Potomogeton*, *Menyanthes trifoliata*)

**Columns 5-7. Horizontal structure for the plant community within each subzone**

1 Barren, very limited, 0-5% cover of plants
2 Open patchy vegetation, scattered clusters of vegetation, 5-50% cover of plants
3 Interrupted closed vegetation, closed vegetation canopy with patches of bare soil, 50-80% cover of planta
4 Closed canopy, 80-100% cover of plants

**Columns 8-10. Total biomass for the plant community within each subzone (aboveground and belowground, g m$^{-2}$ (Bliss and Matveyeva, 1992; Gilmanov, 1997; Shaver, et al., 1997).**

1 0-100 (polar deserts)
2 100-500 (polar semidesert, high arctic mires)
3 500-750 (low arctic mires)
4 750-2000 (tussock tundra)
5 2000-4000 (low shrublands)
6 4000-10,000 (tall shrublands

**Columns 11-13. Net primary production for the plant community within each subzone (aboveground and belowground, g m$^{-2}$) (Bliss and Matveyeva, 1992; Gilmanov, 1997; Shaver, et al., 1997).**

1 0-20 (polar desert, barrens)
2 20-50 (dry tundra, polar semi desert)
3 50-150 (high arctic mires, northern tussock tundra, MNT)
4 150-250 (low arctic mires, southern tussock tundra)
5 250-1000 (low-shrub tundra)
6 >1000 (tall shrublands, forest tundra)

**Look-up Table 2.**

| Veg | Plant functional types | | | Horizontal Structure | | | Total Biomass (g/m2) | | | Net Primary Production (g/m2/y) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | 1 | 2 | 3 | Subzone2 | Subzone3 | Subzone4 | Subzone2 | Subzone3 | Subzone4 | Subzone2 | Subzone3 | Subzone4 |
| **01000** | | | | | | | | | | | | |
| 01010 | 18 | 17 | | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| **02000** | | | | | | | | | | | | |
| 02010 | 8 | 17 | 12 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| 02011 | 8 | 17 | 12 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| 02012 | 8 | 17 | 12 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| 02020 | 6 | 18 | 8 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| **03000** | | | | | | | | | | | | |
| 03010 | 9 | 18 | 6 | na | 4 | 4 | na | 2 | 2 | 2 | 2 | 2 |
| 03020 | 7 | 18 | | na | na | 3 | na | na | 3 | na | na | 3 |
| 03030 | 6 | 18 | 11 | na | na | 4 | na | | 2 | na | na | 2 |
| **04000** | | | | | | | | | | | | |
| 04010 | 9 | | | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 2 | 2 |
| **05000** | | | | | | | | | | | | |
| 05010 | 7 | 19 | 6 | 3 | 4 | 4 | 3 | 3 | 4 | 3 | 3 | 4 |
| 05011 | 19 | 6 | 7 | 3 | 4 | na | 3 | 3 | na | 3 | 3 | na |
| 05020 | 7 | 6 | 19 | na | na | 4 | na | na | 5 | na | na | 4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05030 | 10 | 16 | 7 | na | 4 | 4 | na | 3 | 3 | na | 4 | 5 |
| **06000** | | | | | | | | | | | | |
| 06010 | 11 | 8 | 14 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 |
| 06011 | 11 | 8 | 14 | 2 | na | na | 2 | na | na | 3 | na | na |
| 06012 | 19 | 14 | 6 | na | na | 4 | na | na | 3 | na | na | 3 |
| 06020 | 10 | 16 | | na | na | 3 | na | na | 2 | na | na | 3 |
| 06030 | 10 | 14 | | 3 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 3 |
| 06031 | 10 | 14 | 13 | 3 | na | na | 2 | na | na | 2 | na | na |
| 06032 | 10 | 14 | | 3 | na | na | 2 | na | na | 2 | na | na |
| 06033 | 10 | 14 | | 3 | 3 | 4 | 2 | 3 | 3 | 2 | 3 | 3 |
| 06040 | 10 | 14 | | na | 3 | 4 | na | 3 | 3 | na | 3 | 3 |
| 06050 | 10 | 20 | 14 | | 2 | 2 | 2 | 3 | 3 | 2 | 3 | 3 |
| **07000** | | | | | | | | | | | | |
| 07010 | 20 | 14 | | na | 2 | 2 | na | 3 | 3 | na | 3 | 3 |
| **08000** | | | | | | | | | | | | |
| 08010 | 10 | | | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| **09000** | | | | | | | | | | | | |
| 09010 | 5 | 13 | | na | 3 | 4 | na | 4 | 5 | na | 4 | 5 |
| 09011 | 13 | | | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 2 |
| 09020 | 5 | 10 | 16 | na | 3 | 4 | na | 4 | 5 | na | 4 | 5 |
| 09030 | 5 | | | na | na | 4 | na | na | 6 | na | na | 6 |
| 09031 | 5 | 11 | 7 | na | na | 4 | na | na | 5 | na | na | 5 |
| **10000** | | | | | | | | | | | | |
| 10010 | 17 | 11 | | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 |
| 10020 | 12 | 17 | 11 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 |
| 10030 | 1 | 5 | | na | na | 4 | na | na | 6 | na | na | 5 |
| 10040 | | | | | | | | | | | | |
| 11000 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12000 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 01300 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**LOOK-UP TABLE 3. PRIMARY, SECONDARY, AND TERTIARY PLANT COMMUNITIES WITHIN EACH SUBZONE/SUBPROVINCE/VEGETATION-COMPLEX COMBINATION.** Veg1, Veg2, and Veg3 are primary, secondary, and tertiary plant communities. Secondary and tertiary communities are listed if they normally cover more than 30% of a vegetation complex. Refer to Look-up Table 1, column 1 (above) for list of vegetation codes.

**Column 1. Phytogeographic subzones. Based on Yurtsev (1994)**

| *Code* | *Yurtsev subzone* |
|---|---|
| 1 | High Arctic Tundra (Rosette-forb, lichen, moss subzone) |
| 2 | Arctic Tundra (Prostrate shrub, herb subzone) |
| 3 | Northern Hypoarctic (Sedge, dwarf-shrub subzone) |
| 4 | Southern Hypoarctic (Low-shrub subzone) |

**Column 2. Floristic subprovinces (Yurtsev 1994)**

| *Code* | *Floristic subprovince* |
|---|---|
| 1 | Northern Alaska |
| 2 | Beringian Alaska |

**Column 3. Vegetation complexes**

| *New Code* | *Code on example map* | *Description* |
|---|---|---|
| ***Mountains*** | | |
| 1 | 1 | Acidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation |
| 2 | 2 | Nonacidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation |
| 3 | None | Acidic plateau, basin, or plain complex |
| 4 | None | Nonacidic plateau, basin, or plain complex |

| | | |
|---|---|---|
| 5 | 8 and 10a | Glaciated valley and moraine complex |
| ***Hills*** | | |
| 6 | 4 | Acidic hill complex with rare bedrock outcrops |
| 7 | 5 | Acidic hill complex with occasional bedrock outcrops |
| 8 | 6 | Nonacidic hill complex with rare bedrock outcrops |
| 9 | 7 | Nonacidic hill complex with occasional bedrock outcrops |
| 10 | 3 | Low- to high-shrub tundra complex on uplands |
| 11 | 3a | Subalpine shrubland complex |
| 12 | 17 | Mixed evergreen and deciduous forest on uplands (border area with Canada) |
| ***Riparian areas*** | | |
| 13 | 10 | River floodplain complex |
| 14 | 16 | Bottomland evergreen forest complex |
| 15 | none | Bottomland deciduous forest complex |
| ***Wetlands*** | | |
| 16 | 11 | Acidic mire complex, <25% lakes |
| 17 | 12 | Acidic mire complex, 25-75% lakes |
| 18 | 13 | Nonacidic mire complex, <25% lakes |
| 19 | 14 | Nonacidic mire complex 25-75% lakes |
| 20 | 15 | Coastal mire complex (saline) |
| ***Water and glaciers*** | | |
| 21 | 18 | Water or lake complex (>75% water cover) |
| 22 | 19 | Glacier complex (>75% glacier cover) |

## Look-up Table 3.

| Subzone | Subprovince | Veg. Complex | Veg1 | Veg2 | Veg3 |
|---|---|---|---|---|---|
| 1 | 1 | 1 | na | na | na |
| 1 | 1 | 2 | na | na | na |
| 1 | 1 | 3 | na | na | na |
| 1 | 1 | 4 | na | na | na |
| 1 | 1 | 5 | na | na | na |
| 1 | 1 | 6 | 05011 | 10010 | |
| 1 | 1 | 7 | na | na | na |
| 1 | 1 | 8 | 06011 | 10020 | |
| 1 | 1 | 9 | na | na | na |
| 1 | 1 | 10 | na | na | na |
| 1 | 1 | 11 | na | na | na |
| 1 | 1 | 12 | na | na | na |
| 1 | 1 | 13 | 09011 | 06011 | 11000 |
| 1 | 1 | 14 | na | na | na |
| 1 | 1 | 15 | na | na | na |
| 1 | 1 | 16 | 06032 | 06031 | |
| 1 | 1 | 17 | 06032 | | |
| 1 | 1 | 18 | 6033 | 06031 | |
| 1 | 1 | 19 | 06033 | 12000 | 06011 |
| 1 | 1 | 20 | 08010 | 12000 | 11000 |
| 1 | 1 | 21 | 01200 | 06030 | |
| 1 | 1 | 22 | na | na | na |
| 2 | 1 | 1 | na | na | na |
| 2 | 1 | 2 | 02010 | 11000 | 02020 |
| 2 | 1 | 3 | na | na | na |
| 2 | 1 | 4 | na | na | na |
| 2 | 1 | 5 | na | na | na |
| 2 | 1 | 6 | 05011 | | |
| 2 | 1 | 7 | na | na | na |

| | | | | | |
|---|---|---|---|---|---|
| 2 | 1 | 8 | 06010 | 10020 | |
| 2 | 1 | 9 | 06010 | 02010 | |
| 2 | 1 | 10 | na | na | na |
| 2 | 1 | 11 | na | na | na |
| 2 | 1 | 12 | na | na | na |
| 2 | 1 | 13 | 09010 | 06101 | |
| 2 | 1 | 14 | na | na | na |
| 2 | 1 | 15 | na | na | na |
| 2 | 1 | 16 | 06040 | 05011 | |
| 2 | 1 | 17 | 06040 | 12000 | 05011 |
| 2 | 1 | 18 | 06033 | 06011 | |
| 2 | 1 | 19 | 06033 | 12000 | 06011 |
| 2 | 1 | 20 | 08010 | 12000 | 11000 |
| 2 | 1 | 21 | 12000 | 06030 | |
| 2 | 1 | 22 | na | na | na |
| 2 | 2 | 1 | 02010 | 11000 | 03030 |
| 2 | 2 | 2 | 02010 | 11000 | 02020 |
| 2 | 2 | 3 | na | na | na |
| 2 | 2 | 4 | na | na | na |
| 2 | 2 | 5 | 06010 | 03010 | 02020 |
| 2 | 2 | 6 | 05011 | 10010 | |
| 2 | 2 | 7 | 05011 | 02011 | |
| 2 | 2 | 8 | 06010 | 10020 | |
| 2 | 2 | 9 | 06010 | 02010 | |
| 2 | 2 | 10 | na | na | na |
| 2 | 2 | 11 | na | na | na |
| 2 | 2 | 12 | na | na | na |
| 2 | 2 | 13 | 09010 | 06010 | 11000 |
| 2 | 2 | 14 | na | na | na |
| 2 | 2 | 15 | na | na | na |
| 2 | 2 | 16 | 06040 | 05011 | |
| 2 | 2 | 17 | 06040 | 12000 | 05011 |
| 2 | 2 | 18 | 06033 | 06011 | |
| 2 | 2 | 19 | 06033 | 12000 | 06011 |
| 2 | 2 | 20 | 08010 | 12000 | 11000 |
| 2 | 2 | 21 | 12000 | 06030 | |
| 2 | 2 | 22 | na | na | na |
| 3 | 1 | 1 | 02010 | 11000 | 03030 |
| 3 | 1 | 2 | 02010 | 11000 | 02020 |
| 3 | 1 | 3 | na | na | na |
| 3 | 1 | 4 | na | na | na |
| 3 | 1 | 5 | 06010 | 03010 | 02020 |
| 3 | 1 | 6 | 05010 | 09020 | |
| 3 | 1 | 7 | 06010 | 10020 | 02010 |
| 3 | 1 | 8 | 06010 | 10020 | |
| 3 | 1 | 9 | 06010 | 02010 | |

| | | | | | |
|---|---|---|---|---|---|
| 3 | 1 | 10 | 05020 | 09031 | 09020 |
| 3 | 1 | 11 | na | na | na |
| 3 | 1 | 12 | 10030 | | |
| 3 | 1 | 13 | 09010 | 06010 | 11000 |
| 3 | 1 | 14 | na | na | na |
| 3 | 1 | 15 | na | na | na |
| 3 | 1 | 16 | 06040 | 06020 | 05010 |
| 3 | 1 | 17 | 06040 | 12000 | 05010 |
| 3 | 1 | 18 | 06030 | 06012 | |
| 3 | 1 | 19 | 06040 | 12000 | 06012 |
| 3 | 1 | 20 | na | na | na |
| 3 | 1 | 21 | 12000 | 05010 | |
| 3 | 1 | 22 | 13000 | | |
| 3 | 2 | 1 | 02010 | 11000 | 03030 |
| 3 | 2 | 2 | 02010 | 11000 | 02020 |
| 3 | 2 | 3 | na | na | na |
| 3 | 2 | 4 | na | na | na |
| 3 | 2 | 5 | 06010 | 03010 | 02020 |
| 3 | 2 | 6 | 05010 | 09020 | |
| 3 | 2 | 7 | 05010 | 09020 | 02010 |
| 3 | 2 | 8 | 06010 | 10020 | |
| 3 | 2 | 9 | 06010 | 02010 | |
| 3 | 2 | 10 | 05020 | 09031 | 09020 |
| 3 | 2 | 11 | 09030 | | |
| 3 | 2 | 12 | na | na | na |
| 3 | 2 | 13 | 09010 | 06010 | 11000 |
| 3 | 2 | 14 | 10040 | | |
| 3 | 2 | 15 | na | na | na |
| 3 | 2 | 16 | 06040 | 06020 | 05010 |
| 3 | 2 | 17 | 06040 | 12000 | 05010 |
| 3 | 2 | 18 | 06030 | 06012 | |
| 3 | 2 | 19 | 06040 | 12000 | 06020 |
| 3 | 2 | 20 | 08011 | | |
| 3 | 2 | 21 | 12000 | 05010 | |
| 3 | 2 | 22 | na | na | na |

**Step 6, derived maps**

The IVCM (map 12) and PFM (map 10) are overlaid in a GIS with reference to Look-up Table 3 to derive a map of all the vegetation complex/subzone/subprovince combinations (map 14, Fig. 8). Separate maps are prepared for each theme (PFTs, horizontal structure, biomass, and production), by reference to the look-up tables (maps 16-20, Figs. 9-12).

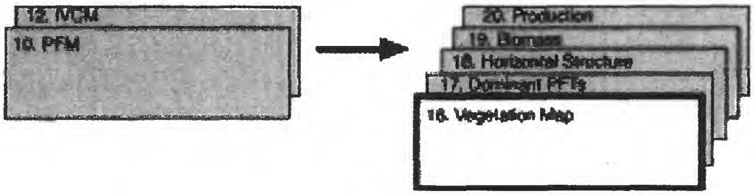


*Figure 7. Making of the final map and other derived maps.*

## Legends for derived maps:

**16. Vegetation:** Dominant plant communities within each Subzone/ Vegetation-Complex combination. Note: there are currently insufficient vegetation data to describe vegetation differences between the floristic subprovinces in northern Alaska, so the Northern Alaska and Beringian Alaska subprovinces have been combined.

| *Subzone* | ***Subprovince*** | ***Vegetation complex*** | ***Common plant communities (primary, secondary, and tertiary)*** |
|---|---|---|---|
| | | **Riparian areas:** | |
| Arctic tundra (2) | Northern Alaska (1) | River floodplain complex (13) | *Epilobium latifolium-Artemisia arctica* comm (gravel bars), *Eriophorum triste-Dryas integrifolia* comm. (moist stable terraces), barrens (active channels) |
| | | **Wetlands:** | |
| | | Acidic mire complex, <25% lakes (16) | *Eriophorum angustifolium-Carex aquatilis-Calliergon sarmentosum* comm. (wet sites), *Carex aquatilis-Saxifraga cernua* comm. (moist sites) |
| | | Acidic mire complex, 25-75% lakes (17) | *Eriophorum angustifolium-Carex aquatilis-Calliergon sarmentosum* comm. (wet sites), water |
| | | Nonacidic mire complex, <25% lakes (18) | *Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), *Carex aquatilis-Saxifraga cernua* comm. (moist sites) |
| | | Nonacidic mire complex 25-75% lakes (19) | *Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), water (lakes), *Eriophorum triste-Dryas integrifolia* comm. (moist sites) |
| | | Coastal mire complex (saline) (20) | *Caricetum subspathacea* (wet saline), water (lakes), barrens (coastal mud flats) |
| | | **Hills:** | |
| Northern hypoarctic tundra (3) | Northern Alaska and Beringian Alaska (1,2) | Acidic hill complex with rare bedrock outcrops, no vertical zonation (6) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (water tracks, raised areas in colluvial basins), *Sphagnum orientale-Eriophorum scheuchzeri* comm (poor fens in colluvial basins) |
| | | Acidic hill complex with occassional bedrock outcrops (7) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Selaginello sibiricae-Dryadetum octopetalae* (ridge crests) |
| | | Nonacidic hill complex with rare bedrock outcrops, no vertical zonation (8) | *Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Saxifraga oppositifolia-Juncus biglumis* comm. (nonsorted circles) |
| | | **Riparian areas** | |
| | | River floodplain complex (19) | *Epilobio latifolii-Salicetum alaxensis* (river margins); *Salico glaucae-Salicetum lanatae* (river terraces), *Dryado integrifoliae-Caricetum bigelowii* (older terraces), barrens (active channels) |
| | | **Wetlands:** | |
| | | Acidic mire complex, <25% lakes (16) | *Carex aquatilis-Carex chordorrhiza* comm. (wet sites), *Sphagno-Eriophoretum vaginati* typicum (moist sites) |
| | | Acidic mire complex, 25-75% lakes (17) | *Carex aquatilis-Carex chordorrhiza* comm. (wet sites), water (lakes), *Sphagno-Eriophoretum vaginati* typicum (moist sites) |
| | | Nonacidic mire complex, <25% lakes (18) | *Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), *Eriophorum triste-Dryas integrifolia* comm. |

| | | | |
|---|---|---|---|
| | | Nonacidic mire complex 25-75% lakes (19) | *Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), water (lakes), *Eriophorum triste-Dryas integrifolia* comm. |
| | | Coastal mire complex (saline) (20) | *Caricetum subspathacea* (wet saline), water (lakes), barrens (coastal mud flats) |
| | | **Mountains:** | |
| Southern Hypoarctic (4) | Northern Alaska a 2 Beringian Alask (1, 2) | Acidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation (1) | *Vaccinio uliginosi-Salicetum phlebophllae* (ridge tops, south-facing slopes), barrens (bedrock and rubble), *Carici microchaetae-Cassiopetum tetragonae* (acidic snowbeds), *Carici microchaetes-Cladonietum stellaris* (high elevation lichen heaths) |
| | | Nonacidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation (2) | *Caricetum scirpoideo-rupestris* (south-facing slopes), barrens (bedrock and rubble), *Boykinio richardsonii-Dryadetum alaskensis*. (snowbeds) |
| | | Acidic plateau, basin, or plain complex (3) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Selaginello sibiricae-Dryadetum octopetalae* (ridge crests) |
| | | Nonacidic plateau, basin, or plain complex (4.) | *Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Selaginello sibiricae-Dryadetum octopetalae* (ridge crests) |
| | | Glaciated valley and moraine complex (5) | *Dryado integrifoliae-Caricetum bigelowii* (mesic colluvium), *Salici phlebophyllae-Arctoetum alpinae* (moraine and kames crests), *Dryas integrifolia-Cassiope tetragona* comm. (snowbeds) |
| | | **Hills** | |
| | | Acidic hill complex with rare bedrock outcrops, no vertical zonation (6) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (water tracks, raised areas in colluvial basins), *Sphagnum orientale-Eriophorum scheuchzeri* comm (poor fens in colluvial basins) |
| | | Acidic hill complex with occassional bedrock outcrops (7) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (water tracks, raised areas in colluvial basins), *Selaginello sibiricae-Dryadetum octopetalae* (ridge tops and south facing slop es) |
| | | Noncidic hill complex with rare bedrock outcrops, no vertical zonation (8) | *Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Saxifraga oppositifolia-Juncus biglumis* comm. (nonsorted circles) |
| | | Noncidic hill complex with occassional bedrock outcrops, no vertical zonation (9) | *Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Saxifraga oppositifolia-Juncus biglumis* comm. (nonsorted circles), *Selaginello sibiricae-Dryadetum octopetalae* (ridge tops and south facing slopes) |
| | | Low- to high-shrub tundra complex on uplands (10) | *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (shrub tundra), *Alnus crispa-Carex bigelowii* (alder savannas), *Eriophorum angustifolium-Salix planifolia* ssp. *pulchra* comm. (water tracks) |
| | | Subalpine shrublands (11) | *Alnus crispa* (subalpine alder shrublands), barrens (active river channels) |
| | | **Riparian areas** | |
| | | River floodplain complex (13) | *Epilobio latifolii-Salicetum alaxensis* (river margins); *Salico glaucae-Salicetum lanatae* (river terraces), *Dryado integrifoliae-Caricetum bigelowii* (older terraces), barrens (active channels) |
| | | Bottomland evergreen forest complex (14) | *Picea glauca-Betula nana* (moderately drained sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (shrub tundra), *Eriophorum angustifolium-Carex aquatilis* comm. (wetlands) |
| | | **Wetlands** | |
| | | Acidic mire complex, <25% lakes (16) | *Carex aquatilis-Carex chordorrhiza* comm. (wet sites), *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (raised sites in colluvial basins), |
| | | Acidic mire complex, 25-75% lakes (17) | *Carex aquatilis-Carex chordorrhiza* comm. (wet sites), water (lakes), *Sphagno-Eriophoretum vaginati* typicum |

| | |
|---|---|
| | (moist sites) |
| Nonacidic mire complex, <25% lakes (18) | *Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), *Dryado integrifoliae-Caricetum bigelowii* (moist sites) |
| Nonacidic mire complex 25-75% lakes (19) | *Eriophorum angtustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), water (lakes), *Eriophorum triste-Dryas integrifolia* comm. |
| Coastal mire complex (saline) (20) | *Caricetum subspathacea* (wet saline), water (lakes), barrens (coastal mud flats) |
| **Other** | |
| Water complex (>75% water cover) (21) | |
| Glacier complex (>75% glacier cover) (22) | |

**17. Dominant plant functional types (See Look-up Table 2, col. 2-4.)**

**18. Horizonatal structure (See Look-up Table 2, col. 5-7.)**

**19. Biomass (aboveground and belowground, g m$^{-2}$) (See Look-up Table 2, col. 8-10.)**

**20. Primary production (aboveground and belowground, g m$^{-2}$) (See Look-up Table 2, col. 11-13.)**

**Geobotanical maps.** Maps portraying the separate geobotanical attributes that went into the Integrated Vegetation-Complex Map (IVCM) can also be prepared (Walker, et al., 1980). A coding sheet (not shown) is prepared with a list of all the polygon ID numbers, and columns corresponding to each geobotanical attribute attribute (surficial geology, bedrock geology, soils, percent water). The polygon ID map (map 12a except with polygon ID numbers) is overlaid on a given adjusted source map (e.g. surficial geology, map 6a) and the attribute code corresponding to each polygon on IVCM is entered on the data sheet. This procedure is repeated for all the geobtonical attributes. This information is then keypunched. This data file, in combination with the file containing the topological information for each polygon, makes up the basic GIS database. Separate maps can be prepared for any one of the attributes, or complex models can be made utilizing information from several attributes. The maps should be checked against the original source information.

## RESULTS

The preliminary vegetation map for northern Alaska is shown in Figure 8. Figures 9-12 show the maps for dominant plant functional types, horizontal structure, biomass, and production.

## CONCLUDING REMARKS

(1) It should be possible to reduce the number of subzone/subprovince/vegetation-complex combinations by creative use of colors. It is recommended that the primary color refer to the dominant vegetation of the vegetation complex and that shades of the colors represent variations related to north-south zonation. East-west variation related to floristic-province differences could be shown by patterns overlaid on the the colors or with the use of letters.

(2) Within Alaska, there was insufficient literature to determine differences in plant communities related to floristic subprovinces. This may be generally true throughout the Arctic, and CAVM editorial board may want to consider portraying only the variation due to 6 floristic provinces instead of the 21 subprovinces.

(3) For consistency, the members of the CAVM project need to agree on the basic set of landscape units and vegetation complexes that will be mapped. It should be expected

that additional terrain units and vegetation complexes will be required in other geographic regions as the mapping proceeds.

(4) We need to thoroughly discuss whether this method is feasible for all members of the CAVM working group. There are some potential pitfalls related to using GIS methods if not everyone is familiar with these techniques, but there are also large benefits including the ability to produce a wide variety of derived maps and the flexibility of the database for modeling purposes.

(5) This method should allow us to begin work immediately without first finalizing the ultimate vegetation legend. Considering the current disagreement regarding vegetation mapping units, an approach based primarily on mapping landscape units first seems like the best alternative. By using the vegetation complexes and look-up tables, each country can proceed with mapping using their own local source maps. The properties of the vegetation, which is what most users will be interested in, are contained in the look-up tables. We can work on the form of the legend for the final map during the coming year, while mapping of vegetation complexes is proceeding.

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## FIGURES

Fig. 1. Existing vegetation map of Alaska (Spetzman, 1959). Arctic areas of the state have four ecosystem types.
Fig. 2. Source maps.
Fig. 3. Simplified source maps adjusted to AVHRR base maps.
Fig. 4. Making the ILUM.
Fig. 5. Preparation of the IVCM and version for digitizing.
Fig. 6. Derivation of look-up tables.
Fig. 7. Making the final vegetation map and other derived maps.
Fig. 8. Vegetation map of northern Alaska derived from the integrated mapping approach.
Fig. 9. Dominant plant functional types in northern Alaska.
Fig. 10. Horizontal structure of the vegetation canopy in northern Alaska.
Fig. 11. Biomass map of northern Alaska.
Fig. 12. Net primary production in northern Alaska.

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# Vegetation

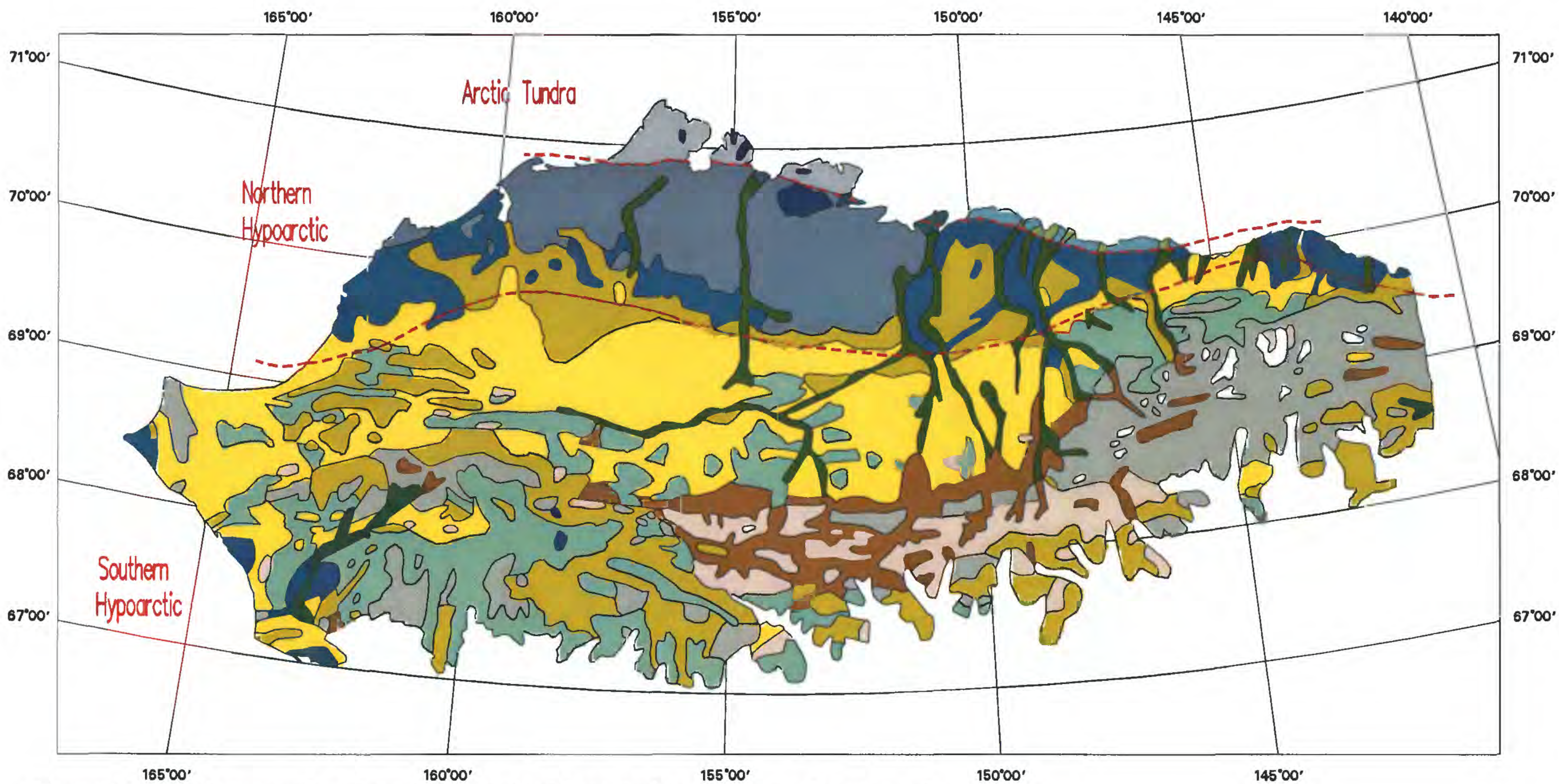



Figure 8. Vegetation map of northern Alaska derived from the integrated mapping approach

| Subzone | Subprovince | Vegetation complex (GIS codes) | Common plant communities (primary, secondary, and tertiary) |
|---|---|---|---|
| Arctic tundra (2) | Northern Alaska (1) | **Riparian areas:** River floodplain complex (13) | *Epilobium latifolium-Artemisia arctica* comm (gravel bars), *Eriophorum triste-Dryas integrifolia* comm. (moist stable terraces), barrens (active channels) |
| | | **Wetlands:** Acidic mire complex (16) | *Eriophorum angustifolium-Carex aquatilis-Calliergon sarmentosum* comm. (wet sites), *Carex aquatilis-Saxifraga cernua* comm. (moist sites) |
| | | Nonacidic mire complex (18) | *Eriophorum angustifolium-Carex aquatilis-Drepanocladus brevifolium* comm. (wet sites), water<br>*Eriophorum angustifolium-Carex aquatilis-Drepanocladus brevifolium* comm. (wet sites), *Carex aquatilis-Saxifraga cernua* comm. (moist sites)<br>*Eriophorum angustifolium-Carex aquatilis-Drepanocladus brevifolium* comm. (wet sites), water (lakes), *Eriophorum triste-Dryas integrifolia* comm. (moist sites) |
| | | Coastal mire complex (saline) (20) | *Caricetum subspathacea* (wet saline), water (lakes), barrens (coastal mud flats) |
| Northern hypoarctic tundra (3) | Northern Alaska and Beringian Alaska (1,2) | **Hills:** Acidic hill complex (6) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (water tracks, raised areas in colluvial basins), *Sphagnum orientale-Eriophorum scheuchzeri* comm. (poor fens in colluvial basins) |
| | | Nonacidic hill complex (8) | *Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Saxifraga oppositifolia-Juncus biglumis* comm. (nonsorted circles) |
| | | **Riparian areas:** River floodplain complex (13) | *Epilobio latifolii-Salicetum alaxensis* (river margins), *Salico glaucae-Salicetum lanatae* (upper terraces), barrens (active channels) |
| | | **Wetlands:** Acidic mire complex (16) | *Carex aquatilis-Carex chordorrhiza* comm. (wet sites), *Sphagno-Eriophoretum vaginati* typicum (moist sites), water (lakes) |
| | | Nonacidic mire complex (18) | *Eriophorum angustifolium-Carex aquatilis-Drepanocladus brevifolium* comm. (wet sites), *Eriophorum triste-Dryas integrifolia* comm., water (lakes) |
| | | Coastal mire complex (saline) (20) | *Caricetum subspathacea* (wet saline), water (lakes), barrens (coastal mud flats) |

Legend to Figure 8



| Subzone | Subprovince | Vegetation complex (GIS codes) | Common plant communities (primary, secondary, and tertiary) |
|---|---|---|---|
| Southern Hypoarctic (4) | Northern Alaska and Beringian Alaska (1,2) | **Mountains:** Acidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation (1) | *Vaccinio uliginosi-Salicetum phlebophyllae* (ridgetops), barrens (bedrock and rubble), *Carici microchaetae-Cassiopetum tetragonae* (acidic snowbeds), *Carici microchaetae-Cladonietum stellaris* (high elevation lichen heaths) |
| | | Nonacidic mountain complex with coarse rubbly deposits, extensive bedrock, and vertical zonation (2) | *Caricetum scirpoides-rupestris* (south-facing slopes), barrens (bedrock and rubble), *Boykinio richardsonii-Dryadetum alaskensis* (snowbeds) |
| | | Glaciated valley and moraine complex (5) | *Dryado integrifoliae-Caricetum bigelowii* (mesic colluvium), *Salici phlebophyllae-Arctoetum alpinae* (moraine and kames crests), *Dryas integrifolia-Cassiope tetragona* comm. (snowbeds) |
| | | **Hills:** Acidic hill complex (6) | *Sphagno-Eriophoretum vaginati* typicum (moist sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (water tracks, raised areas in colluvial basins), *Sphagnum orientale-Eriophorum scheuchzeri* comm. (poor fens in colluvial basins) |
| | | Nonacidic hill complex (8) | *Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Saxifraga oppositifolia-Juncus biglumis* comm. (nonsorted circles)<br>*Dryado integrifoliae-Caricetum bigelowii* (moist sites), *Saxifraga oppositifolia-Juncus biglumis* comm. (nonsorted circles), *Selaginello sibiricae-Dryadetum octopetalae* (ridge tops and south facing slopes) |
| | | Low- to high-shrub tundra complex on uplands and Subalpine shrublands (10) | *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (shrub tundra), *Alnus crispa-Carex bigelowii* (alder savannas), *Eriophorum angustifolium-Salix planifolia* spp. *pulchra* comm. (water tracks), *Alnus crispa* (subalpine alder shrublands), barrens (active river channels) |
| | | **Riparian areas:** River floodplain complex (13) | *Epilobio latifolii-Salicetum alaxensis* (river margins), *Salico glaucae-Salicetum lanatae* (upper terraces), barrens (active channels) |
| | | Evergreen forest complex (14) | *Picea glauca-Betula nana* (moderately drained sites), *Sphagno-Eriophoretum vaginati betuletosum nanae* subass. prov. (shrub tundra), *Eriophorum angustifolium- Carex aquatilis* comm. (wetlands) |
| | | **Wetlands:** Nonacidic mire complex (18) | *Eriophorum angustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), *Dryado integrifoliae-Caricetum bigelowii* (moist sites)<br>*Eriophorum angustifolium-Carex aquatilis-Drepanocladus brevifolius* comm. (wet sites), water (lakes), *Eriophorum triste-Dryas integrifolia* comm. |
| | | Coastal mire complex (saline) (20) | *Caricetum subspathacea* (wet saline), water (lakes), barrens (coastal mud flats) |
| | | **Other:** Water complex (>75% water cover) (21) | |
| | | Glacier complex (>75% glacier cover) (22) | |

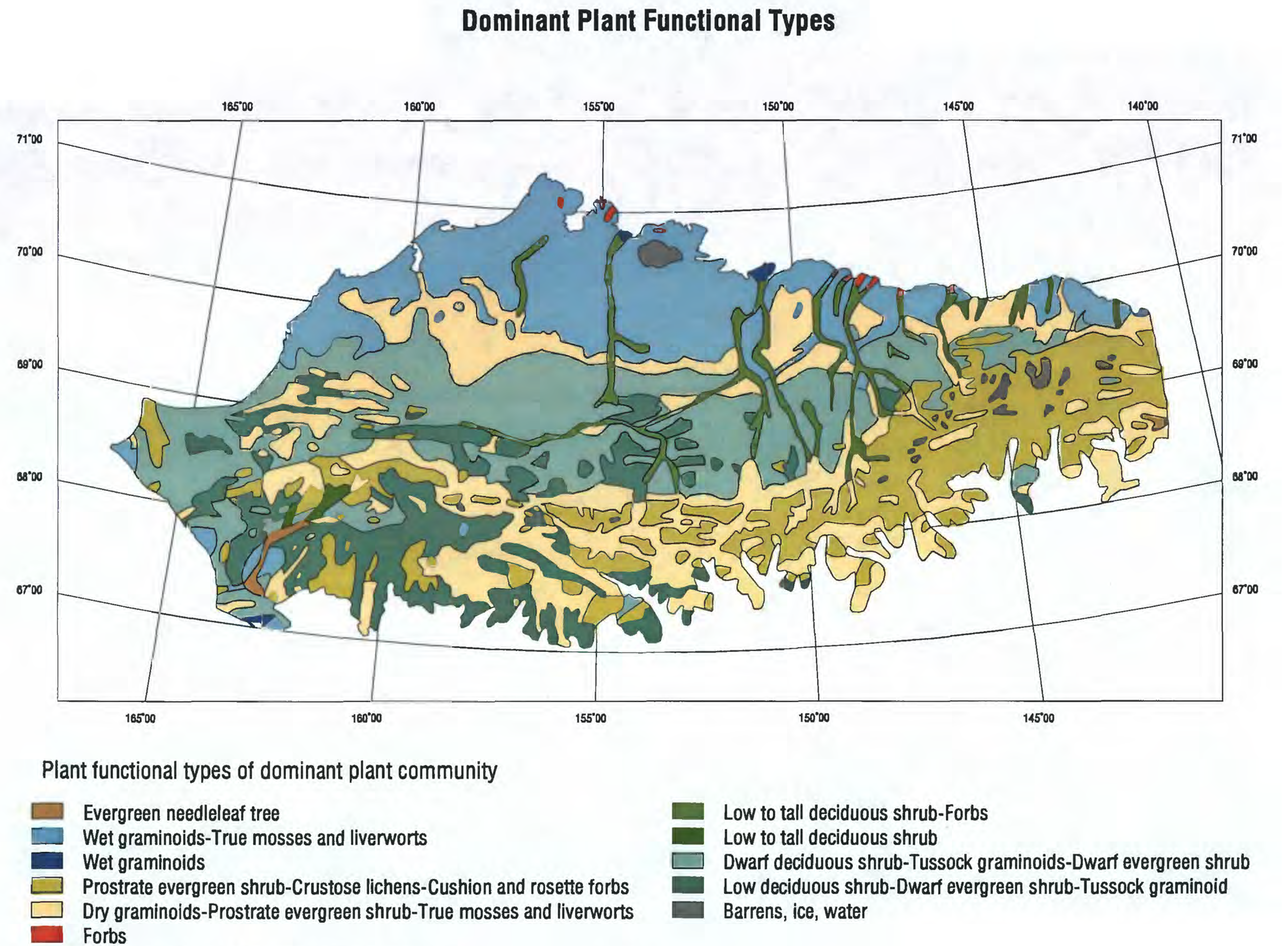
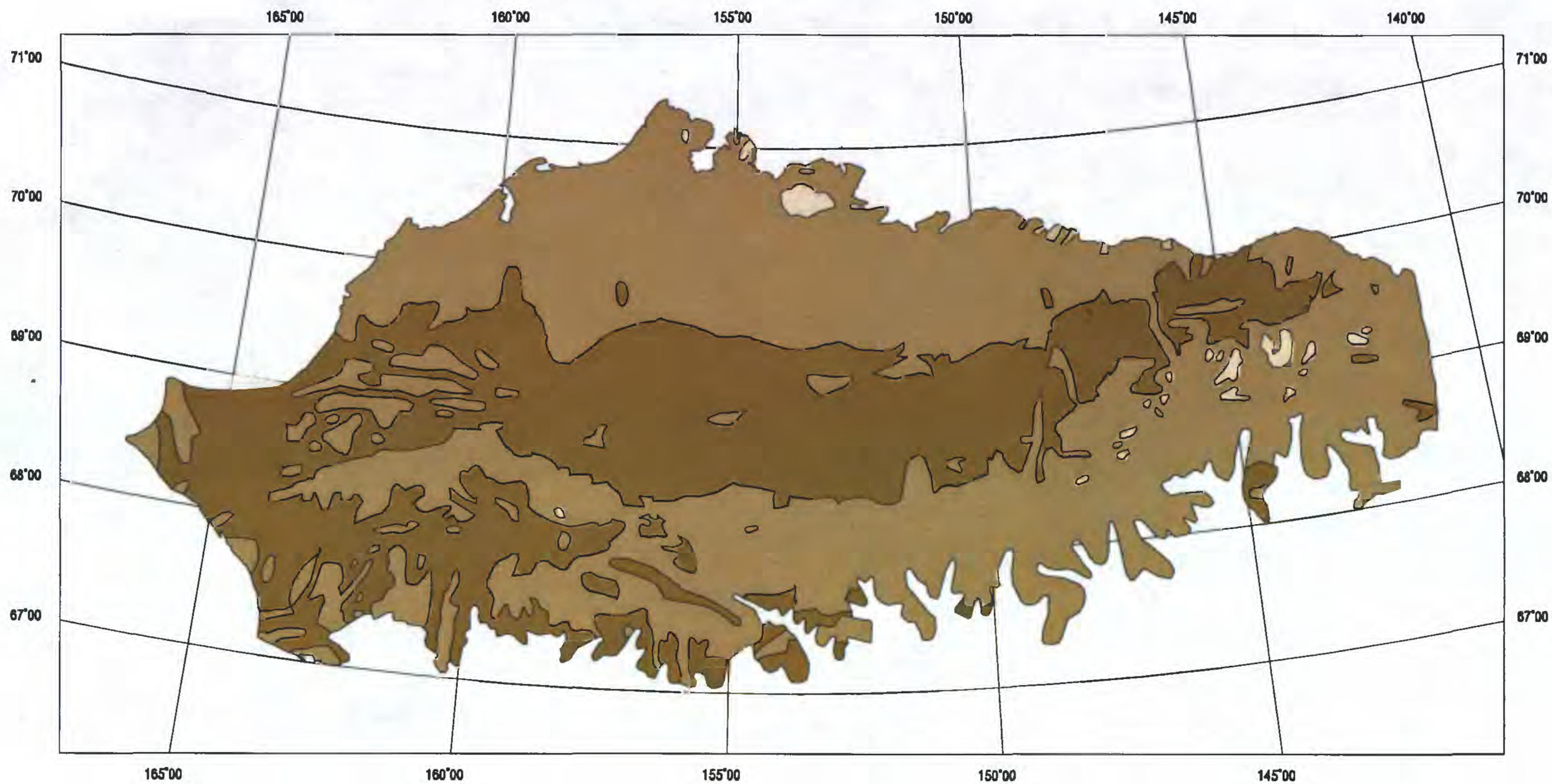


Figure 9. Dominant plant functional types in northern

# Horizontal Structure

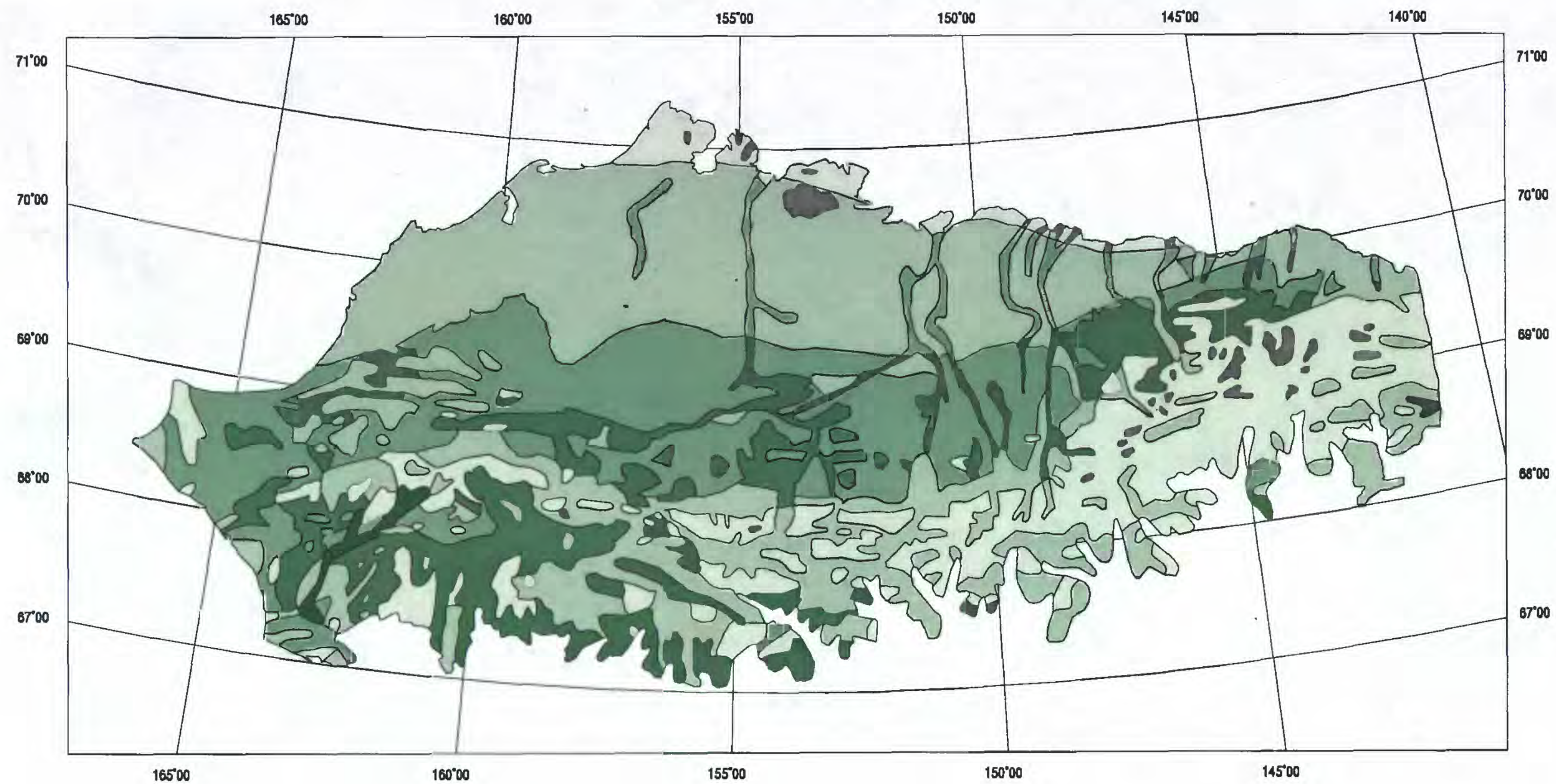



## Horizontal Structure

- Barren, very limited, 0-5% cover of plants
- Open patchy vegetation, scattered clusters of vegetation, 5-50% cover of plants
- Interrupted closed vegetation, closed vegetation canopy with patches of bare soil, 50-80% cover of plants
- Closed canopy, 80-100% cover of plants

Figure 10. Horizontal structure of the vegetation canopy in northern Alaska

# Biomass

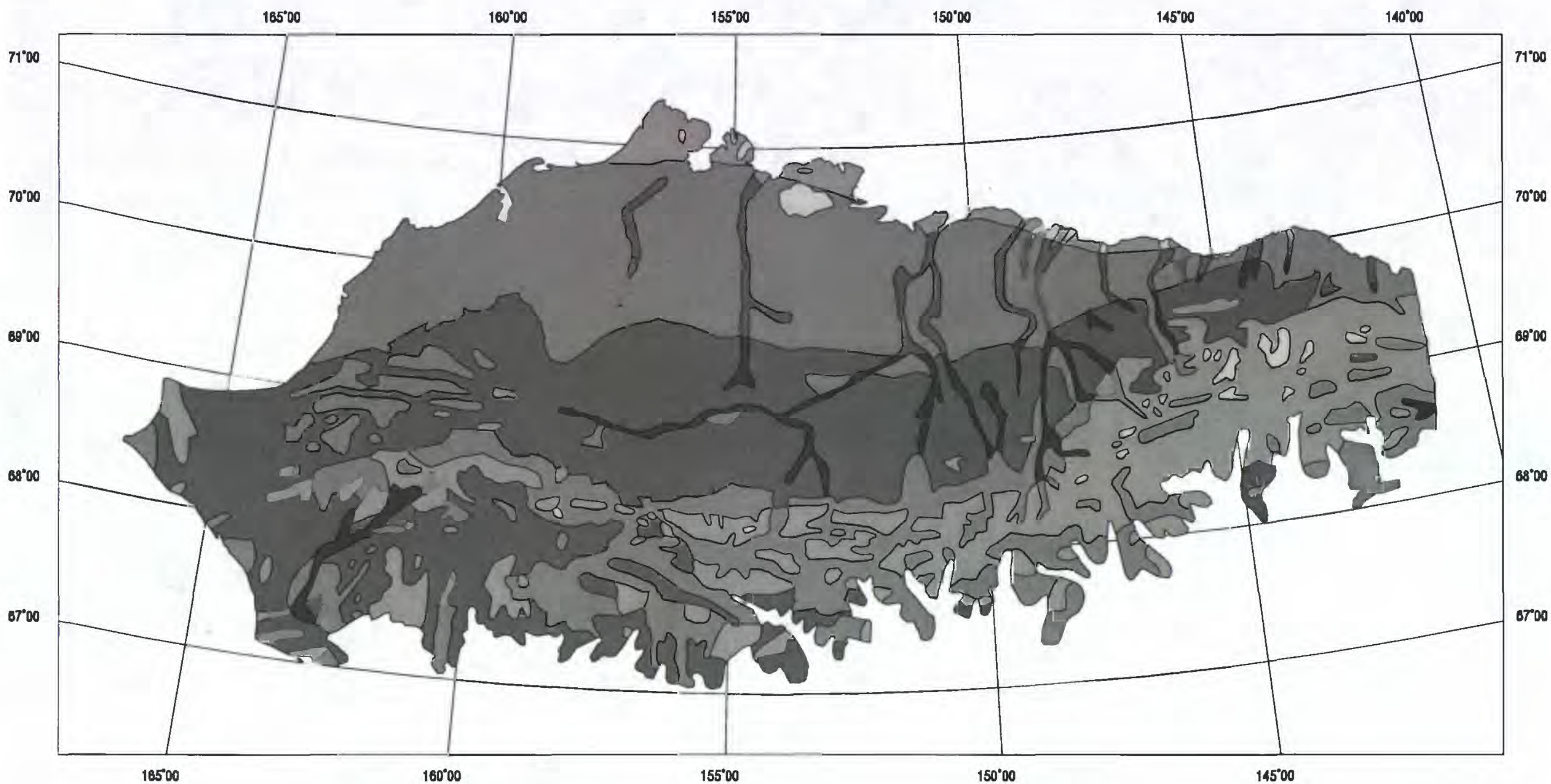



Biomass (aboveground and belowground, g m $^{-2}$ )

- 0-100 (polar deserts, water, ice)
- 100-500 (polar semidesert)
- 500-750 (low arctic mires)
- 750-2000 (tussock tundra)
- 2000-4000 (low shrublands)
- 4000-10000 (tall shrublands)

Figure 11. Biomass map of northern Alaska

# Primary Production




Primary production (aboveground and belowground, g $m^{-2}$)

- 0-20 (polar desert, barrens)
- 20-50 (dry tundra, polar semi desert)
- 50-150 (high arctic mires, northern tussock tundra, MNT)
- 150-250 (low arctic mires, southern tussock tundra)
- 250-1000 (low-shrub tundra)
- >1000 (tall shrublands, forest tundra)

Figure 12. Net primary production in northern Alaska

## 3rd International CAVM Workshop Schedule

June 2
Scheduled Arrival for Participants

June 3

| | |
|---|---|
| 8:00-9:00 | Breakfast |
| 9:00-9:15 | Welcome, history and goals of the 3rd International CAVM Workshop – Skip Walker |
| 9:15-9:30 | Welcome to the USGS EROS Alaska Field Office – Carl Markon |
| 9:30-9:45 | AVHRR Images for Developing a Circumpolar Arctic Vegetation Map – Mike Fleming |
| 9:45-10:15 | An Integrated Vegetation Map for Northern Alaska: A Prototype for Circumpolar Arctic Vegetation Mapping – Skip Walker |
| 10:15-10:45 | Beverage Break |
| 10:45-11:00 | Yukon-Kuskokwim River Delta - Steve Talbot and Carl Markon |
| 11:00-11:15 | Prototype Vegetation Maps for the Canadian Arctic - Bill Gould |
| 11:15-11:45 | Keynote Address: Canadian Arctic Remote Sensing Programs and Their Possible Relevance to the CAVM Project – Helmut Epp |
| 11:45-12:00 | Progress of CAVM Project in Greenland and the Feasibility of the Integrated Geo botanical Mapping Approach for Greenland - Christian Bay and Fred Daniels |
| 12:00-1:30 | Lunch |
| 1:30-2:00 | 1) Is it Possible to Prepare a Remote Sensing Based Bioclimatic Zone Map of Svalbard?<br>2) The Zonal Conception in the Arctic: Its Differences from Vegetation Mapping and its Demands for Criteria - Arve Elvebakk |
| 2:00-2:15 | Progress in Mapping the Vegetation of Iceland Since the CAVM Arendal Worshop - Eythor Einarsson |
| 2:15-2:30 | Possibilities to Apply a Small-Scale Russian Arctic Landscape Map to Circumpolar Vegetation Mapping - Natalia Moskolenko |
| 2:30-2:45 | Approach to Compiling the Russian Part of the Circumpolar Arctic Vegetation Map - Boris Yurtsev, Sergei Kholod, and Adrian Katenin |
| 2:45-3:00 | Progress in Elaboration of the Vegetation Map of East Siberian Arctic - Alexei Polezhaev |
| 3:00-3:30 | Beverage Break |
| 3:30-5:00 | Plenary session: Can the integrated mapping approach be extended to Europe and Asia? Is there a better plan? |
| 6:00-7:30 | Dinner |
| 7:30-9:00 | Poster session, Alaska Field Office<br>Christian Bay and Fred Daniels: Integrated Geobotanical Mapping Approach (Walker, 1997) applied to the Ammassalik area, Southeast Greenland |

| | |
|---|---|
| June 4 | |
| 8:00-9:00 | Breakfast |
| 9:00-12:00 | Making small prototype integrated maps of selected areas |
| 12:00-1:30 | Lunch |
| 1:30-6:00 | Making small prototype integrated maps of selected areas (continued) |
| 6:00-7:30 | Dinner |
| 7:30-9:00 | Slide presentation of everyone's concepts of zonal vegetation in each subzone and floristic subprovince |
| June 5 | |
| 8:00-9:00 | Breakfast |
| 9:00-12:00 | Development of Look-up Tables |
| 12:00-1:30 | Lunch |
| 1:30-3:00 | Development of Look-up Tables (continued) |
| 3:00-5:00 | Plenary session: wrap up, plans for the future |
| 6:00-8:00 | Dinner at Mike Flemings |
| June 6 | |
| 8:00-9:00 | Breakfast - UAA (Pub or Student Center), pick up box lunch for field trip |
| 9:00 | Depart for Nike Missile site |
| 4:00 | Return to UAA |
| 5:30 | Banquet - UAA Cuddy Center |
| June 7 | |
| 8:00-9:00 | Breakfast |
| 9:00-12:00 | Planning for the future |
| 12:00-1:30 | Lunch |
| 1:30-6:00 | Planning for the future (continued) |
| 6:00-7:30 | Dinner |
| June 8 | |
| 8:00 | Breakfast / Departures |