Proceedings of

THE SECOND CIRCUMPOLAR ARCTIC VEGETATION MAPPING WORKSHOP, ARENDAL, NORWAY, 19-24 MAY 1996

and

THE CAVM-NORTH AMERICA WORKSHOP, ANCHORAGE, ALASKA, US, 14-16 JANUARY 1997

Edited by Donald A. Walker and Andrew C. Lillie

CAVM
Circumpolar Arctic Vegetation Map

Occasional Paper No. 52
1997

Institute of Arctic and Alpine Research • University of Colorado

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Sponsored by the National Science Foundation Arctic System Science Program and the Conservation of Arctic Flora and Fauna Program

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PREFACE

This volume contains the proceedings from two workshops that describe progress toward a Circumpolar Arctic Vegetation Map (CAVM). The bulk of the volume is devoted to the Second International CAVM Workshop in Arendal, Norway, 19-24 May 1996. This workshop was attended by representatives from all of the circumpolar nations. Twenty-seven papers described the progress that had been made since the first workshop in St. Petersburg, Russia, in 1994, and the abstracts of those papers are presented here. The second part of this volume contains the results of a North American CAVM workshop held in Anchorage, Alaska, 14-16 January 1997. This workshop was attended by participants from Greenland, Canada, and the US. A summary of the proceedings, and a paper describing a prototype map for northern Alaska are presented. The purpose of these proceedings is to keep the arctic-science and vegetation-science communities appraised of progress and to provide documentation to the membership of the CAVM working group.

Overview of the CAVM initiative

During the next few decades the Arctic will be affected by many forces from within and outside the region including global climate change, cumulative impacts of resource development, native-population increases, and tourists. The simple, fragile ecosystems could be dramatically altered through changes to the vegetation, wetland destruction, and thawing of ice-rich permafrost. This could have important consequences to the wildlife resources and to the native peoples within the Arctic, as well as feedbacks to the global hydrological and atmospheric systems. A new vegetation map of the Arctic is needed for a wide variety of purposes related to anticipated global changes, land-use planning, and education.

In the US, the Arctic System Science (ARCSS) program of the National Science Foundation is developing an integrated program of scientific research that involves the marine, terrestrial, atmospheric, paleoenvironmental, and human aspects of the Arctic as they are related to global change. There are numerous parallel efforts in Europe, Russia, and Japan. The International Arctic Science Committee (IASC) and the Conservation of Arctic Flora and Fauna project (CAFF) have recognized the circumpolar arctic vegetation map as a priority research item, and numerous organizations including GRID (Global Resource Information Database)-Arendal are devoted to developing spatial databases for the circumpolar region. Many ongoing circumpolar database efforts, such as the new environmental atlas of Russia and the proposed circumpolar ecoregions mapping project, will require accurate spatial vegetation information based on the latest scientific knowledge.

The CAVM project will provide a variety of mapped vegetation information for the arctic tundra and polar desert region based on our most recent scientific understanding. The project is confined to the region north of the arctic treeline. This region has clear climatic and ecological boundaries, as well as many common political, cultural, and scientific issues that need to be addressed. By limiting the project to the arctic tundra region, the project has a clear focus, a relatively small and well-defined group of regional experts who will do the mapping, and a relatively small area for which the mapping protocols and legends can be developed. This is essential to keep the budget constrained and produce useful products within a short time frame. It is expected that once the arctic tundra region is mapped, it will be possible to expand the mapping effort into areas south of treeline. The project will produce three products at a scale of 1:7,500,000, the first two of which are currently in draft form:

(1) A photo-quality, cloud-free and snow-free false-color infrared image of the circumpolar region derived from satellite imagery. This product is needed as a base map on which to draw vegetation boundaries. It is the first view of the terrain of the entire Arctic, and hence has a wide variety of applications for arctic science and education. The product is derived from a time series mosaic of Advanced Very High Resolution (AVHRR) images with 1-km picture elements.

(2) A map of the relative vegetation greenness of the circumpolar region as portrayed by the maximum Normalized Difference Vegetation Index (NDVI). Similar products have been prepared for the globe and North America and are extremely useful for examining spatial patterns of leaf-area-index and biomass production and for modeling the effects of climate change. This is derived from a mosaic of Advanced Very High Resolution (AVHRR) images.

(3) A geobotanical database and derived maps of the circumpolar arctic tundra and polar desert region. The database will consist of an integrated map coded with landscape and vegetation information as interpreted on an AVHRR base map at 1:4,000,000 scale and reduced to 1:7,500,000 scale.

The CAVM project is organized so that experts in each region of the Arctic will do the initial mapping. Synthesis will be done at the subcontinental scale at three GIS centers in Alaska (USGS Alaska Data Center), Scandinavia (GRID-Arendal) and Russia (Komarov Botanical Institute in collaboration with Moscow State University). The location of the final synthesis has not been determined yet, but will draw on the unique expertise at GRID-Arendal, the USGS Alaska Data Center, the Komarov Botanical Institute, and the Tundra Ecosystem Analysis and Mapping Laboratory (TEAML), University of Colorado. Close coordination with other continental and circumpolar vegetation efforts will be achieved through the Panarctic Flora project, the Conservation of Arctic Flora and Fauna (CAFF) project, the European vegetation mapping effort, and the Circumpolar Arctic Vegetation Classification. Contingent on funding, regional draft maps will be completed by 1998, the continental syntheses by 1999, and the circumpolar synthesis by 2001.

D.A. Walker
17 July, 1997

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PART I

SECOND CIRCUMPOLAR ARCTIC VEGETATION MAPPING WORKSHOP

ARENDAL, NORWAY, 19-24 MAY 1996

I.A. INTRODUCTORY ADDRESS AND KEYNOTE ADDRESS

WELCOME ADDRESS

PROGRESS SINCE THE FIRST CAVM WORKSHOP AND GOALS OF THE SECOND

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I am very pleased that we are able to meet again and take the next step toward the development of a vegetation map of the circumpolar arctic tundra region. Welcome to everyone, and particularly those that were not at the first meeting in St. Petersburg in March of 1994.

I am pleased that GRID (Global Resource Information Database)-Arendal has agreed to host the meeting and provide the logistic support. We are all excited to be here to learn more about this famous facility. Karen Folgen has worked diligently making the arrangements for this workshop; it has all happened smoothly through the internet. In the US, Andrew Lillie has worked very hard at putting together the schedule, compiling the abstracts, and communicating with all of you.

This workshop was funded by the US National Science Foundation through the Arctic System Science Program. There was also a considerable amount of support that came through individual contributions to some of your air fares and the time that you are all devoting to coming here and to writing your papers. This support from you and your home institutions is much appreciated because it increased the number of individuals that I could invite and has enriched the quality of the workshop.

I think the biggest acknowledgment has to go to you participants who recognize the need for a circumpolar vegetation map, who have provided support and encouragement for this endeavor, and who are willing to move forward in the face of the considerable difficulties involved in any international activity of this nature. It is not a minor task.

As an example of the magnitude of the type of endeavor we are seeking to accomplish, we can look to the Map of the Natural Vegetation of Europe. Udo Bohn, who is the principal coordinator of the natural vegetation map of Europe and who will be presenting the keynote talk this morning, recently sent me a reprint (Bohn 1994) describing the conception, the problems, and the coordination required to make the European map. He notes that the original idea for a European map goes back to 1959 at the International Symposium on Vegetation Mapping in Stockholm when the Permanent Commission for the Vegetation Map of Europe was established under the leadership of Reinhold Tüxen. The map gradually evolved through many meetings, and took thirty-six years to complete! The final map is a testimony to Tüxen's original vision and the diligence of all the contributors. The problems involved with developing a unified legend that could be agreed upon by all the European countries seemed almost insurmountable at times. Many problems involving procuring funds, developing true international cooperation, and achieving a fully integrated map legend with a comparable level of detail across all countries stretched the project over several decades.

We do not have the luxury of several decades with the Circumpolar Arctic Vegetation Map. The current problems facing the arctic regions due to many forces of global change are immediate. There is an urgent need for a new map for many scientific, cultural, educational, conservation, and development purposes. Luckily, the task will be hastened through modern telecommunication systems and automated methods of making and compiling maps. We also have relatively few countries involved. Whereas, the European map demanded the coordination of activities in 28 countries and seven republics within the former USSR, there are only six countries with true arctic tundra. Much of the planning for the European map occurred during the Cold War era when communication and travel to Russia was very difficult; now communication with Russia is relatively simple.

Our task is also easier because we are a relatively tightly-knit scientific group with many common objectives and scientific issues to be addressed. We are working in a system with many close climatic, cultural, and ecological ties. The arctic scientific community also has a voice through the International Arctic Science Committee (IASC), which is becoming a more powerful force in shaping the scope and nature of international arctic science. In the US, our primary sponsor, the Arctic System Science (ARCSS) program, is pushing to develop a truly integrated global program of scientific research that involves the marine, terrestrial, atmospheric, paleoenvironmental, and human aspects of the Arctic as related to global change. And there are numerous parallel efforts in Europe, Russia, and Japan. Many international projects such as the High Latitude Ecosystems portion of Man and the Biosphere (MAB) Programme and the Conservation of Arctic Flora and Fauna (CAFF) Program need maps that portray the nature and diversity of the circumarctic vegetation. Numerous other organizations such as GRID-Arendal are already devoted to developing spatial databases for the circumpolar region. The vegetation of the Arctic is also relatively simple compared to that of all of Europe. We will not have the 650 map units that occur on the European map and hopefully by the end of this meeting, we will have already agreed on the framework for the map legend.

So, in many ways our task is easy compared to that which faced Tüxen in 1959. Our greatest challenge will be to keep the project funded and continuously moving so that we can complete the maps as rapidly as possible so they can be used by scientists and decision-makers. I think that we can do this, but it will require hard work at this workshop to lay the foundation for the legend and develop concrete proposals for funding.

History of the CAVM

In 1991, at the International Workshop on Classification of Circumpolar Arctic Vegetation, in Boulder, Colorado, US, the participants recognized the need for a new vegetation map of the circumpolar tundra regions. One of the resolutions of the workshop was to begin the task of developing the organizational mechanism to accomplish this task. This Boulder workshop created the first synthesis of detailed classification of arctic vegetation, much of it using the Braun-Blanquet approach, and the results of this workshop were published in a special issue of the *Journal of Vegetation Science* (M.D. Walker *et al.* 1994).

Following the Boulder workshop, a proposal was co-funded by the US National Science Foundation and the US Fish and Wildlife Service to hold the first workshop devoted entirely to arctic vegetation mapping. This delightful occasion was hosted in March 1994 by the Komarov Botanical Institute in the small village of Lakta on the outskirts of St. Petersburg, Russia. At this workshop, 51 participants reviewed the status of arctic vegetation mapping in each of the circumpolar countries. We also developed a strategy for making a new series of maps that portray our current knowledge of arctic vegetation. This workshop led to three publications, all of which are contained in the USGS Open File Report 96-251. The first paper (Walker 1995), published in *Arctic and Alpine Research,* gives an overview of the workshop and sets forth a plan for making the maps; the second paper by all the members of the CAVM Executive Committee (Walker *et al.* 1995) reviews the current status of vegetation mapping in each of the circumpolar countries. The most recent publication (Walker and Markon 1996) is a compilation of all the abstracts and papers presented at the first workshop, and it also contains reprints of the other two publications. The volume summarizes the various approaches to vegetation mapping currently being used for the Arctic, and I hope that you have all had time to read this and review what transpired at the first workshop.

At the St. Petersburg workshop, we proposed to make several types of map products. First, we saw the need for an accurate base map of the circumpolar region that is derived from a mosaic of satellite images at a scale of 1:5,000,000. This is being worked on by the US Geological Survey, and we will see a preliminary version at this workshop. Secondly, we agreed to make a variety of products derived from the AVHRR Normalized Difference Vegetation Index (NDVI). These maps will include a variety of products such as maximum NDVI, which is a measure of vegetation greenness and hence biomass, and other maps portraying the dates of initiation of green-up, start of senescence, etc. Mike Fleming from the USGS EROS (Earth Resources Observation Systems) Alaska Field Office will present a summary of much of this activity.

Following the St. Petersburg workshop, the project received the endorsement of the International Arctic Science Committee (IASC) and the US Polar Research Board (PRB) and has been recognized as a priority task of the Conservation of Arctic Flora and Fauna (CAFF) project.

Goals of the 2nd CAVM workshop

At this workshop we have three primary goals. First, we need to develop a sound legend framework on which to build the synthesis map. Second, we need to establish the methods for international cooperation that will be needed to integrate the efforts of all the circumpolar countries. Third, we need to outline a funding strategy. Finally, we need to begin work on a set of proposals to make the maps.

To start this process, the first day-and-a-half of the workshop will be devoted to papers summarizing the progress in the each of the circumpolar countries. Today, we will hear reports from representatives of each of the countries regarding progress on the mapping legend and various approaches. Tomorrow we will focus on some of the circumpolar databases, remote-sensing products and GIS activities.

After lunch tomorrow, we will break into two working groups. One working group will address the legend of the synthesis maps, and the other will focus on the GIS and remote-sensing activities. As currently scheduled, these groups will meet once tomorrow and in four 1.5 hour sessions on the third day with intervening plenary sessions and breaks for coffee and lunch. At the plenary sessions, the working group chairs will report progress. On the fourth day, we will reconfigure the working groups and focus on the topics of international cooperation and mapping strategy, and developing proposals to fund the mapping.

Toward a legend framework

Our biggest challenge here is to develop a legend framework with terminology that is acceptable to all of the circumpolar countries. Over the past century, vegetation science has evolved very differently in North America, Scandinavia, and Russia. There have been numerous isolating forces including language barriers, difficulties in travel, different geographic, scientific and societal forces, and the isolation imposed by the Cold War. Now these forces are beginning to break down, and we are seeing increased impetus for a more detailed circumpolar map. We are realizing, though, that some of the differences in language cause major barriers for an international synthesis. These differences are not trivial and must be addressed before we can move forward.

In the US, vegetation science has focused largely on ecophysiology and modeling vegetation processes. There has been relatively little interest or funding for developing a national vegetation mapping program or pursuing a coherent classification system for the nation. The result has been that each federal and state agency developed its own mapping system to satisfy its own mission requirements. This has led to some innovative methods, but for the most part, it has left the US with little to show the world in the way of useful classification methods or vegetation maps. The view of the earth from space and the US Global Change Program have awakened some US vegetation scientists to the need for a coherent international vegetation classification and maps.

The very existence of the UNEP (United Nations Environment Programme)-GRID network of GIS centers is testimony to the international need for accurate maps. We cannot possibly model the global ecosystem and examine interactions between the land, oceans, and atmosphere unless we have useful global vegetation maps based on sound scientific principals.

In Europe and Russia, centers of vegetation mapping formed in nearly every country, and great traditions developed in Toulouse, Montpellier, Zurich, Bonn, and St. Petersburg under the leadership of personalities such as Gaussen, Tüxen, Lavrenko, and Sochava. At the St. Petersburg workshop in 1994, we saw the results of Sochava's leadership in the many vegetation maps that cover the entire arctic portion of Russia. And Dr. Bohn has brought with him the result of the European effort. These results are very impressive. When we look to North America, a great challenge faces us in making maps at a comparable level of detail for all of arctic Canada and Alaska. We do have relatively good knowledge of the structure and composition of vegetation in relation to climate and other environmental gradients. We also have good information on arctic plant species distributions. And we know, with a fair degree of predictive power, how plant communities are organized in typical arctic landscapes. But we have to look to Europe and Russia for guidance and methodological leadership in making new vegetation maps that will reflect an international perspective.

The work of Gorodkov, Andreev, Tolmachev, Alexandrova, and Yurtsev has given us a framework from which to view the gross zonal and floristic-sectoral patterns of Russian arctic vegetation. Comparable frameworks have been developed in North America by Bliss, Polunin, Edlund, and Young. And in Scandinavia, Dahl, Elvebakk, Ahti, and Tuhkanen have described the major zonal patterns. The problem is that the terminology used by the above authors is far from consistent.

For example and perhaps most obviously, the term "High Arctic" is used to describe the region of discontinuous plant cover and landscapes that are dominated by cushion plants, prostrate shrubs, and rosette forbs (Bliss and Matveyeva 1992); whereas in Russia this term is currently used to describe the coldest extremes of the Arctic, where plant cover is exceedingly sparse with only a few occasional forbs (Yurtsev 1994). Also, in North America the term "Low Arctic" is used to describe the same tundra types that the Russians have called "subarctic" or "hypoarctic". Within North America, there are also different approaches to describing zonal patterns. For example, the terminology used by Edlund (1996) is quite different from that of Bliss and Mayveyeva (1992). In Scandinavia, we see many similarities between the climatic-phytogeographical zonal map and the Russian zonal approach (Elvebakk 1996), but again with differences in terminology. The approach proposed for Greenland (Daniëls 1994, 1996) incorporates close connections to the Braun-Blanquet terminology and offers intriguing possibilities for a global synthesis.

Perhaps, the most interesting aspect of all this is that we are not even in agreement on a name for the object which we are attempting to map, i.e. the region north of the latitudinal treeline. Some authors call this the Arctic region and some call it the Arctic Tundra region. The term "tundra" which is at the root of the whole matter is not understood by all of us to be the same thing. Aleksandrova (1980) and Bliss and Matveyeva (1992) seem to agree that tundra is associated with landscapes that have more or less continuous cover of vegetation that has a large component of low and dwarf shrubs. Whereas, in Alaska the term tundra is more of a landscape term applied to the totality of all arctic and alpine landscapes above and north of treeline including the polar desert regions (Gabriel and Talbot 1984).

Developing a consistent nomenclature system will be a difficult task. I would like to promote a spirit of compromise about the terminology we will adopt. This will be necessary because many of the words crucial to our science have very different meanings in different countries, but I think we all recognize the underlying kernels of similarity in all the approaches. Our only option is to develop hybrids of our terminologies that take the best characteristics of each. During this workshop, we must strive to reach consensus on some of these basic terms. Dave Murray and I will present one possible solution to get around the terminology problem with respect to the zonation of the Arctic. Also, I see by glancing through the abstracts that there are other hybrids that will appear at this workshop. These terms are at the root of our disagreements regarding vegetation legends, and we must reach consensus on them and define them in a mutually acceptable way for the international community.

At the St. Petersburg workshop, we made an initial step. I would like to draw your attention to the Recommendations of the Russian Working Group at the First Workshop (Russian CAVM Working Group, this volume). These were summarized after the St. Petersburg meeting and many of you may not have seen these. They are not in any of the publications from the last meeting, so I encourage everyone to read these and consider the ideas in your deliberations.

Developing a mapping strategy

I think that the problems faced by the remote-sensing and GIS group are somewhat less formidable because the major tasks involve assembling remotely-sensed imagery and using existing algorithms to produce some of the NDVI-derived maps. This is not to say that it will not be a big job, but it seems that the task will be relatively straight-forward if we can clearly define the scope of the task we wish to accomplish and move quickly to develop the base maps and the NDVI-derived maps.

With regard to collaboration on assembling the synthesized regional maps into a single vegetation map of the Arctic, the task is much more challenging, and I am hoping that we can learn from Dr. Bohn's experience with the European collaborative effort.

Developing a funding strategy

Finally, we must be prepared to write the proposals to obtain the necessary funding. We have to get the word out to all relevant national and international bodies that this project has international endorsement by IASC and that it is essential to all of our arctic national and international political, cultural, educational, and scientific interests. We have to identify who can accomplish the work that is needed and how we can take advantage of the key experts in each of the participating institutions and then boldly move forward, again with a spirit of cooperation.

In the US we are learning that large integrated projects can be successful only if there is an underlying desire to collaborate. The US National Science Foundation (NSF) is interested in promoting international projects of this nature, and I am confident that we can write a proposal that will be successful. But NSF and the US funding agencies cannot pick-up the tab for the entire map. We have to demonstrate that there is major cost sharing by the international community. Steve Talbot will be presenting some of plans that we are developing in the US, and I hope that others of you have come with similar concrete funding ideas.

So, again I would like to welcome everyone. I want this to be a relaxed atmosphere, but with enough structure to keep things moving along.

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KEYNOTE ADDRESS

HIERARCHIC CLASSIFICATION OF THE LEGEND AND MAPPING UNITS OF THE MAP OF NATURAL VEGETATION OF EUROPE, SCALE 1:2.5 M

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Introduction

As present principal coordinator of the international mapping project of the Map of Natural Vegetation of Europe (MNVE), I want to thank Skip Walker for the invitation to this decisive workshop of the Circumpolar Arctic Vegetation Map (CAVM) working group. Our long-lasting mapping project has now reached the final stage: digitizing of the map sheets is in progress, and printing of the vegetation map should take place next year. The draft of the explanatory textbook should be finished at the end of this year.

There are two good reasons for my participation in this workshop:

1. As the two mapping areas (CAVM; MNVE) are overlapping in the north of Europe, we should try to harmonize the classification and content of their mapping units. Also, I think the working group can profit from the experiences and results of our work. Some of our co-workers are also involved in the CAVM project.

2. I want to take the opportunity to fill in some gaps in our legend and explanatory text concerning the natural vegetation of Svalbard and Iceland. I think that there are also some weak points in our classification of the arctic vegetation which should be improved.

Aims, Content, and Basic Principles of the European Vegetation Map

The aim was to construct a map of the potential natural vegetation because of the small scale and because of the importance of this information for different purposes of application: nature protection, environmental protection, bioproductivity, consequences of climate change, and so on (Bohn 1994).

Content, classification, and representation of the map was based primarily on vegetation criteria. The mapping units were named by dominant vegetation types or specific regional vegetation complexes.

The classification of the legend consists of an hierarchic system which takes into account vegetation-specific criteria at different ranks, such as

- structure and physiognomy of the plant cover (formations and formation complexes) at the highest level
- dominant species
- species combination and floristic differentiation at lower levels.

The higher levels of classification take into consideration vegetation zones, subzones, altitudinal belts, and phytogeographic sectors. Edaphic differentiation is represented on lower levels. The applied system of mapping units and their names had to be simple, transparent, and neutral, so that it could be used by all contributors of the different "schools" of geobotany in Europe.

The explanatory text of a mapping unit should contain information about structure, characteristic and dominant species, differential species, site conditions, and as far as possible and necessary, geographic localization.

Each mapping unit should be clearly identified on the map by a code consisting of the letter of the formation and the number of the mapping units within this formation. From the beginning, basic colors were used for related groups of mapping units on different levels. All national vegetation maps were compiled from existing vegetation maps at larger scales or constructed with the help of other basic maps.

The mapping area is composed of the whole of Europe to the Ural Mountains, including the Caucasian countries, the arctic islands (Novaya Zemlya, Franz Josef Land, Svalbard), and Iceland.

At present about sixty geobotanists from thirty-six institutions in thirty European countries are cooperating on the project. The main coordinating centers are: the Komarov Botanical Institute, St. Petersburg, Russia; the Botanical Institute in Pruhonice near Prague, Czech Republic; and the Federal Agency for Nature Conservation in Bonn, Germany.

Structure of the Entire Legend

The highest units of classification are formed by nineteen vegetation formations and formation complexes based on physiognomic-ecological features, designated by capital letters A to U. Fourteen of these main units (A to O) represent the predominant zonal formations characterized by the prevailing life-forms corresponding to the main macroclimatic zones and belts in a sequence following the gradient from cold and wet to warm and dry climates. Five are azonal formation types (P to U) with major extension, such as coastal, mire and flood-plain units.

Main Formations

The main formations are differentiated according to physiognomy and environmental conditions:

Zonal and extrazonal vegetation (depending primarily on climate)

A Polar deserts and subnival vegetation of high mountains (5 units)

B Tundras and alpine vegetation (58 units)

C Subarctic, boreal, and nemoral-montane birch woodlands and subalpine vegetation (50 units)

D Mesophytic and hygromesophytic coniferous and broad-leaved coniferous forests (65 units)

E Atlantic dwarf shrub heaths (16 units)

F Mesophytic deciduous broad-leaved and mixed coniferous broad-leaved forests (177 units)

G Thermophilous deciduous broad-leaved forests and mixed coniferous broad-leafed forests (177 units)

H Hygro-thermophilous mixed broad-leaved forests (2 units)

J Mediterranean sclerophyllous forests and scrub (50 units)

K Xerophytic coniferous forests and scrub (34 units)

L Forest steppes (meadow steppes, alternating with deciduous broad-leaved forests) (15 units)

M Steppes (21 units)

N Oroxerophytic vegetation (thorn-cushion communities, tomillares, mountain steppes, partly scrub) (8 units)

O Deserts

Azonal Vegetation (depending on soil and hydrological conditions)

P Coastal vegetation and inland halophytic vegetation (35 units)

R Reed and sedge swamps (3 units)

S Mires (27 units)

T Swamps and fen forests (6 units)

U Vegetation of flood-plains, estuaries, and freshwater polders (38 units)

Vegetation types with similar structure and species composition, such as polar deserts and subnival vegetation of high mountains or tundras and alpine vegetation, are put together in one formation group.

Relevant formations for the arctic mapping project are especially A and B from zonal, and P, S, and U from azonal vegetation formations.

The further (second and third level) subdivision of the main formations into vegetation zones, subzones, and altitudinal belts should be explained by the example of formations A and B: It is mainly caused by changing climatic conditions on a gradient from north to south. (This classification is based on the Russian approach.)

TABLE 1

Subdivisions of Zonal Types A (polar deserts) and B (tundra)

A	Polar deserts and subnival vegetation of high mountains			
	1	Polar deserts		
		1.1	Lowland polar deserts	
		1.2	Montane polar deserts	
	2	Subnival vegetation of high mountains in the boreal and nemoral zone		
B	Tundras and alpine vegetation			
	1	Tundras		
		1.1	Arctic tundras	
		1.2	Northern tundras	
		1.3	Southern tundras	
			1.3.1	Low-shrub tundras
			1.3.2	Shrub tundras
		1.4	Mountain tundras and sparse oroarctic vegetation	
	2	Alpine vegetation (Alpine grasslands, low creeping shrub, dwarf shrub, and shrub vegetation, rock and scree vegetation) in the boreal, nemoral, and Mediterranean ones.		

Concerning polar deserts and tundras, no sectoral differentiation on the second and third levels of classification has been carried out, unlike in the boreal forests, which are subdivided into west and east boreal types at a high level because of complete changing of the dominant tree species. The same is with nemoral (temperate) broad-leaved forests (formation F), which are subdivided on the 2nd level according to the dominant tree-species (*Fagus, Quercus, Carpinus, Tilia cordata*) and their combinations.

The final subdivision into mapping units goes along with characteristic species composition and vegetation types which represent specific site conditions and patterns either in a more-or-less homogenous or in a complex situation. They are characterized by dominating zonal vegetation units, by typical combinations on zonal and azonal vegetation types (for instance with mires and wetlands) or by altitudinal or geographical variants of zonal vegetation types. The dominant plant communities are represented by the predominant and indicator species. Specific site conditions are indicated by attributes such as petrophytic, psammophytic or hydrophytic.

Geographical variants are characterized by geographically differential species listed behind *with* . . . and their geographical location such as *Novaya Zemlya, Kanin, Pecora,* or *Jugar.*

TABLE 2

Excerpt From the Entire Legend for Formation B, divided into mapping units

B	Tundras and alpine vegetation	
	1	Tundras
		1.1 Arctic Tundras
	B1	Herbaceous low creeping shrub-moss tundras (*Hylocomium splendens* var. *alaskanum, Ditrichum flexidaule, Deschampsia brevifolia, Carex ensifolia* ssp. *arctisibirica, Salix polaris*) with *Myosotis asiatica, Parrya nudicaulis* in Novaya Zemlya
	B2	Petrophytic moss-lichen tundras (*Cladina* sp. div., *Cladonia* sp. div., *Racomitrium lanuginosum*) with *Dryas octopetala, Silene acaulis, Papaver polare* in Novaya Zemlya
		1.2 Northern Tundras
	B3	Herbaceous moss tundras (*Tomentypnum nitens, Aulacomnium* sp. div., *Carex ensifolia* ssp. *arctisibirica*) with *Valeriana capitata, Petasites frigidus* on the Kolguev Isle and in the territory of Pecora
	B4	Herbaceous moss tundras alternating with willow tundras and brown-moss mires in the territory of Kanin and Pecora
	B5	Hemi-psammophytic low creeping shrub-lichen tundras (*Cetraria* sp. div., *Cladonia* sp. div., *Alectoria* sp. div., *Dryas octopetala, Salix nummularia*) with *Betula nana* on the Kolguev Isle and in the territory of Pecora
	B6	Hemi-psammophytic low-creeping shrub-lichen tundras alternating with willow tundras in the territory of Kanin and Pecora
	B7	Herbaceous moss tundras (*Tomentypnum nitens, Aulacomnium* sp. div., *Carex ensifolia* ssp. *arctisibirica*) with *Calamagrostis homii, Salix pulchra* on the Jugor Peninsula
	B8	Willow tundras (*Salix glauca, S. lanata*) with mosses and herbs, with *Salix pulchra* on the Jugor Peninsula
	B9	Herbaceous moss tundras alternating with brown-moss mires on the Jugor Peninsula

Within the azonal formations such as S (mires and bogs) the 1st level subdivision is, according to the various trophic conditions, into ombro-, ombro-minero-, and minerotrophic types. The 2nd-level division represents zonal and geographical-sectoral floristic-ecological differentiation. So, the system of classification of vegetation and mapping units within the different formations depends on the fundamental structural, ecological, and floristic-vegetational conditions.

For the individual mapping units, detailed information is given about dominant plant communities (and their scientific names), their structure and species composition, their habitat (bedrock, soil conditions, altitude, climatic conditions), characteristic associated natural vegetation types, geographical distribution, land use, substitute vegetation, status of protection, and other important subjects in a standardized questionnaire. This information is very important for characterization of the mapping units and for their comparison with related units in other parts of the mapping area.

Recommendations for the Construction of a Circumpolar Arctic Vegetation Map Based on Experiences from the European Mapping Project

- The map should be established within a short period (few years) because of the soon and rapidly decreasing interest and enthusiasm of the cooperating members.

- The construction of the overview map should be based on clear mapping criteria and on a clear hierarchic classification of the legend.

• Point out similarities and distinctions between zonal and sectoral classes on different levels by tabular matrices with information on site conditions, vegetation coverage and structure, plant communities, and floristic composition (dominant, characteristic, differential species).

• Substantiate vegetational divisions into zones, subzones, sectors, and mapping units by significant climatic and other environmental data (bedrock, soil conditions, moisture, topography).

• Combine closely cartographic work (outline of polygons) with description and characterization of mapping units.

• For different well-investigated parts of the mapping area there should be detailed information about the characteristic natural vegetation patterns (zonation, mosaics, altitudinal belts) by maps or sketches on a larger scale.

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I.B. GENERAL AND NONREGIONAL ABSTRACTS

RECOMMENDATIONS OF THE RUSSIAN WORKING GROUP AT THE 1ST WORKSHOP "CIRCUMPOLAR ARCTIC VEGETATION MAPPING" SCALE 1:7,500,000 CONCERNING THE PRINCIPLES OF THE LEGEND COMPILATION

Russian CAVM Working Group[1]

The working group participants suggest:

(a) The map will cover the polar territories north of the northern boundary of a more-or-less continuous distribution of woodlands and open woodlands (except for some secondarily forestless islands, such as the Faroes, Hebrides, Shetland, and North Kuriles). The boundary of the area to be mapped will cross the longitudinally-oriented mountain ranges (such as Ural or the Verkhoyansk Range), linking the northernmost protrusions of the woodlands in the valleys and on the pediments. Isolated massifs of woodlands among tundra (such as More-You in Terra Magna Samoje-dorum or Ary-Mass in the southern Taimyr) will be included in the map.

(b) The map will also include the following small-scale inserted maps: 1) The schematic map of zonal (subzonal) division of the Arctic with subsequent subdivision of the subzones into sectors, i.e., producing the map of geobotanical division of the Arctic [In the Russian literature it became a tradition to divide the tundra zone (the Arctic with or without inclusion of polar deserts, or high-Arctic tundras) into subzones; in the western works they are usually considered as separate zones]. 2) The schematic map of floristic division of the Arctic. 3) The proposed map of the location of protected areas within the Arctic.

(c) The content of the Legend units will be the diverse characteristics of the vegetation itself: 1) the dominant or characteristic (differential, indicatory) biomorphs and/or eco-biomorphs (see below); 2) dominant or characteristic species; 3) vertical and horizontal structure of plant communities; 4) various combinations of communities characterizing the vegetation cover structure. For the designation of zonal (latitudinal) and sectoral (longitudinal) subdivisions the geographic epithets will be used in the Legend (e.g. "northern hypoarctic tundras: East-Siberian," etc.) characters, and the restriction of certain units of vegetation cover to some topographic features or kinds of rocks could be also recorded.

(d) It has been decided to test both the text and matrix forms of the Legend.

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[1] The following members of the 1st workshop participated in the evening meeting of the legend compilation working group: Yurtsev, B.A. (the informal chairman), Kholod, S.S., Katenin, A.E., Polezhayev, A.N., Perfilieva, V.I., Moskalenko, N.G., Meltser, L.I. The results were briefly presented by Yurtsev, B.A. at the concluding session, but were not thoroughly discussed. The written version was compiled by Yurtsev a month later and distributed among the participants (e-mail on May 11, 1994). It was approved by the Russian participants listed above.

(e) The Legend will have an hierarchic structure and will include the three basic levels: the upper - corresponding to the vegetation of different subzones, reflecting the availability of summer warmth; the middle - corresponding to the vegetation of longitudinal sectors of the subzones, reflecting the continentality - oceanity of climate, etc.; and the lower - the vegetation of the mapped units themselves, i.e., of those subdivisions of a given sector which could be shown at a scale of 1:7,500,000 and which reflect contrasting forms of relief and/or lithological units (e.g., carbonate, basic to middle siliceous, acid, mixed, sand, silt, etc.). and sometimes also some minor variants of climate. The participants approved, in general, the 1st draft of the upper level of the Legend (proposed by B.A. Yurtsev) with diagnoses of the vegetation of subzones. It has been decided to prepare by the next workshop (Arendal, Norway) the 1st draft of the middle level of the Legend with diagnoses of the vegetation of at least the Asian sectors of all the subzones, and for separate sectors, a draft of the Legend text for the lower level.

(f) The complexity of the vegetation cover structure is to be reflected as far as possible at every level of the Legend by listing the community types specific to the Legend unit along with the predominating ones (including the plakor type). The vegetation entities (syntaxa) can have different syntaxonomical ranks, but they should be easy to identify.

(g) A hierarchic ecological-structural-dominant (the so-called "physiognomic") approach to the classification of vegetation (plant communities) is suggested, with the upper units being determined by the dominant or differential biomorph or the combination of biomorphs (which results in a certain structure of communities) and the lower units - by the combination of dominant and differential (indicatory) plant species. One could use, in addition to the concept of biomorphs (growth forms), also eco-biomorphs which are determined as the biomorphs with certain key ecological or ecological-geographic characteristics (e.g., oligotrophic hypoarctic hemiprostrate shrubs or dwarf shrubs; eutrophic arctic-alpine prostrate summer-green dwarf shrubs, etc.). For the identification of regional (sectoral) subdivisions (at the middle and lower levels of the Legend), vicarious species or subspecies acquire the prime importance [G - species, EG - species; e.g., vicarious species of dwarf birches of the *Nanae* section]; the vicarious dominant species are of the greatest diagnostic value. In perspective, such an approach could link the above units with the syntaxa of the ecological-floristic school. For the identification of the regional (sectoral) variants at the 2nd level, the vicarious, highly active species can also be used (i.e. the species with a very wide habitat range and abundant over their characteristic habitats). The regional variants, however, could be distinguished also by the presence or dominance of certain vegetation types (e.g., mesic meadows in oceanic sectors, or cottongrass tussock tundras in the continental ones with a shallow soil active layer.)

(h) The Legend items that are devoted to montane vegetation will be subordinated to the upper level units (i.e. the vegetation of subzones) and will be placed after the listing and characterization of the plain-and-lowland vegetation entities. The next subdivisions of the montane vegetation units will be those belonging to one subbelt or belt (in the Russian phytogeographic literature the vertical zones or subzones are usually referred to as belts or subbelts) representing the montane version of the respective subzone (zone), and those differentiated into two or more subbelts (belts). In the last case, the full set of subbelts will be presented and shortly characterized in generalized form (the so-called, "belt column"), starting from below. It would be rational to coordinate the terms and criteria for demarcating subbelts with those of latitudinal subzones (e.g.: the southern hypoarctic tundra subzone - the lower oro-hypoarctic tundra subbelt; the arctic tundra subzone - the oro-arctic tundra subbelt; the high-arctic tundra subzone - the oro-higharctic tundra subbelt, etc.), providing them with letter indices. So, one could give short description of each subbelt (belt) only once and then list the respective indices (e.g. A-B-C-D or B-C-D).

Since in the Arctic, upper parts of mountains are usually dominated by open stony barrens and rubble screes, the identification and demarcation of subbelts (belts) should be based on the characters of more or less mature vegetation on stabilized areas enriched with fine-grained material. At the 2nd (middle) level of the Legend, the regional variants of vertical zonation within each longitudinal sector are to be shown and characterized (e.g., via the replacement of dominant and/or differential species in the respective subbelts, the set of basic community types, etc.). At the 3rd (lowest) level of the Legend one is supposed to mark (using a special designation system) the situations where the certain subbelt areas are absolutely dominated by unvegetated stony barrens and screes, and the mature vegetation is extremely scattered. The major edaphic variants of montane vegetation will be also shown and briefly characterized, which reflect contrasting lithological compositions of rocks (e.g.: the prevalence of carbonate rocks, of basic to mid-siliceous ones, of acid rocks, the combinations of basic and acid rocks, etc.). (Compiled by B.A. Yurtsev.)

The aim of this mapping project is to reflect the present status of circumpolar Arctic vegetation which fortunately almost throughout the Arctic is more-or-less close to its virgin status; also, the 1:7,500,000 scale does not permit showing small areas of disturbances. But in some territories with long-term anthropogenic impact, such as Iceland, it is quite possible to show secondarily-deforested areas, and reflect in the Legend their derivative types of vegetation.

LONGITUDINAL (SECTORAL - 2ND LEVEL) SUBDIVISIONS OF VEGETATION SUBZONES OF THE CIRCUMPOLAR ARCTIC: THE REFLECTION IN THE 1:7.5 MIN. SCALE MAP LEGEND

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At the 1st International Workshop on Circumpolar Arctic Vegetation Mapping (CAVM) it was proposed that a three-level legend structure be considered, where the 1st level would reflect the longitudinal (zonal, subzonal) differentiation of vegetation cover (VC); the second one, the longitudinal (sectoral) one; and the third, a more subtle differentiation of VC depending on the relief forms and lithology.

One may be able to reach synthesis of the 1st and 2nd levels by means of simply superimposing phytogeographic subzones and floristic sectors shown on maps 1 and 2 in the paper by Yurtsev (1994).

However, an attempt to combine zonal (phytogeographic) and sectoral (floristic) subdivisions within a single map meets serious difficulties:

(1) Sets of differential species of each longitudinal sector in different subzones are also different; thus, they should be characterized separately at least for the arctic and hypoarctic groups of subzones (Yurtsev, 1994);

(2) Lists of differential plants of floristic sectors usually include rare species (e.g., local endemics) which do not play a notable part in VC, whereas with the geobotanical division of subzones into sectors, priority is given to regular components of plant communities with increased frequency and abundance (though rare communities specific to a given sector should also be considered);

(3) Many common communities of plains (including plakors), usually well-represented on vegetation maps, are rather poor in differential species; the latter are often most abundant in ecologically peculiar (sometimes ecologically extreme) communities which are not being included in small-scale map legends (and the units mapped) due to their relatively small extension (snowbed vegetation, dry rubble chionophobic dwarf shrub-lichen tundras and fellfields, cryophyte steppes, moist eutrophic herb-dwarf, shrub-moss, frost-boil tundras on floodplain vegetation, etc.). Thus, small-scale vegetation maps obviously ignore or under-represent many obligatory components of intralandscape differentiation of VC, including those sensitive to climate (indicatory) and/or differential changes, due to scale limitations.

To make the characteristics of basic subdivisions of the Arctic VC more full and important, it was suggested that (1st level) lists that not only prevail by area, but also some other characteristic vegetation types specific to a given subzone, be introduced into subzone vegetation diagnoses.

At the 2nd level of the legend structure, it is suggested that characterization on a regular basis (separately for the hypoarctic and arctic groups of subzones) of the species composition of vegetation in 10-12 basic (more-or-less universal) habitat classes of a sector occur. The draft list of such habitat (biotop) classes is as follows: 1) plainy (silty or clayish) watersheds, moderately drained (including plakors); 2) sandy plains; 3) hygromorphic (wet) tundras and tundra mires on poorly drained, flat watersheds, terraces, and some sorts of extensive depressions; 4) aquatic vegetation of lakes, ponds, etc.; 5) mesomorphic montane tundras and tundra-meadows (with good drainage, soils, rich in detritus: rubble, gravel or stones, and with moderately deep snow in wintertime); 6) semi-hygromorphic (moist) eutrophic tundras; 7) cryoxeromorphic (dry) chionophobic tundras of well-exposed windswept sites; 8) cryoxerophyte and cryomesoxerophyte herbaceous closed or sparse vegetation (including cryophyte steppes on south-facing bluffs); 9) nival (snowbed) tundras and meadows; 10) flood-plain vegetation (with subdivisions); 11) coastal halophyte vegetation (11a - on marshes, 11b - on sand-gravel beach).

Perhaps, one should enumerate separately the species set of true shrubs (in a given sector of hypoarctic subzones). For each habitat class within a given sector the principal dominant (and more important subdominant) species will be enumerated, following differential species (absent in both neighboring sectors of the same group of subzones), and then the co-differential ones - western and eastern (in common with either the western, or the eastern neighboring sector). The differential species of dominants have the highest value.

Finally, negative features in species composition could be emphasized and discussed. A list for each habitat class will include sections of acidophyte and calciphyte (basiphilous) communities. In the beginning of the list for every sector of subzone groups, highly active (essentially euritopic, ubiquitous) species (Yurtsev 1968, 1994) could be enumerated (e.g. some hypoarctic shrubs and ericoid dwarf shrubs in the hypoarctic group of subzones). The habitat types could be classified by their landscape position into prevailing, subordinated, and rare ones. Such a set of lists is to be compiled for each of the 20 floristic subprovinces and 2 autonomous oceanic areas of the Arctic floristic region (Yurtsev, 1994: Fig. 2). The features of larger longitudinal sectors (provinces according to Yurtsev, l.c.) will manifest themselves due to greater floristic similarity of the respective subprovinces. It is impossible to put voluminous lists of dominant and differential species into the legend itself where only the names of respective sectors can be given: the Svalbard, Kanin-Pechora, Ural-Novaya Zemlya, Yamal-Gydan, Taymyr, Anabar-Olenek, Kharau-lakh, Yana-Kolyma, Continental-Chukotka, Wrangel Island, South-Chukotka, Beringian-Chukotka, Beringian Insular oceanic, West-Alaskan, North-Alaskan, Central-Canadian, West Hudson, Baffin-Labrador, Ellesmere-North Greenland (could be divided into 2 separate sectors of a subprovince rank), West-Greenland, East-Greenland, Jan-Mayen Insular oceanic.

As to the lists themselves, they will be given as a spacious supplement to the legend ("Floristic composition of vegetation on basic habitat classes in the longitudinal sectors of the arctic and hypoarctic groups of subzones"), presumably in matrix form. In the presentation at the 2nd CAVM workshop such sets of lists will be demonstrated for several neighboring sectors of the Siberian and Beringian Arctic. In the CAVM international project, the author would take upon himself the compilation of the Supplement, and sections for Beringian and some East Siberian sectors. For the other sectors, only first drafts of such lists could be prepared according to data from available literature-- for supplements and correction by regional specialists in floristics and geobotany. Thus, the arrangement of the second level of the legend demands the concerted work of a team of scientists. If we compile such sets of lists for every sector of the arctic and hypoarctic groups of subzones, it will essentially extend our understanding of differentiation of the circumpolar Arctic plant cover, will provide the basis for the geobotanical division of the tundra zone, stimulate progress in the classification of circumpolar Arctic vegetation, and provide insight into the problems of the origin of the Arctic flora and vegetation. Besides, it will facilitate the selection of characteristic species for the diagnoses of dominating plant communities in the legend.

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"TUNDRA" AND THE "ARCTIC"

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As we begin the second CAVM workshop with the express purpose of writing map legends, it is appropriate to review our goals and immediate objectives, to reflect upon where we ought to be headed, and finally to determine how to get there.

The Arctic is a natural unit with much of the flora common throughout the region, albeit with variation, recognized and highlighted by subdivisions into phytogeographic zones and floristic provinces. Traditional methods of developing vegetation maps have been directed from the bottom-up; that is, from plot studies to regional generalizations through a series of increasingly synthetic aggregations. Another school of mapping has developed using wholly new data obtained by remote-sensing methods, which proceeds from the top-down using proxies for vegetation. Thus, the problem lies in tying those inclusive symbols to the traditionally-defined units on the ground.

Maps have been prepared at large and small scales for a variety of purposes, and taken together they very clearly show how differently the same patterns in nature can be portrayed. The CAVM was established to unify concepts and methods, and to integrate and apply the rich legacy of vegetation mapping to our task, which for the lack of ground-based information over large parts of the Arctic means dependence upon new technologies. Names applied to the subdivisions of Arctic and the descriptive terms in map legends reflect disparate methods and traditions, corresponding to the North American, Scandinavian, and Russian approaches.

Furthermore, the merger of information from such distinctly different sources as plot data on one hand with satellite imagery on the other challenges us to select informative terminology. Mixtures of terms that reflect abstract zones, physiography, plant life-form (physiognomy), dominant (primary) species, moisture regime, or successional stage have all been used to some degree and can even be found in a single classification. Whereas some terms have been so widely applied they cannot, without careful and explicit redefinition, be made more precise, others have been used for so long in such a restricted sense that they cannot now be applied more widely.

We must step back and reconsider the terminology with our original objectives in mind. Consensus is needed first for the terms *arctic* and *tundra*; Arctic is the region and tundra is the vegetation of that region. Once having fixed the usage of these terms, then others will logically follow. In some classifications, Arctic Tundra also designates a subzone of the Arctic and, similarly, tundra also refers to a community type. We must address this problem of dual meanings. It is essential to determine equivalents and, for CAVM purposes, to establish formal synonymies (e.g., for such terms as High Arctic, Polar Desert, and Northern High Arctic Tundra). For our current map-scale of 1:7,500,000, complex classifications must be collapsed into fewer units.

We propose that the term tundra be applied to all vegetation north of (and above) treeline as proposed by Gabriel and Talbot (1984, p. 116):

> *Tundra* - (1) From the Finnish 'tunturi', meaning a treeless plain and describes the landscape beyond the cold limits of tree growth. (2) a cold-climate landscape having vegetation without trees. The absence of trees is caused by a complex of conditions that is ultimately related to regional climate. This regional aspect distinguishes tundra from treeless bogs and similar local areas without trees due to edaphic extremes in areas that otherwise support a forest cover. (3) The landscape beyond the temperature limits of tree growth, both to the north [arctic tundra] and west of treeline in Alaska and at elevations above treeline on mountains [alpine tundra; brackets enclose our added text]. (4) The so-called 'barren ground' north of the circumpolar coniferous forests. (5) Treeless areas where dwarf shrubs and low herbaceous plants predominate, often with many lichens and mosses, on a permanently frozen subsoil.

Arctic Tundra, therefore, defines the totality of arctic vegetation north of treeline including polar deserts. For mapping at a scale of 1:7,500,000, it can be subdivided first into two basic components, High Arctic and Low Arctic in the manner of Bliss and Matveyeva (1992). Each of these can be similarly divided into two subunits, northern and southern, roughly following the Russian subzone boundaries. Then, to recognize a second level of complexity, floristic subdivisions at the rank of province can be superimposed over this structure. We fully realize that the term tundra has many other shades of meaning. However, if this broad definition can be accepted, the inconsistencies among the various approaches to classifying arctic vegetation will vanish and a consistent nomenclature to describe zonal vegetation within the Arctic will be established.

In summary, the Arctic zone can be divided as follows:

- High Arctic subzone,
  - Northern High Arctic
  - Southern High Arctic
- Low Arctic subzone,
  - Northern Low Arctic
  - Southern Low Arctic.

Northern High Arctic is the latitudinal portion where polar desert vegetation *sensu* Bliss is the dominant vegetation on the placors or moderate sites. (= Yurtsev's high arctic tundra subzone, and Alexandrova's polar desert.) Southern High Arctic is the portion where polar semidesert sensu Bliss is the dominant vegetation on the placors. (= Yurtsev's northern and southern arctic tundra subzones.) Northern Low Arctic is the portion where the sedge-dwarf shrub tundras and steppe tundras (in Russia) are dominant on the placors (= Yurtsev's northern and middle hypoarctic tundra subzones.) Southern Low Arctic is the portion where the shrub tundras are dominant on the placors. We would include the Russian Stlaniks here since they consist of essentially shrub growth forms. (= Yurtsev's southern hypoarctic tundra subzone + Stlaniks.)

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BRAUN-BLANQUET SYNTAXA AND THEIR IMPORTANCE FOR THE LEGEND OF A CIRCUMPOLAR ARCTIC VEGETATION MAP

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Introduction

The same, simple but clear, vegetational language has to be spoken by the whole CAVM community. This is a *conditio sine qua non* for the achievement of an ecologically relevant 1:7,500,000-scale vegetation map.

The Braun-Blanquet vocabulary in particular should be part of this language, which might be derived from the results of the international workshop on Classification of the Arctic Vegetation in Boulder in 1992 (Walker *et al.* 1995) (See also Daniëls 1996).

Why Braun-Blanquet syntaxa?

The characteristic species combination including character, differential and constant companion species, make each Braun-Blanquet syntaxon a well-defined vegetation unit with its own typical ecology (cf. Westhoff and Van der Maarel 1978, Dierschke 1994). A variety of relevant vegetation-ecological information is hidden behind names such as Oxycocco-Sphagnetea Br.-Bl. et R. Tx. 1943, Caricion nardinae Nordh. 1935, or Rhododendro-Vaccinietum Daniëls 1982.

Moreover, the syntaxonomical nomenclature is unambiguous, which is quite an advantage when comparing vegetation units and landscapes of different regions for ecological evaluation.

For example, are the following equivalent vegetation types: biomorph vegetation type II4, the willow-scrub variant of the Southern hypoarctic tundras of Chukotka (Katenin 1996); the dwarf birch and willow-dwarf birch, shrub-graminoid-green moss, low hillocky tundras, mapping unit 4 of the West Siberian Tundra (Meltzer 1996); and the low, erect deciduous thicket tundra, low tundra of the Low Erect Shrub Zone (L), 2 (Edlund 1996)? What information is hidden behind these units? If they are the same, why do they not have the same name? If not, what is the difference and why? Such nomenclature of vegetation types does not contribute very well to a comparison and overall understanding of the variation in plant cover of the circumpolar arctic region. A syntaxonomical evaluation of these three units immediately would reveal the ecological and historical relationships between these three units and thus the characteristics of the regions.

Another benefit of the use of syntaxa in connection with the CAVM legend is their importance in delineation of phytogeographical zones (cf. Bliss 1979, Alexandrova 1980, Yurtsev 1994), which was demonstrated by Elvebakk (1985) for the European Arctic (cf. Daniëls 1995, 1996). Especially circumpolar syntaxa with a good status of character species, ecological characterization, coherence of geographical distribution of character species and spatial structure. For example, Caricetea curvulae, Carici curvulae, Carici-Kobresietea, Loiseleurio-Vaccinietea, Salicetea herbaceae, Oxycocco-Sphagnetea, Scheuchzerio-Caricetea and Potametea (Pignatti *et al.* 1995) might be used to delineate the latitudinal (climatological) division of the circumpolar arctic territory or to adjust existing divisions (examples by Daniëls 1996). The same applies to lower syntaxonomical units (e.g. associations): the Phyllodoco-Salicetum callicarpaeae is diagnostic for low arctic Greenland as delineated by Bliss (1979), while its *Pyrola grandiflora* vicariant characterizes the Southern Hypoarctic tundra subzone in Greenland (e.f. Yurtsev 1994, p. 768, Fig. 1).

What to do now?

The syntaxonomical evaluation and interpretation of existing vegetation descriptions should be started now, and also fieldwork and further exploration of the circumpolar arctic territory by sampling the vegetation according to the Braun-Blanquet approach. For each mapping area with uniform climatic conditions, regional history and landscape geomorphology (cf. Iljina and Yurkovskaya 1996), a survey of the plant communities (syntaxa) with indication of their importance values in the landscape is needed. Territories with a similar set of characteristic plant communities (including zonal, azonal, and extrazonal) should be grouped together, considered ecologically uniform, and mapped as one entity (cf. Daniëls 1996). Thus, such an inductive CAVM map product will show regions with similar syntaxonomical inventories expressing similar ecological settings or conditions. Comparable approaches have been regionally or locally used by A.O. Böcher (1954) and Feilberg (1984) in Southwest and South Greenland in the distinction of vegetation zones.

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Classification of Arctic Vegetation Based upon Plant Structure

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Classification of the vegetation within a biome can be based upon dominant species, general floristics, or the structure of vegetation. The structure of deciduous forests in North America remains the same and thus units or associations are based upon dominant species such as oak-hickory, oak-pine, or beech-maple. The arctic is best classified on the basis of plant structure. On the broadest scale, the Arctic is divided into Low Arctic and High Arctic based upon plant structure, plant and animal species richness, and environment.

The Low Arctic is comprised mostly of tundra where plant cover is 100% consisting of wetland mires and uplands where woody species are abundant. The High Arctic contains small areas of tundra (mires with graminoids), but most of the ice-free landscapes contain polar semidesert with 20-80% total plant cover and polar deserts with only 1-5% total plant cover.

The mountains of northern Alaska and the Yukon Territory separate the boreal forests from the low shrub and tussock-dwarf shrub tundras to the north. The remainder of the Canadian Low Arctic was heavily glaciated, resulting in restricted development of soils and vegetation as major units or zones. The more continental, huge landscape of the Taimyr Peninsula has a more gradual change in climate and vegetation that enabled Russian ecologists to map and discuss zones of vegetation (Alexandrova 1980, Bliss and Matveyeva 1992, Yurtsev 1994). However, in Alaska, Canada, and much of Russia a mosaic pattern rather than clear-cut zones of vegetation predominate from south to north. The major units of vegetation within the Low and High Arctic follow.

Low Arctic

Shrub Tundras

North of the forest tundra in Alaska, Yukon Territory, and the Mackenzie Delta Region plant communities are dominated by tall shrubs along river and lake banks with shorter shrubs in uplands. These include *Betula*, *Salix*, and some *Alnus* with an abundance of dwarf-heath shrub species and upland species of *Carex*, *Eriophorum*, lichens, and mosses. Very similar patterns of shrub-dominated communities extend from the Ural Mountains to the Chukotka Peninsula.

Sedge-dwarf Shrub Tundras

The common heath genus of *Vaccinium*, *Ledum*, *Empetrum*, and *Arctostaphylos* with *Carex ensifolia* in Russia and *Carex bigelowii*, *C. lugens*, and *Eriophorum vaginatum* predominate in North America beyond the shrub tundras.

Tundra Mires

Wetlands in North America, the Central Yamal Peninsula, and in the lowlands of the Yana, Indigirka, and Kolyma rivers in Russia are dominated by *Carex*, *Eriophorum*, and in places *Arctophila* and *Dupontia*. There are very few woody species in these habitats.

Wetlands are much more limited in the Canadian arctic islands and in northern Russia, but where they occur, structurally and also in species they are generally the same as in the Low Arctic.

Polar Semideserts

Cushion plant-cryptogam semidesert

In the mountains of Alaska, Yukon Territory and the southern Canadian arctic islands, the northern parts of the Yamal, Gydan, and Taimyr Peninsula mats of *Dryas*, *Salix*, *Saxifraga*, and *Draba* predominate with an abundance of mosses and lichens. These communities and vegetation types extend into the Russian islands, especially Wrangel Island. Vascular plant cover seldom exceeds 20-30%.

Cryptogam-herb semidesert

Communities dominated by mosses and lichens but with scattered species of *Draba*, *Saxifraga*, *Luzula*, *Alopecurus*, and *Minuartia* predominate in the central and western Canadian High Arctic. There are probably comparable areas near the tip of the Taimyr Peninsula and on the Russian Arctic islands. Vascular plant cover is usually less than 20%.

Polar Deserts

These are the most barren lands in the Canadian High Arctic and on the Russian arctic islands. There are very few species of vascular plants and in many places, other than snowflush habitats almost no lichens and mosses. Vascular plant cover seldom exceeds 1-5%. These lands do not occur in a zonal pattern nor are they restricted to uplands or plateaus. Geologic substrate, surface soil moisture, soil churning, and soil nutrient levels are controlling factors.

In summary, the Arctic is best divided into Low and High Arctic with the major types of vegetation named and classified in terms of structure and not floristics. All of these vegetation types form mosaic patterns and are not easily classified or mapped as zones (Bliss 1988).

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NATURAL AND LONG-TERM ONGOING DISTURBANCES AS RELATED TO VEGETATION DISTRIBUTION IN THE ARCTIC

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In contrast with most vegetation regions, the Arctic is subject only to local natural disturbances, such as floods, landslides, eolian erosion or deposition. The vegetation is, therefore, in equilibrium with the climate, soils, fauna and competing vegetation. However, long-term, ongoing disturbances do occur. Cryoturbation, slope processes and frost-heaving tend to disturb the vegetation and the soil-forming processes, hindering the development of a soil nutrient base. These processes, together with climatic parameters and soil moisture, influence the kind and distribution of vegetation that are adapted to the long-term disturbance regime. In general terms, frost-caused disturbances can be related to soil parent materials, which, in turn, can be related to bedrock types. Coarse textured materials, whether derived from sandstone bedrock or from secondary deposition, are generally stable, but are subject to ice wedge development. Medium and fine textured soils of glacial till or colluvial origin are most unstable, with extensive slope movements (stripes), and with sorted and non-sorted cryoturbated surface forms. The heavier soils, occurring in depressions, are usually more moist and are subject to intense cryoturbation (earth hummocks).

At a regional scale, the expected frost-caused disturbances can be related to the dominant bedrock types from which the soils have been derived. In addition to the frost-related physical disturbances, the nutrient store of the soil influences the abundance and composition of the vegetation. Measurements show that on locally-enriched sites (lemming runs, near animal carcasses or human habitations) the nitrogen and phosphorus content of the soil is significantly higher than at non-enriched sites. This is accompanied by an increased biomass production and by the presence of other plant species. The parent material of the soils also influences the texture of the soil and the availability of soil nutrients. The limestone plains of the Canadian Arctic are singularly devoid of vegetation, in a large extent due to the unfavorable chemical environment of the roots. On a broad regional scale, the combined effects of climate and parent materials (with frost activity and soil moisture regime implications) determine the abundance and composition of the vegetation. Changes in climatic conditions (e.g. due to elevation, rain shadow, etc.) and/or regional changes in parent soil material will cause changes in the vegetation composition and abundance. A combination of soil and vegetation patterns can be readily discerned on remotely-sensed information. By qualifying and quantifying the vegetation of these units on the basis of existing vegetation/landform maps, a reliable broad-scale vegetation map can be constructed for the Canadian Arctic.

Map Representation of Ecosystem Production Processes

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Vegetation and its characteristic parameters are reliable indicators of the state of ecosystems and the degree of their transformation due to certain impacts. The ecosystem biomass represents the intensity of the biogeocoenotic process.

In order to provide a detailed description of the organization and dynamics of terrestrial ecosystems the whole set of indicators is required. Appropriate measurements are possible only within limited areas. On the other hand, it is clear that among the most informative and multipurpose indicators there are bioproductivity, production, and volumes of plant living and dead biomass. Important ecological parameters include the participation of individual species in the overall structure of plant biomass and its annual production, and the ratio between above-ground and below-ground, as well as live and dead components. The importance of ecosystems in the biosphere is determined by parameters describing the processes of organic matter formation and destruction.

Criteria suggested by Schwartz (1976) could be successfully applied as the integral indicators for assessment of the state of eco-systems. He pointed out that the most essential features of a "good biocoenosis" were high productivity allowing for rapid metabolism and recovery after natural or man-induced disturbances, and maximum values of the product of production and biomass, providing for the high stability of ecosystems.

The values of ecosystem biomass and production as well as their derivatives are indicators of its state. On this basis, a system of integral characteristics has been elaborated to give a quantitative description of the ecosystem functioning.

1. The *biosphere potential* characterizes the "activity" of an ecosystem and its contribution to biosphere processes such as photosynthesis and

nutrient cycling. It is expressed as a product of the total biomass of the ecosystem multiplied by its productivity: Bp = M * m, where M is the plant biomass, m is production, or the increase in plant biomass during the period of vegetation, and Bp is the biosphere potential.

This parameter could be expressed in terms of energy and, therefore, being correlated with the amount of photosynthetically active radiation available for a certain territory, it describes the efficiency of this ecosystem. This approach was used, for example, to evaluate the ecosystem stability for the Moscow region.

2. Specific features of the natural system functions and the trends of its changes could be also described by the *coefficient of activity* of the assimilation mechanism (Ca):Ca = m / M, where m is the ecosystem production, and M is the plant biomass. This value indicates the "rate" of plant biomass accumulation within the ecosystem.

3. The *index of destruction* (Id): Id = M / D, where M is the plant biomass and D is the mass of dead vegetation. This parameter represents the rate of organic matter destruction.

The definitions and the techniques of calculation of all proposed indicators provide for more correct assessment of the state of the ecosystem and the trends of its functioning.

For the territory of the Russian Arctic the maps of biosphere potential, the coefficient of activity, and the index of destruction have been compiled at the scale of 1:8,000,000 using the maps of plant cover, and plant biomass by Bazilevich (1993). Information on these maps contain some new aspects because the proposed criteria allow one to group different types of ecosystems that have similar biotic potential, and, on the other hand, subdivide the ecosystems that are similar in species composition but different in the rate of production processes. For example, different types of bog vegetation are grouped together, while within tundras there are ecosystems with quite different trends of accumulation and degradation of organic matter. The resulting picture gives the information on the distribution of ecosystems that are more-or-less "active" in the biosphere processes and allows assessment of their stability under both regional and global environmental changes.

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Methodological Aspects of the Investigation of the State of Arctic Ecosystems

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The intense technogenic impact on Arctic ecosystems does not yet have a long history, but its recent increase is pronounced. It rapidly affects the state of ecosystems which function under extreme natural conditions by destroying their fragile internal functional and structural links. The use of remotely-sensed satellite data for supporting the operational monitoring of the state of the Arctic environment requires the development of corresponding region- , ecosystem- , and impact-specific methodologies.

Vegetation, as a component which integrally reflects the impacts of both natural and human-related processes, serves as one of the most sensitive indicators of the state of ecosystems as well as of their transformation. The use of remotely-sensed data for assessing the impact on ecosystems, and the elaboration of approaches for the interpretation of Multispectral satellite images, are based on analysis of the state of vegetation cover and its spectral reflectance signatures in relation to the change of vegetation structure.

Moscow State University, the World Conservation Monitoring Center, and the Scott Polar Research Institute of the University of Cambridge are conducting a joint project aimed at the creation of a geo-referenced database reflecting the role of Arctic ecosystems in global and regional processes. The Kola peninsula was used for the first stage of the project development which included the elaboration of methodologies for data assembling and processing, the selection of a minimum set of indicators, and field studies to compare results of *in situ* and helicopter-based high-resolution spectrometry with the state of vegetation cover for supporting the interpretation of satellite data.

The results of studies of the structure of vegetation cover for mountain tundras on the Kola peninsula lead to the following conclusions: (1) As the technogenic pressure increases the total number of species falls from 12-14 to 1-2. (2) Lichens are the most sensitive to pollution, and their number falls from 7-9 to 0. (3) As the technogenic pressure grows, the species composition changes and some life forms are replaced by others. (4) Percentage vegetation cover decreases from 100% to 5%. (5) The total amount of plant biomass tends to decrease along with the ecosystem degradation. (6) The share of lichens in the total volume of plant biomass is constantly decreasing from 83% to 1%. (7) The plants of mountain tundra ecosystems studied on the Kola peninsula could be arranged into a succession according to their tolerance of technogenic pressure (Fig. 1).

Modern investigations of land-cover mapping from satellite images use computer methods based on standard classification algorithms (maximum likelihood, parallelepiped). Such an approach permits the discrimination of objects with different spectral signatures, but it does not take into account the character of the spectral signature as the main indicator of the types of objects. The idea of our new approach is to investigate the possibility of identifying different types of vegetation damaged by pollution by their spectral reflectance characteristics and, if this is successful, to try to develop new algorithms for image classification, based on the forms of the spectral signatures.

The results of *in situ* spectrometry in 4 bands (Fig. 2) show that the following types of tundra vegetation may be distinguished on the basis of their spectral reflectance characteristics: lichens; dwarf/shrub; mixed lichens and dwarf/shrub; stones with lichens; stones without lichens; and dead remains. Some individual species of lichens may be distinguished: *Cetraria nivalis, Cetraria islandica, Alectoria nigricans, Cladina mitis.* Mixed tundra vegetation may be divided by degree of industrial damage to technogenic deserts, strongly damaged tundras, and other tundras without their differentiation. The "pre-computer" (visual) interpretation was first made based on data from previous field studies. Twenty-seven classes have arisen from visual interpretation, including industrial areas and settlements, technogenic deserts in the areas of industrial impact, damaged and healthy tundra, and forest vegetation. A map of damaged vegetation was compiled at a scale of 1:200,000. A generalized version of this map, with eight classes, is shown in Fig. 2 at a scale of 1:500,000. Multispectral reflectance data were acquired for determining spectral signatures.

The spectral signature curves derived from 120 test areas were then assigned to the classes used in Figure 2, as shown in Figure 3. Analysis of these curves shows that the following classes may be distinguished on the basis of spectral signature: settlements and industry; technogenic deserts; stony deserts of the nival zone; mixture of stony deserts of the nival zone and tundra vegetation; tundra vegetation, differentiated as significantly damaged and not damaged; forests-- severely damaged (80-100%), strongly damaged (50-80%), slightly damaged (up to 50%) differentiated as coniferous, mixed, and deciduous; water-- clear and contaminated. On the basis of this material, a new algorithm has been developed which takes into account the form of the spectral signatures curves. The algorithm uses a different approach for processing non-vegetated and vegetated objects. This approach gives the possibility of optimal classification of industrially-damaged northern vegetation.

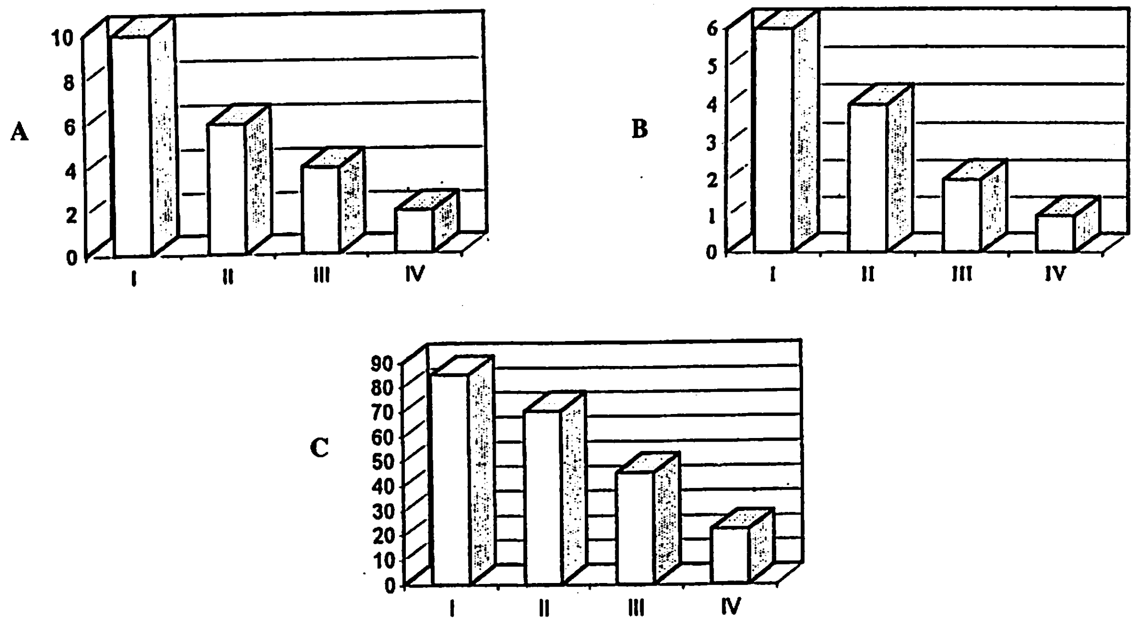

FIGURE 1. *Mean number of (A) species; (B) lichens and (C) protective cover (%) according to state of ecosystems (I - background, II - relatively good, III - satisfactory, and IV - poor).*

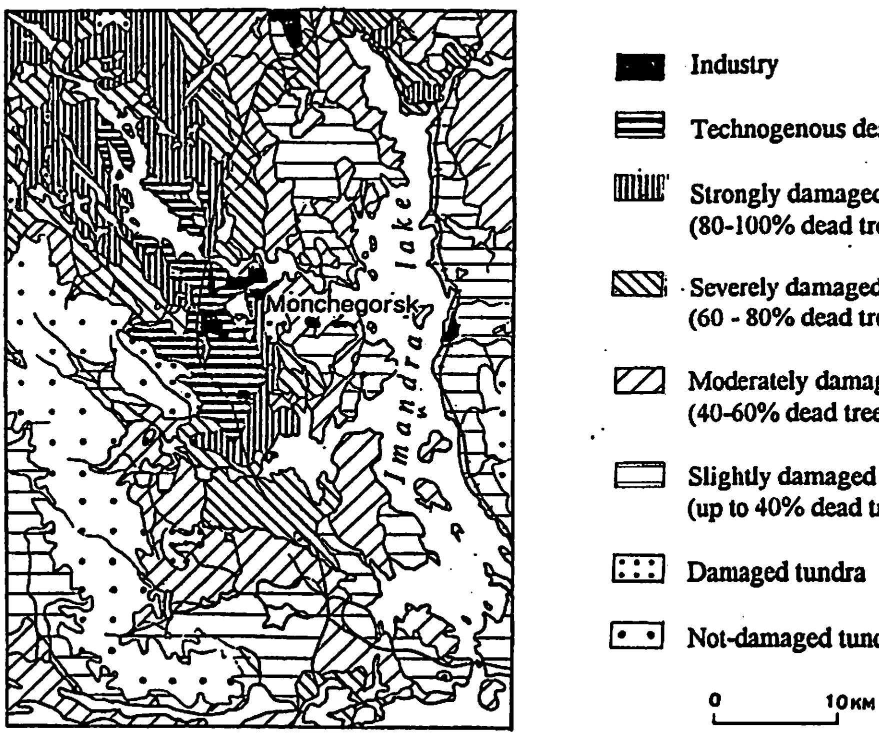

FIGURE 2. *Zones with industrial change to vegetation around Monchegorsk.*

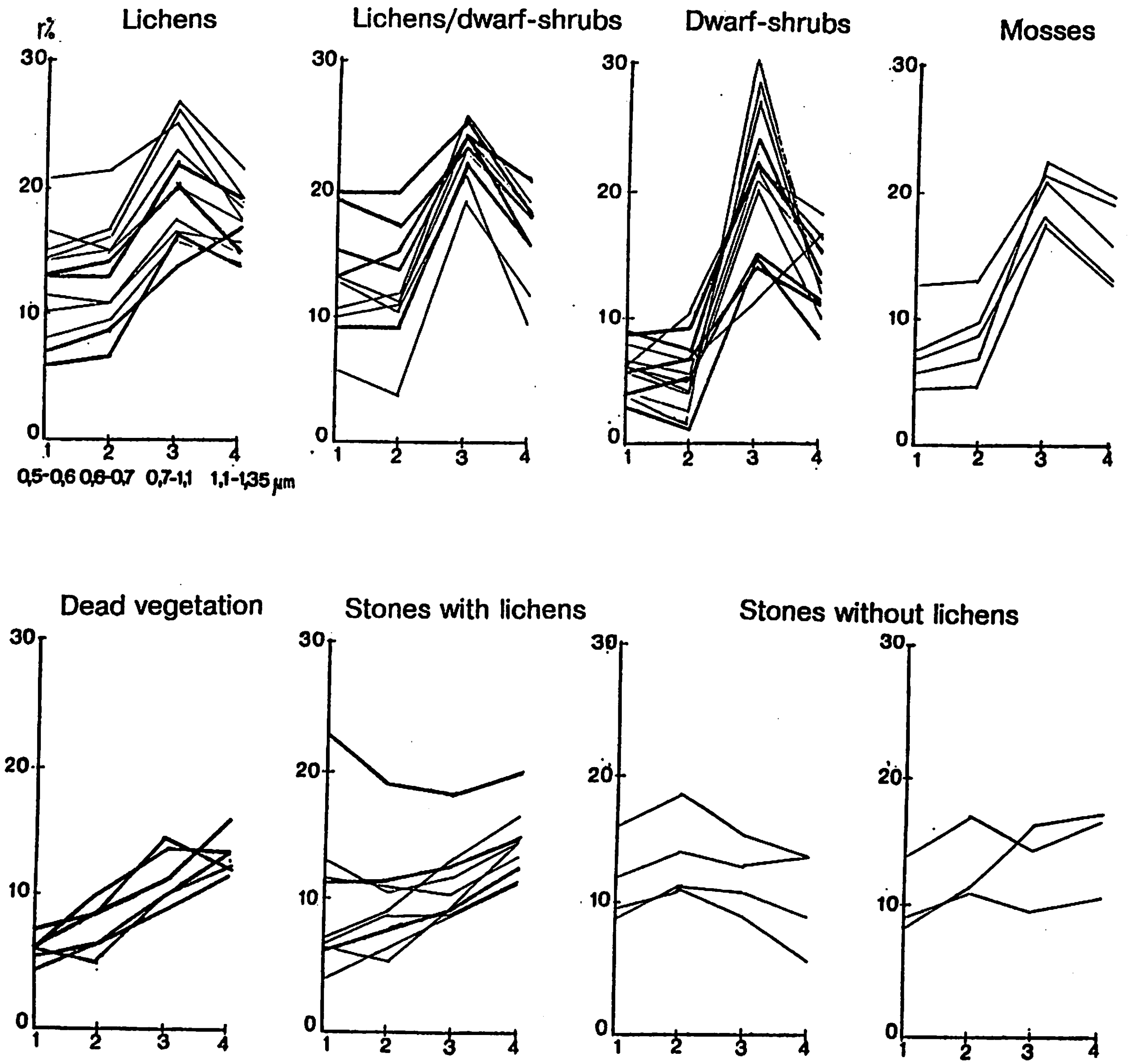

FIGURE 3. *Spectral signatures of different objects. Ground spectral radiometry data (4-band).*

GRID-ARENDAL AND THE 2ND CIRCUMPOLAR ARCTIC VEGETATION MAPPING WORKSHOP, ARENDAL, NORWAY, 19-24 MAY 1996

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As a United Nations Environment Programme (UNEP) institution with the mandate for information support of environmental protection and management in polar areas, GRID (Global Resource Information Database) -Arendal, through its Polar Programme, is continuously involved in regional and international processes related to circumpolar environmental mapping and the development of corresponding data sets and databases.

The most recent examples include:

• the support to the Arctic Environmental Protection Strategy (APES) initiatives such as Conservation of Arctic Flora and Fauna (CAFF; background environmental mapping, protected areas), Protection of Arctic Marine Environment (PAME; mapping of Arctic environmental conventions and agreements), and the Arctic Monitoring and Assessment Programme (AMAP; meta-data and radiation pollution modeling database);

• Arctic Environmental Database for Europe and Asia (AEDEA), a project aimed at the development of an Arctic environmental database, with primary focus on Arctic Russia;

• Barents region and circumpolar wilderness mapping;

• Circumpolar Arctic Ecoregions, a joint project in cooperation with US Environmental Protection Agency (EPA), US Geological Survey (USGS), the Norwegian Directorate for Nature Management, and a number of other institutions aimed at providing an integrated regionalization of the Arctic environment.

Based on experience gained so far, it can be said that there exists a need for circumpolar vegetation mapping. The perceived applications may be:

• background mapping/ regionalization;

• spatial framework for presenting the state of ecosystems and habitats;

• assessment of ecosystems' sensitivity and response to impact;

• characterization of transfer media in trophic chain/ health issues;

• assessments.

It can be added that the extent to which the product is used in such applications may substantially depend upon the clearness of the legend and of related definitions, especially for those who are not necessarily professional geobotanists.

There is a range of circumpolar and regional data resources and processes relevant to vegetation mapping which can be used for the map compilation. These include remotely-sensed data, digital sources of topographic data [e.g., Digital Chart of the World (DCW), the International Permafrost Association (IPA) digital circumpolar permafrost map, and a number of paper products covering among others, land use and land cover themes, and various regional (in particular North American and Russian) paper and digital sources]. The operational networks, AEPS, national focal points, and world-wide UNEP/ GRID centers can also be used.

I.C. NORTH AMERICAN PAPERS

A PLAN FOR A NORTH AMERICAN ARCTIC VEGETATION MAP

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This paper discusses the idea that the best approach to mapping circumpolar arctic vegetation in North America is from a central facility and not necessarily on a country-by-country basis. We argue that the most effective strategy for North America is for a single country to lead a mapping effort that would include the arctic regions of

Canada, Greenland, and the United States. Because of the economies of scale, and the fact that data acquisition is one of the most expensive parts of the study, map production efforts would be more efficient if concentrated at one facility.

The EROS (Earth Resources Observation Systems) Alaska Field Office (AFO) in Anchorage is a modern scientific facility with a highly experienced staff, state-of-the-art hardware and software, and supplemental map data (Shasby and Carnegie 1986; Fleming 1988; Markon 1995). The AFO also has the capability to efficiently communicate and transfer information to Canada and Greenland, and has at its disposal the staff and facilities of the US Geological Survey's EROS Data Center in Sioux Falls, South Dakota, US.

The AFO could accomplish this task in partnership with the University of Colorado and the US Fish and Wildlife Service. Specialists with a strong background in the vegetation of arctic Canada, Greenland, and Alaska would supplement the process by providing maps from their respective countries and their field knowledge. This would require travel of two or three individuals from Canada and Greenland (Denmark) to the AFO during the mapping process for one or more brief periods of time.

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A STATEWIDE VEGETATION MAP OF ALASKA USING PHENOLOGICAL CLASSIFICATION OF AVHRR DATA

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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. Instead of analyzing the spectral response of the earth's surface from a single point in time with several bands, a maximum Normalized Difference Vegetation Index (NDVI) 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, any clouds that might hinder determining the maximum NDVI value for that period. In studies in various parts of the world, the length of the periods has varied between 10 days and a month, depending on the amount of cloud cover and rate of change of the vegetation condition. The span of time over which the data are acquired also varies, and can be as short as seven months, as in Alaska, to an entire year in equatorial regions. The data sets currently being developed for the Global Change community have periods one month long and extend for an entire year, 1 April to 31 March.

Loveland *et al.* (1991) have produced a detailed land characterization of the conterminous United States using time-series AVHRR data and digital image processing techniques. Their work demonstrated that regional patterns may be effectively mapped in conjunction with ancillary data. The unique spatial and temporal qualities of the AVHRR data provide information that leads to a better understanding of regional biophysical characteristics of vegetation communities and patterns. The data provide synoptic views of the landscape and depict phenological diversity, temporal vegetation phenology (green-up, peak of green, and senescence), photosynthetic activity, and regional landscape patterns. In this study, NDVI data derived form the AVHRR satellite were used to characterize regional phenological vegetation patterns in Alaska.

The procedures used to collect the AVHRR data and generate the NDVI composites are described by Eidenshink (1992). The NDVI values are derived from a ratio of the visible and near-infrared spectral channels of the AVHRR sensor. For the Alaskan data set, the NDVI data were composed of 11 half-month periods, between 1 May 1991 and 15 October 1991. This 11-band set was used to develop the land characterization products that describe the vegetation characteristics of the Alaskan landscape. A 54-class phenological classification was derived using a combination of an unsupervised classification of the NDVI values over vegetated areas in the state, a reclassification dropping "bad dates" where cloud contamination was still a problem, stratification of the classes using reference data sets, and pooling of phenologically and geographically similar classes. Labeling and evaluation during the analysis was accomplished by using existing land cover classifications where available. This training data set was built from a series of Landsat MSS data classifications developed by the various land management agencies in the state over the last 15 years. The MSS classifications were resampled and reprojected into the 1-km statewide projection and the legend classes translated to a standardized statewide legend.

A detailed statistical description page was developed for each of the final 54 phenological classes summarizing the characteristics of the class. Many different types of data were used in the descriptions, including: (1) the NDVI curve for the 1991 season and data points for 1990 and 1992 NDVI values; (2) areal extent of the class; (3) geologic rock types and ages; (4) permafrost types; (5) soil sub-order classes; (6) average elevation, slope and precipitation; (7) vegetation classes; (8) hydrologic regions; (9) ecoregions; (10) and physiographic provinces. Other products generated from the data include; phenological composite maps (onset, peak, and duration of greenness), photosynthetic activity maps (mean and maximum greenness), and a regional vegetation classification. The regional vegetation classification was developed from the land characterization classes by combining the 54 classes that had similar vegetation, geographic distribution and phenological curve, resulting in 24 vegetated and 3 non-vegetated classes.

The most distinct classes in the classification were those that also identified the most significant disturbance to the area during the growing season, i.e. fire. The analysis demonstrates how the AVHRR data can be used in combination with other data sets to characterize the land cover and its changes over time. The time-series data provide opportunities to study phenological processes at small landscape scales over periods of weeks, months, and years. Regional patterns identified on some maps are unique to specific areas, others correspond to biophysical or ecoregional boundaries. The data provide new insights into landscape processes, ecology, and landscape physiognomy that allow scientists to look at landscapes in ways that were previously difficult to achieve.

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AN ELECTRONIC HIERARCHIC GEOBOTANICAL ATLAS FOR ARCTIC SYSTEM SCIENCE

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An electronic hierarchic geobotanical atlas is being developed through the Arctic System Science (ARCSS) Land-Atmosphere-Ice Interactions (LAII) Flux Study. ARCSS is part of the US Global Change Research Program. LAII is a component of ARCSS. The two main goals of ARCSS LAII are to: (1) understand the variables and processes controlling the fluxes of energy, water, CO_2 and CH_4 from arctic ecosystems to the atmosphere and ocean, and (2) determine how these fluxes will change in response to future variations in climate. Detailed and accurate geographic information is needed at a variety of scales to determine the spatial variability of key ecosystem processes.

The Hierarchic Geographic Information System (HGIS) is designed to address a wide variety of questions ranging from plant-level responses to the global distribution and function of tundra ecosystems. The area of focus for the atlas is the Kuparuk River basin in northern Alaska, but extrapolation is planned for subcontinental and eventually circumpolar scales. Access to the electronic atlas of the HGIS is via the World-Wide Web (http://www.colorado.edu/INSTAAR/ TEAML/atlas/).

Floristic Division and Vegetation Zonation of Greenland of Relevance to a Circumpolar Arctic Vegetation Map

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Greenland has the largest extension in south-north direction of all the arctic territories stretching from 60°N in the south to the northernmost land in the world at almost 84°N. Such a large area has a wide variation in climate, geology, soils, and consequently, differences in local flora and vegetation. Except for a few inland areas in southernmost Greenland all of the island is classified by most botanists as belonging to the Arctic and is subdivided into a low arctic section and a high arctic section.

Thanks to three major papers on the floristic phytogeography of South, West, and North Greenland (Bay 1992, Feilberg 1984, Fredskild 1996) published within the last decade we have a large updated knowledge on the distribution of the vascular plants and the regional flora plus information on the vegetation of Greenland. The present number of vascular plants in 1993 was 513 species (Bay 1993). Only very few species are considered endemic to Greenland and most of the plant species have migrated to Greenland mostly via three routes. Low Arctic and boreal species have either immigrated from eastern North America or from Europe via The Faeroe Islands and Iceland. High Arctic species have mainly immigrated from northern parts of North America as they have had an easy access to Northwest Greenland and have spread further into the high arctic parts of Greenland. When comparing species of the floristic provinces with either a North American or Eurasian distribution it appears that the number of western species exceed the number of eastern species in most parts of Greenland. The only place in Greenland where the eastern species are in the majority is in Southeast Greenland. Thus, Greenland is biogeographically more closely related to North America than to Europe.

With the substantial knowledge from the phytogeographical studies we have a basis for revising the delimitation of the floristic provinces and districts proposed nearly 40 years ago. This division is based on more than 120,000 herbarium specimens. There are three major changes: (1) The floristic province North Greenland is divided into two districts of which the coastal one comprises all the polar deserts of Greenland. (2) The border in West Greenland, which is a distinct phytogeographical border dividing West Greenland into the low and middle arctic zone, is revised. (3) The delimitation of the South Greenland province has been extended northwards. In addition, minor changes to the division of Northeast Greenland are proposed. The northern district of central East Greenland is divided into two districts giving a total of four district in this province, and the border between coastal and continental inland areas is moved eastwards leaving only minor areas in the coastal district. Areas in Southwest and Southeast Greenland hitherto considered coastal are now included in the continental provinces.

Contributions to Level 1

According to Yurtsev's phytogeographical zonation (Yurtsev 1994) no areas in northern Greenland are included in the High Arctic Tundra Subzone leaving Greenland as the only area without areas in this zone. Recent investigations in northern Greenland (Bay 1992, Bay in press, Bay and Fredskild 1997) showed that the coastal areas of North Greenland do belong to the High Arctic Tundra Subzone, giving this subzone a complete circumpolar distribution. Yurtsev includes the northern half of Greenland in the northern variant of Arctic Tundra Subzone. Most of this area (70°-80°N) should be included in the southern variant leaving only the area 80°-83°N in the northern variant of the Arctic Tundra Subzone. This is in agreement with the delimitation of the Middle Arctic Tundra Zone proposed by Elvebakk (1985) and the "Dwarfed and Prostrate Shrub Zone" of Edlund (1990).

Contribution to Level 2

The major change to Yurtsev's level 2 is that all the areas in the southern half of Greenland should be included in the Arctic, only leaving the warm inland fjord region outside the Arctic. Based on a high proportion of boreal, particularly boreal-oceanic, species (cf. Böcher 1978), Yurtsev (1994) excludes large coastal areas of southern Greenland from the Arctic in his floristic division. Yurtsev suggests these areas to be part of the Hypoarctic Subzone, which is outside the Arctic, together with Iceland. These Greenlandic areas are otherwise considered low arctic by most botanists. To test this statement a comparison of the proportion of boreal species in the floras of these North Atlantic areas shows that Greenland has the lowest number of boreal species and that the number of arctic species exceeds the number of boreal species. The proportion of boreal species is 25% in the northern part of Southwest and Southeast Greenland and 47% in the southernmost part (Böcher 1978), whereas no less than 67% of the Icelandic flora comprises boreal species (Einarsson 1963). A comparison of the flora of the Baffin-Labrador province, which is included in the Arctic, and southern parts of Greenland at the same latitude, considered outside the Arctic by Yurtsev (1994), shows that there is an overlap of 49% of the species (Böcher *et al.* 1978, Porsild and Cody 1979). 87% of the species (n = 62) of the Baffin-Labrador province not found in Greenland are boreal, whereas only 58% (n = 142) of the species in hypoarctic Greenland not found in the Baffin-Labrador province are boreal.

These facts strongly favor the concept that the coastal areas in the southern half of Greenland are a part of the circumpolar Low Arctic. The only area in Greenland which is classified "non-arctic" is the inner fjord region in South Greenland characterized by the occurrence of low birch trees (*Betula pubescens*), and a number of boreal species only found in these warm inland areas. The Ellesmere Island-North Greenland subprovince is slightly revised by also including the Thule district in Northwest Greenland. A floristic comparison of North Greenland with Northwest and Northeast Greenland on one hand and Ellesmere Island on the other clearly supported the conclusion that North Greenland belongs to the Ellesmere Island- North Greenland subprovince. The delimitation of the Ellesmere Island-North Greenland province should, however, be south of the Thule district in Northwest Greenland as there is a closer floristic relation between Ellesmere Island and the Thule district than between Ellesmere Island and the whole of the West Greenland province. 63% of the species of the total number of species in Ellesmere Island and Thule district are common to these areas. The figure for North Greenland compared to Ellesmere Island is 67%, whereas there is only about a 50% overlap between Ellesmere Island and West and East Greenland.

Contribution to Level 3

A zonation of the vegetation of Greenland of relevance to a circumpolar vegetation map is proposed. Greenland is divided into seven vegetational regions comprising a coastal and continental region in High, Middle, and Low Arctic Greenland in addition to a boreal region in continental South Greenland. Each region has a similar set of major vegetation types characterized by the dominating species, indicator species, species diversity, and degree of cover of vascular plants.

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TABLE 1

Vegetation zonation of Greenland relevant to a circumpolar arctic vegetation map

ARCTIC REGION

Zone	Geographical distribution	Dominating vegetation	Zonal vegetation	Indicator species	No. of vasc. species/ vasc. plant cover (%)
Polar deserts (coastal High Arct.)	North of 80°N	Herb barren	Herb barren	*Ranunculus sabinei*	40/ 0-5
High Arctic; continental part	North of 80°N	Fell field *Dryas* community *Salix arctica* community *Cares stans* fen	*Dryas* community	*Erysimum pallasii*	120/ 0-10
Middle Arctic; coastal	E.Grl.: 70°-80°N W.Grl.: 70°-76°N	*Cassiope* heath Fell field *Salix arctica* snowbed (only E.Greenl.)	*Cassiope* heath	*Carex ursina*	250/ 5- 50
Middle Arctic; continental part	E.Grl.: 70°-80°N W.Grl.: 70°-72°N 76°- 79°N	*Cassiope* heath *Betula nana* heath (< 75°N) *Salix arctica* snowbed (only E.Greenl.) *Carex stans* grassland *Carex stans* fen	*Cassiope* heath	*Ranunculus nivalis,* *Draba alpina,* *Epilobium arcticum*	
Low Arctic; coastal part	60°-70°N	*Empetrum* heath Mixed dwarf shrub heath *Salix herbacea* snowbed *Salix glauca* copse *Veronica* herb slope *Eriophorum scheuchzeri* fen	*Veronica alpina* herb slope	*Empetrum hermafrodit.* *Salix herbacea* *Ledum groenlandicum* *Diapensia lapponica* *Veronica alpina,* *Gentiana nivalis*	325/ 10-50
Low Arctic; continental part	E.Grl.: 63°-66°N W.Grl.: 62°-70°N	*Betula nana-Ledum palustre* heath *Vacc. uliginosum-Salix glauca* heath *Salix glauca* copse *Carex supina* steppe *Eriophorum scheuchzeri* fen	*Betula nana* heath	*Betula nana* *Carex supina* *Salix glauca* *Ledum palustre*	

"NON-ARCTIC" REGION

Boreal	60°-62°N continental parts	*Betula pubescens* woodland Low arctic, continental vegetation types	*Betula pubescens* woodland	*Betula pubescens* *Sorbus groenlandica* *Streptopus amplexifolius*	350/ 10-75

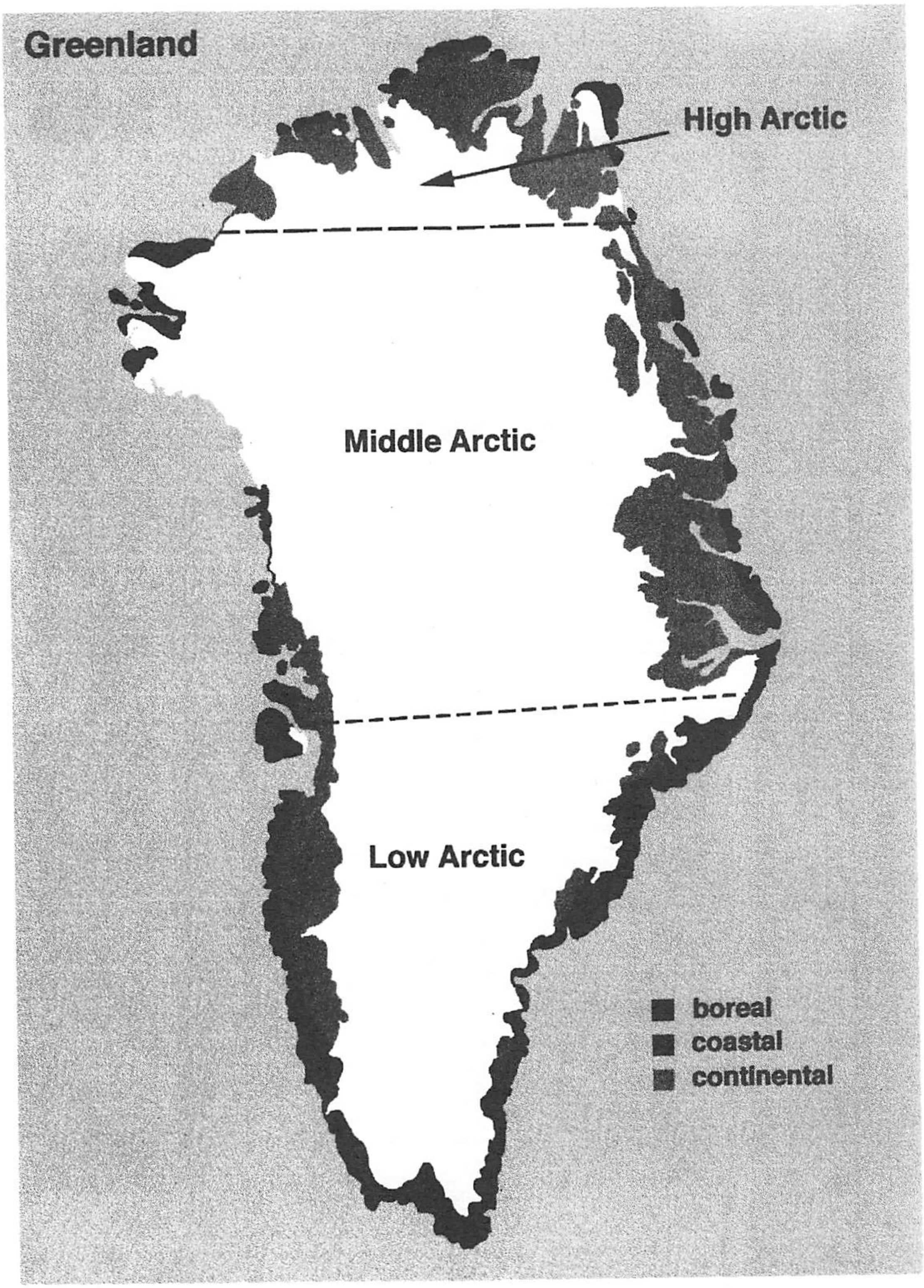
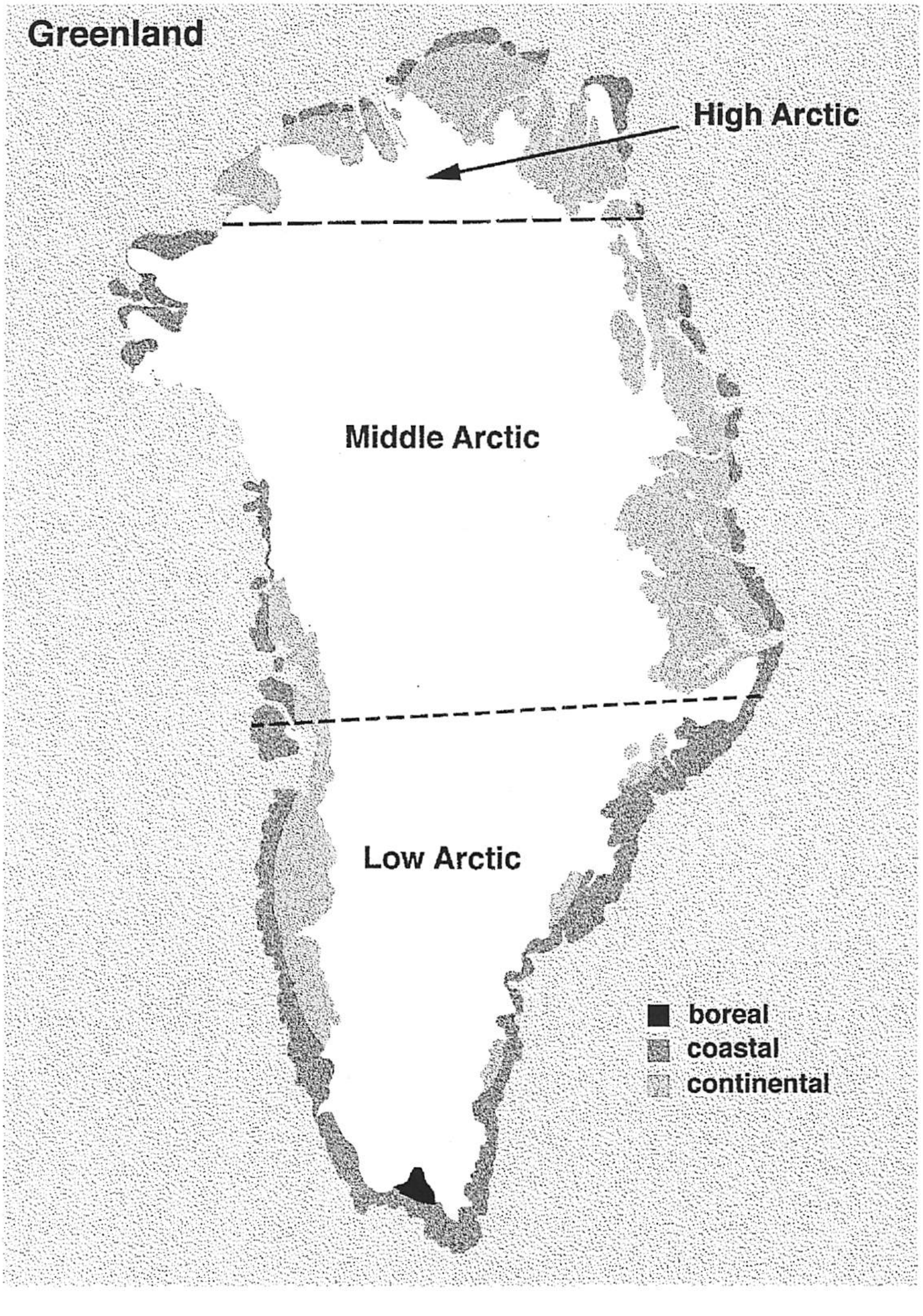


FIGURE 1. *Vegetation zonation map of Greenland.*


Greenland
High Arctic
Middle Arctic
Low Arctic
boreal
coastal
continental

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I.D. SCANDINAVIAN PAPERS

VEGETATION MAPPING IN THE NORTH ATLANTIC REGION AND RELEVANCE TO THE CIRCUMPOLAR MAP

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In accordance with Yurtsev's (1994) north-south vegetation zones Iceland belongs to the oceanic Hypoarctic subzone number VI. Floristically, on the other hand, it is situated just south of the border of the Arctic region, as only approximately one-third of its 485 species of vascular plants have their main distribution in the Arctic. The majority of the species also either have a circumpolar or Eurasian distribution, while only a small percentage of the species have their main distribution in America, and therefore Iceland can without doubt be accounted floristically as distinctly European.

Mapping of the vegetation of Iceland started about 40 years ago and is briefly described by Gudbergsson (1981) and Einarsson (1995). The legend units used, defined by S. Steindórsson and described by the same author in 1981, consisted of two complexes: dryland vegetation and wetland vegetation, with each complex divided into several sociations based on growth forms and dominant species in the upper layers of the vegetation, without much regard to mosses and lichens. The main purpose of the mapping work was to provide information about the plant communities, evaluate their quality for agricultural use, and to provide a basis for wise planning and use of the land. Therefore, the treatment of the plant communities on land with more or less continuous vegetation cover, considered to be the most valuable to agriculture, is much more detailed than that of communities on land with sparse vegetation cover. A total of about 60% of Iceland is thus covered by such vegetation maps in various stages of publication. Based on these existing maps, it will not be difficult to make a vegetation map of Iceland as a part of the planned Circumpolar Arctic Vegetation Map.

It is considered to be highly relevant to make and publish a vegetation map of the Arctic as a whole, with the same legends applied for the whole area, even on a rather small scale as is being planned here where only the main features of the vegetation can be shown.

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THE FENNOSCANDIAN PERSPECTIVE FOR A CIRCUMPOLAR ARCTIC VEGETATION MAP LEGEND

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The task of finding the best alternative for a legend of the circumpolar vegetation map meets the following major challenges:

(1) The use of representivity; each mapping polygon will cover a vast mosaic of different vegetation types because of the low spatial resolution of the product.

(2) The use of simple systems that will be user-friendly; otherwise the map legends will be neglected or simplified or changed by others beyond our group of geobotanists who demand simpler names of the units.

(3) To reach consensus between names that have strong national traditions.

Before these problems are addressed some important agreements achieved so far should be summarized. The contents of the five latitudinal zones proposed by Yurtsev (1994) are generally agreed upon, as are his latitudinal floristic zones. To supply a third hierarchical level following Russian arctic vegetation map traditions is also a task that has not been met with objections. The mapping group has also agreed to delimit the Arctic according to its lowland distribution. That means that the penetration towards the south of more-or-less similar vegetation along mountains, e.g. in Iceland, Fennoscandia, the Urals, in Alaska/Canada, is neglected in our mapping process.

The most difficult and probably one of the most important tasks in our process is to agree on the latitudinal zone terminology. Following the criterion of user-friendliness only the following terms are available: 'Polar Desert', 'High Arctic', 'Low Arctic', 'Arctic Tundra', and 'Subarctic'. The terminology 'High-Low Arctic' has mostly been used by authors that are not represented in this group, but have the widest audience covering all disciplines and laypersons alike. We have advocated the rejection of this terminology and instead reserve the use of the prefix 'High - Low' for altitudinal belt zonation in mountains. If we do so we need to have very good alternatives. The term 'Subarctic' is also rejected because it has been used so often for the northernmost forest zone; but again, this word has a very strong foothold in the arctic literature.

'Arctic Tundra' remains as a commonly accepted terminology. It reflects the core of the arctic ecosystem: the tundra in its typical aspect, a cover of low-growing vegetation that is situated in the Arctic, as opposed to in the alpine (many authors use the term 'tundra' to describe alpine vegetation). According to Fennoscandian and Soviet/Russian tradition, the terms 'northern', 'middle', and 'central' can be used, and we can reserve these names to the three zones being situated in the central core area of the Arctic. To use names like 'Northern variant of the southern zone' is considered here to be in conflict with the demand for simplicity, and 'arctic proper' implies that we are not sure of the true location of the Arctic.

We also lack names for the two most extreme zones to the north and to the south. To the north the term 'Polar Desert' (or 'Arctic Polar Desert' as opposed to the 'Antarctic Polar Desert') has now been accepted universally, although there are mixed opinions in Russia, and Yurtsev is of the opinion that this name is not descriptive enough. It is agreed here that there are areas with a higher vegetation cover within the climate zone considered to be polar desert. The production of a vegetation index map will greatly contribute to our knowledge on such areas. They exist on easternmost Edgeøya on Svalbard (dominated by temperature-indifferent mosses like *Tomentypnum nitens*), possibly also in northernmost Ellesmere Island and in smaller areas on Zemlja Frantsa-Josifa. This can be interpreted and described on our third-level legend. The same is the case with polar desert-like vegetation on limestone south of the climatic polar desert areas, e.g., in arctic Canada.

The southernmost zone is problematic, because the two names applied to this zone, 'hemiarctic', and 'hypoarctic' in Fennoscandia and Russia, respectively, are practically unknown outside their respective countries and will probably very slowly be accepted by a wide audience. We propose here that the new and very simple term 'arctic shrub-tundra' should be considered. It points to the major aspect of this zone, the zonal dominance of shrubs.

Zonal maps covering Svalbard, based on Elvebakk (in press) and northernmost Fennoscandia based on Dahl *et. al* (1986) are presented. The latter needs to be correlated with the boundaries on the Kola Peninsula, and the former to neighboring Greenland where vegetation conditions are quite similar.

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I.E. RUSSIAN PAPERS

TOWARDS STANDARDIZATION OF LAND COVER AND LAND USE DATA AND INFORMATION: ANALYSIS OF THE MAP 'VEGETATION OF THE USSR'

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Following expert meetings convened by the United Nations Environment Programme (UNEP) and the Food and Agriculture Organization (FAO) in 1993 [UNEP/GEMS (Global Environment Monitoring System), 1993] and 1994 (UNEP/FAO, 1994), a joint project between UNEP, FAO and the Institute of Terrestrial Ecology (ITE) was initiated to develop a General Global Nomenclature for Land Cover and Land Use.

The purpose of this nomenclature is to serve as a general reference framework and as a means of inter-conversion between different specialist classification systems, and emphatically not as a universal system. This project is clearly relevant to the development of the Circumpolar Vegetation Map because whatever legend is developed for the Arctic regions will need to be incorporated into the global nomenclature comparison.

Development and application of this global nomenclature involves the careful scrutiny of existing schemes, to separate their categories into a discrete set of parameters. Classification of existing natural terrestrial cover in, for example, the vegetation map of the former USSR, 1990, is hierarchical with the top hierarchy comprising main categories such as glacier, Arctic desert, tundra and boreal forest. The second-level categories describe community type: open association, grass, moss and dwarf shrub. The third level is a floristic description. These categories have been examined and the land cover attributes disaggregated to serve as key terms being developed by ITE and World Conservation Monitoring Centre (WCMC) within the land cover glossary (Wyatt *et al.* 1995). When the terms occur in combination, Boolean operators are used to describe the categories; e.g. (grass AND moss) OR (dwarf shrub AND grass AND moss). Commonality of these terms can then be sought between different classifications across different regions, facilitating standardization of land use and land cover data for reporting, analysis, and mapping.

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COMPILING THE RUSSIAN PART OF THE CIRCUMPOLAR ARCTIC VEGETATION MAP: THE PRESENT STATE AND ASSOCIATED QUESTIONS

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At present the compilation of the Russian part of the map (phytogeographic version: scale 1: 7,500,000) is carried on in the following sectors: (a) East European (with Polar Ural and Novaya Zemlya); (b) West Siberian; (c) Taimyr; (d) Yakutian (with Novo-Sibirskiye Ostrova- New Siberian Islands); (e) Chukotka (with Wrangel Island). The works in the West-Siberian and Yakutian sectors are most advanced now. The preliminary versions of the legends are already prepared, though the maps themselves are still not ready. The vegetation map for the Chukchi Peninsula (the draft version) is available, too, for the other parts: Central and West Chukotka, Taimyr, East-European Tundra with Arctic Ocean islands. An enormous amount of work is needed on the transformation of the available large-scale materials into the 1:7,500,000 scale map.

At the meeting of the Russian participants of the CAVM project, held 17-19 April, 1996 in St. Petersburg, the existing map legends for different sectors of the Russian Arctic were compared and discussed with respect to possibilities for their unification. Some questions arose that are associated with the third level of the legend, such as follows:

1. Should a lower unit of the map legend show only the zonal (usually extensive) types of plant communities (in placor positions) or may it include, besides some other ones such as snowbed vegetation, plant cover of crystalline bedrock exposures among a silty or sandy plain, thermokarst depressions, etc.? And, of secondary importance, what are the criteria for selecting those communities, their extension, frequency, etc.? It is hardly necessary to list most of the syntaxa met within a third-level division contour, because doing so would cause the legend to become vast. While characterizing any vegetation unit (syntaxon) in the legend, one should follow the principle of ecological uniformity and, besides, provide (in brackets) the names of a few differential species in addition to the dominant ones which can be common to several units of the legend. When syntaxa are selected to be included in the legend units in addition to the prevailing ones, those specific for a sector or indicative of peculiar lithological conditions should take priority.

2. Another case is when a few vegetation units (each with a limited extension) regularly alternate within a contour forming a single integrated entity which is usually referred to as a "vegetation complex". Numerous types of polygonal, frost-boil or cracked-hummock tundras belong here. They (and analogous structures) need clear definition. So, we need a convention that relates what sorts of complexes we should call "the tundra mires" (e.g. if micro-elements of both tundras and mires are represented), and what are simply "mire complexes" of higher vegetation units for the legend construction?

3. Will we use a word combination "in complex with ..." or "in combination with ..."? Both are in wide use in some West European vegetation maps (e.g. Wagner's maps for Germany and Austria) as well as in the Vegetation Map of Europe of scale 1:25,000,000. If we mean by the term "complex" the polygonal, frost-boil, and similar vegetation systems (see above, point 2), we can avoid using the term in the legend. The other cases all could be covered by the term "combination" (see point 1).

4. According to what principle will we classify the vegetation units in the legend (the 3rd level) within a regional category (1-2 levels)? For instance, within a subdivision:

Arctic Tundras

West Siberian 1, 2, 3, etc.

According to their territorial extension? Or according to the typological principle?

For instance the participants of the Russian team's meeting in April 1996 supported listing communities in the following order:

(1) Zonal tundras of silty, moderately drained watersheds (placors); (2) psammophyte tundras of sandy plains; (3) tundra mires of wet flat plains and depressions, etc.; followed by intrazonal vegetation, e.g. (4) flood-plain vegetation; (5) vegetation of coastal lowlands, including the halophyte zone, etc. The third approach would be: listing at first simple (relatively homogenous)

vegetation units, then complexes, and afterward, still more heterogeneous units (with combinations).

5. What place in the legend will vegetation units reflecting vertical zonation of mountainous territories occupy? Will they all be placed at the end of the legend (with a subtitle: "Montane tundras", as a 1st level division - of the same rank as is given to the subzonal tundra vegetation divisions) or they will be subordinated to subzonal and sectoral categories? (See Russian CAVM Working Group, this volume). The second approach was repeatedly supported by the Russian team at the last meeting (in April 1996).

At the present stage, the participants of the CAVM International Project urgently need a baseline map of scale 1:7,5,000,000 of the same projection which will be accepted for the final author's model of the map, with the same hydrographic system, etc. as well as other cartographic products useful for the vegetation mapping (including false-color remote-sensing products, scale 1:7,500,000). It is especially important since the next stage of works should be started by creating the contour-network of the map for each sector of the Arctic. This basic contour system could be essentially corrected by the remote-sensing materials (including the correction of the southern boundary of the Arctic) and thus could effect the legend construction.

There are many technical questions associated with the creation of the map which need to be solved before the author's model of a Circumpolar Arctic Vegetation Map will be compiled. They concern indexing the legend's units (including sector's indices), the reflection in the legend of relative roles of species or growth forms in polydominant plant communities, the scale of colors and the system of shading, and the use of extra-scale symbols for rare, but important, vegetation units, etc.

COMPILATION OF THE RUSSIAN ARCTIC ENVIRONMENTAL DATABASE

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This paper presents the first results of compiling the database for the Northern region of European Russia (Murmanskaya and Arkhangelskaya oblasts, Carelian Republic) within the joint project of WCMC (World Conservation Monitoring Center), SPRI (Scott Polar Research Institute) and the Faculty of Geography of Moscow State University.

The creation of a Russian environmental database will promote the development of an information base for environmental management and conservation in the North. As a basic source of information, a series of maps for universities at a scale of 1:4,000,000 was chosen. Most of the original maps were compiled by specialists from the Research Laboratory for Complex Mapping and Atlases, Faculty of Geography, Moscow State University. The large-scale maps will also be considered when they provide necessary details and reliability, while small-scale maps will be used for global change research. The latter applies to the map of vegetation, since vegetation is one of the most vulnerable parts of the environment, and its properties quickly respond to changes in environmental conditions. Thematic information of the database consists of four thematic blocks, and is presented in the form of digitized maps using ARC/INFO 7.03 software installed on the SUN SPARCstation 10 and PC ARC/INFO 3.4.2 for a PC 486, as well as a digitizer. Each data layer incorporates a detailed legend which is organized as a database, i.e., a two-dimensional set where each spatial area is characterized by a number of attributes. All data are stored in a computer and could be easily extracted either as digital or hard copies. At the moment, work is concentrated on a compilation of map layers and databases for the area of Murmanskaya and Arkhangelskaya oblasts and the Carelian Republic, Barents region. Four layers are being created and three layers are completed. We present completed layers on three thematic maps, namely a land-use map, a map of river basins and a cryolithological map.

Original maps were compiled using the same geographic and mathematical basis in the scale of 1:4,000,000 in equidistant projection. A land-use map of the USSR (Yanvareva 1991) shows the main types of lands and their territorial combinations. These combinations differ in types of lands, their area ratios, and spatial structure. In total, 80 types of lands and their territorial combinations were distinguished on the original map, 37 of them being typical to the Barents region.

The method of map compilation is based on the concept of system geographical mapping. Territorial complexes with different types of land use that are shown on the map have been formed due to natural features of the territory as well as the character of people's economic activities. All types of lands and their territorial combinations are grouped into lands of plains and those of mountains. The separate group includes land complexes of river valleys with their specific regime of land utilization. Territorial complexes are characterized using five major categories of lands: arable lands, natural grasslands, forests and woodlands, partially used lands and unused lands. Regular distribution of land-use types all over the territory has made it possible to group them according to geographical belts and natural zones. The total number of attributes for each spatial unit is five. A portion of the land use map and full legend are shown in Table 1 and Figure 1.

TABLE 1

Legend for the Land Use Map, Barents region

SOURCE MAP Class No	GENERAL LAND USE CATEGORY	TOPOGRAPHY	GEOGRAPHIC BELT	GEOGRAPHIC ZONE	LAND USE / ECOSYSTEM TYPE
1.3	Arable lands	Plains	Temperate	Forest	Arable lands (>80%)
4.3	Arable lands	Plains	Temperate	Forest	Arable lands (>50%)/Natural grasslands
15.1	Natural grasslands	Plains	Polar	Tundra	Tundra reindeer pastures
15.2	Natural grasslands	Plains	Polar	Forest-tundra	Tundra reindeer pastures
16.1	Natural grasslands	Plains	Polar	Tundra	Tundra reindeer pastures/Wetlands
17.1	Natural grasslands	Plains	Polar	Tundra	Reindeer pastures in protected open woodlands
17.2a	Natural grasslands	Plains	Polar	Forest-tundra	Reindeer pastures in protected open woodlands
17.2b	Natural grasslands	Plains	Polar	Forest-tundra	Reindeer pastures in currently logged protected open woodlands
17.3a	Natural grasslands	Plains	Temperate	Forest	Reindeer pastures in protected open woodlands
17.3b	Natural grasslands	Plains	Temperate	Forest	Reindeer pastures in currently logged protected open woodlands
32.2	Forests and woodlands	Plains	Polar	Forest-tundra	Protected forests and woodlands
32.3	Forests and woodlands	Plains	Temperate	Forest	Protected forests and woodlands
33.3	Forests and woodlands	Plains	Temperate	Forest	Restricted-use timber forests and woodlands
34.3	Forests and woodlands	Plains	Temperate	Forest	Timber forests and woodlands
36.3	Forests and woodlands	Plains	Temperate	Forest	Restricted-use timber forests and woodlands/Natural grasslands/Arable lands(<20%)
37.3	Forests and woodlands	Plains	Temperate	Forest	Restricted-use timber forests and woodlands/Natural grasslands/Shrub
43	Natural grasslands	Mountains	Temperate	Forest	Mountain reindeer pastures
71	River valley complexes	River valleys	Temperate	Forest	Arable lands (>50%)/Unimproved grasslands
75	River valley complexes	River valleys	Temperate	Forest	Natural meadows/Arable lands (<20%)/Protected forests
78	River valley complexes	River valleys	Temperate	Forest	Natural meadows/Protected forests
79	River valley complexes	River valleys	Temperate	Forest	Natural meadows/Shrub
83	River valley complexes	River valleys	Temperate	Forest	Protected forests/Arable lands(<20%)/Natural meadows
85	Partially used lands	Plains	Temperate	Forest	Wetlands/Tundra reindeer pastures
86	Partially used lands	Plains	Temperate	Forest	Wetlands/Tundra reindeer pastures/ Protected forests
87	Partially used lands	Plains	Polar	Tundra and forest-tundra	Wetlands/Reindeer Pastures
88	Unused lands	Plains	Temperate	Forest	Wetlands
88a	Unused lands	Plains	Polar	Tundra and forest-tundra	Wetlands
92	Unused lands	Plains	Polar	Tundra	Tundra
93	Unused lands	Plains	Polar	Tundra	Tundra/Protected open woodlands
94	Unused lands	Plains	Polar	Arctic deserts	Polar deserts
96	Unused lands	Mountain	Temperate	Forest	Mountain tundra
97	Unused lands	Mountains	Polar	Arctic deserts	Stone-fields
98	Unused lands	Mountains	Polar	Arctic deserts	Glaciers
99	Unused lands	River valleys	Temperate	Forest	Valley wetlands

The map "River Basins of the Barents Region" (Shenberg 1995, unpublished) shows the basins of the first and second order rivers with drainage areas of more than 2,000 km, as well as several rivers with smaller drainage areas (for more comprehensive treatment of the territory under study). Each basin is characterized by the following hydrological parameters: name of the river, its drainage area, data on average annual streamflow (flow rate and water discharge), data on minimum summer-autumn and winter flow of 80% duration (30-day flow rates and water discharge, daily water discharge), information about river flow regulation and the accuracy of data. The total number of attributes is 15.

The Cryolithological Map of the USSR for the permafrost area (Popov and Rozenbaum, 1985) shows the territorial distribution of the major genetic types of permafrost grounds and types of cryogenic rocks.

It represents causal interactions between underground ice, lithology, facial and genetic type and age of container deposits, as well as zonal and regional regularities of cryolithogenesis. Classification of cryogenic rocks is based on their typology according to combinations of ice and rocks (3 types), genetic typology of ice (7 types); structure of cryogenic rocks of upper and basement horizons which include different kinds of cryogenic textures and various container rocks, and on the typology of cryolithogenesis (3 types). The total number of attributes is six.

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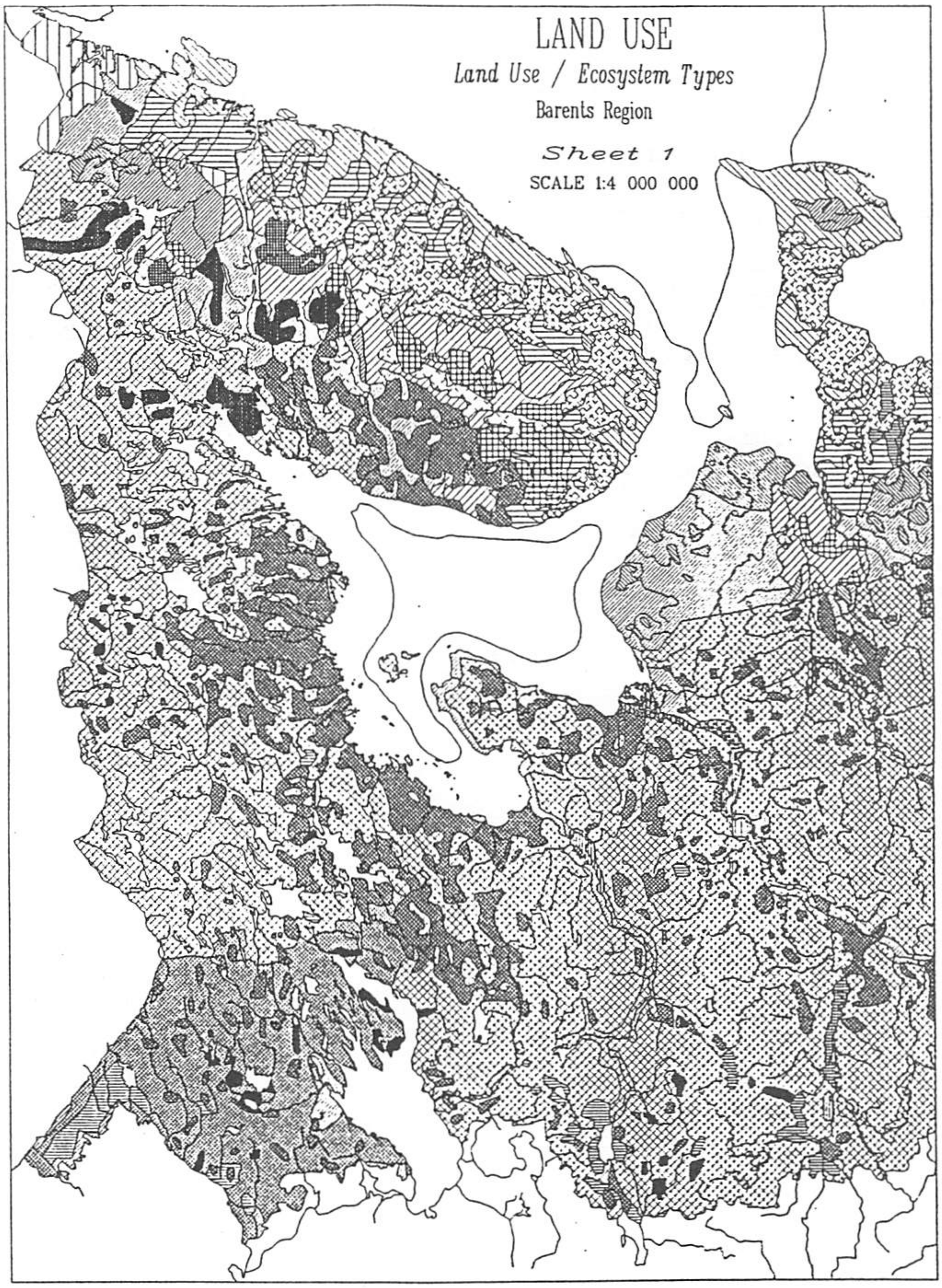

KEY

- Arable Lands (>80% of the area, Forest Zone)
- Arable Lands (>50% of the area, Forest Zone)
- Tundra Reindeer Pastures (Tundra Zone)
- Tundra Reindeer Pastures (Forest-Tundra Zone)
- Tundra Reindeer Pastures / Wetlands (Tundra Zone)
- Reindeer Pastures in Protected Open Woodlands (Tundra Zone)
- Reindeer Pastures in Protected Open Woodlands (Forest-Tundra Zone)
- Reindeer Pastures in Currently Logged Protected Open Woodlands (Forest-Tundra Zone)
- Reindeer Pastures in Protected Open Woodlands (Forest Zone)
- Reindeer Pastures in Currently Logged Protected Open Woodlands (Forest Zone)
- Protected Forests and Woodlands (Forest-Tundra Zone)
- Protected Forests and Woodlands (Forest Zone)
- Restricted-Use Timber Forests and Woodlands (Forest Zone)
- Timber Forests and Woodlands (Forest Zone)
- Restricted-Use Timber Forests and Woodlands / Natural Grasslands / Arable Lands (<20% of the area, Forest Zone)
- Restricted-Use Timber Forests and Woodlands / Natural Grasslands / Shrub (Forest Zone)
- Mountain Reindeer Pastures (Forest Zone)
- Arable Lands (>50%) / Unimproved Grasslands (Forest Zone)
- Natural Meadows / Arable Lands (<20%) / Protected Forests (Forest Zone)
- Natural Meadows / Protected Forests (Forest Zone)
- Natural Meadows / Shrub (Forest Zone)
- Protected Forests / Arable Lands (<20%) / Natural Meadows (Forest Zone)
- Wetlands / Tundra Reindeer Pastures (Forest Zone)
- Wetlands / Tundra Reindeer Pastures / Protected Forests (Forest Zone)
- Wetlands / Tundra Reindeer Pastures (Tundra and Forest-Tundra Zone)
- Wetlands (Forest Zone)
- Wetlands (Tundra and Forest-Tundra Zone)
- Tundra (Tundra Zone)
- Tundra / Protected Open Woodlands (Tundra Zone)
- Polar Deserts (Arctic Deserts Zone)
- Mountain Tundra (Forest Zone)
- Stone-Fields (Arctic Deserts Zone)
- Glaciers (Arctic Deserts)
- Valley Wetlands (Forest Zone)
- No Data

FIGURE 1. *Portion of the Land Use map.*

PROGRESS ON THE ENVIRONMENTAL DATABASE, GIS AND REMOTE SENSING FOR THE RUSSIAN ARCTIC

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Our country participates in international projects such as GRID (Global Resources Information Database) and Global Changes, and much attention is given by Russian specialists to investigation of Arctic ecosystems and to the creation of local, regional, and circumpolar GIS and environmental databases using the remote-sensing data.

The structure of the Russian arctic environmental database

Moscow State University, the World Conservation Monitoring Centre, and the Scott Polar Research Institute of the University of Cambridge conducted a joint project aimed at the creation of a geo-referenced database reflecting the role of Arctic ecosystems in global and regional processes. The project included two separate, although interrelated, parts: (1) the development of an environmental database for the Russian Arctic (Table 1); (2) the elaboration of a methodology for the interpretation of remotely-sensed data, aimed at the subsequent use of remote imagery for assessing the state of arctic ecosystems.

The identification of information sources has now been completed. The data will be drawn from Russian maps, institutional and personal archives, satellite imagery interpretation products, and fieldwork dealing with factors such as topography, geology, geomorphology, permafrost, climate, hydrogeology, soils, vegetation, animal habitats and species distribution, endangered species, land use, industry, transportation, settlements and population, environmental quality and pollution, protected areas, and environmental conservation activities. Given the coverage of the database, the maps of scales from 1:1,000,000 to 1:5,000,000 will be used as primary sources of cartographic data. At the same time, the large-scale maps will also be considered when they provide necessary details and reliability.

As a basic source of information were chosen the series of maps for the Higher School of scale 1:4,000,000, compiled at Moscow State University. In order to produce computer versions of maps and to compile the database, we used the following programs: ARC/INFO 7.03 installed on the SUN SPARCstation 10, PC ARC/INFO 3.4.2. for PC 486. The currently active pilot phase of the project is aimed at the development of a prototype for a bigger information system.

The information sources and the potential data layers are being evaluated not only on the basis of their relevance with respect to local environmental problems, but also on the basis of the relevance, consistency, and availability of similar data for the rest of the Russian Arctic. The data can be used for the Circumpolar Arctic Vegetation Database and Map. The Kola Peninsula was used for the first stage of the project development which included the elaboration of methodologies for data assembling and processing, the selection of a minimum set of indicators, and the field studies to compare results of the grounded helicopter-based high-resolution spectrometry with the state of vegetation cover for support of the satellite data interpretation. It is planned to carry out elaboration in the Norilsk region in connection with the Far North Agricultural Research Institute.

Methodology of the tundra ecosystems state assessment using on-the-ground and remote-sensing data

Vegetation is one of the most vulnerable parts of the environment, and its reflectance properties quickly respond to changes in environmental conditions. The study covered the most common types of tundra communities in the area under investigation. The expert assessment of the state of each ecosystem was based on the analysis of geobotanic descriptions.

Each community has received a certain point estimate according to the adopted ten-point scale: one point estimate corresponds to background conditions (tundra communities of the Nyavka tundra range in the Laplandsky reserve) while ten

TABLE 1

Proposed structure of an environmental database for the Russian Arctic

Background Data	**Natural Heritage**	**Risk Factors**	**Environmental Management**
• Basemap (topography, settlements) • Geology • Tectonics • Quaternary Sediments • Hydrogeology • Landforms • Climate • River Flow • Soils • Landscapes • Environmental; Economic Zoning • Land-use • Population • Economic and Development History • Political Boundaries	• Permafrost and Glaciers • Vegetation Communities • Vertebrate Animal Habitats and Communitites • Mammal and Bird Species Distribution • Terrestrial Invertebrate Animals Distribution • Fish Species Distribution • State of Freshwater Invertebrate Communities • Endangered Species; Wetland Ecosystems • Contaminants in Living Organisms (Background Levels) • State of Ecosystems in Impact Areas • Contaminants in the Physical Environment (air, water, soil)	• Mineral Resources • Transportation • Nuclear Risks • Pollution Sources • Transboundary Pollution and Atmospheric Deposition • Military Areas	• Existing and Planned Protected Areas • Environmental Monitoring Network • Environmental Agencies, Research Institutions, Colleges and Universities, Public Groups

points mean the extreme suppression and the total lack of plants, as on the Sopcha Mountain (1800 m south-west of the Severonickel plant).

In order to evaluate the state of communities we have distinguished four groups representing different states of ecosystems. The response of vegetation cover to anthropogenic influence could be studied using the following characteristics: species composition (vegetation diversity due to ecological conditions), indicator species, and indices of production processes quantifying the degree of plant suppression. Each of these criteria by itself is not sufficient to determine the degree of influence, but their combination shows certain regularities of ecosystems' dynamics.

Concentrations of heavy metals due to specific anthropogenic pollution in soil, litter and some vegetation types is considered an indicator of soil and vegetation contamination. Distribution curves of copper and nickel concentration in soil, litter and lichens show high degrees of correlation and are indicative of a long-term anthropogenic effect. According to the summary pollution coefficient (SPC), three groups of ecosystems have been distinguished. Groups of ecosystems distinguished by phytocoenosis criteria and spectral images coincide practically with the groups distinguished according to the level of pollution by heavy metals and could allow us to rank the territories and ecosystems by the level of their anthropogenic destruction.

GIS for western Siberia environment assessment and management

The Institute of Geography in the Russian Academy of Sciences, in cooperation with the Center for Advanced Geoinformation Technologies, developed the GIS, "Environment of the Western Siberia North," for environmental assessment and management in the Yamalo-Nenetsky Autonomous Okrug (District). The GIS has an hierarchical structure and includes interrelated digitized maps at four scales: 1:4,000,000 for the total area of the Yamalo-Nenetsky Autonomous Okrug; 1:1,000,000 for the Yamal Peninsula; 1:200,000 for the South Yamal and Tazovsky Peninsula; and 1:25,000 for selected areas subjected to the strongest human impacts. Every scale level includes maps and numeric data sets, compiled into four thematic blocks. A GIS was created for IBM-compatible computers using ARC/INFO and GeoDraw/ GeoGraph (developed by the Institute of Geography). The GIS includes some mathematical models.

SMALL-SCALE ARCTIC VEGETATION MAPPING OF WESTERN SIBERIA

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When mapping vegetation cover on the basis of KOSMOS images, it is important to take into consideration the correlations between vegetation communities, relief, soils, permafrost, and surface and underground water. These correlations are reflected on the landscape maps. Therefore these maps are possible to use for small-scale vegetation mapping. The compiling of a small-scale vegetation map on the landscape basis was performed by the author for the Western Siberian Arctic.

The map of natural complexes of Northwest Siberia (scale 1:1,000,000) prepared by the group of scientific workers headed by E.S. Melnikov was used. For localities singled-out on the map, there are characteristic combinations of vegetation communities, arranged for specific relief forms, composition of soils, landform and drainage conditions. Using this map, the landscape basis of Arctic West Siberia (scale 1:7,500,000) was prepared.

The generalization of landscape and locality contours was performed by means of joining different-level landscapes of similar genesis. This landscape basis can be used for the compilation of a vegetation map of the same scale.

In the legend, combinations of vegetation communities are shown that are typical. Microrelief, life forms, and dominant species are shown for each unit. For example, on the lacustrine-alluvial plains subzone of southern hypoarctic tundras, complexes of sandy deposits, and complexes of patchy Labrador tea-lichen tundras on well-drained surfaces and hummocky Labrador tea-moss-lichen tundras on slightly drained surfaces are typical. On the flat boggy surfaces of lacustrine-alluvial plains covered by modern biogenic deposits, the polygonal cloudberry-Labrador tea-peat moss-lichen peatlands are developed in combination with hummocky cotton grass-sedge-moss bogs and sedge-*Betula nana*-lichen-moss tundras. In contrast, for marine plains of the same subzone, composed of sandy-loamy deposits, the combination of hummocky, patchy sedge-willow-Labrador tea moss-lichen tundras on the hill tops and willow lichen-moss stands on the slopes are typical. The landscape basis (1:7,500,000-scale) was prepared for other regions of Russia and can be used for compiling the Circumpolar Arctic Vegetation Map.

PHYTOGEOGRAPHIC SUBDIVISION OF THE PLANT COVER OF TAIMYR

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According to the scheme of plant cover zonation for the Taimyr area (Alexandrova 1977, Shchelkunova 1980), the three vegetation zones can be recognized within the ranges of the latter zones, namely the polar deserts, the tundras, and the taiga forests. A detailed geobotanical subdivision map at scale 1:2,400,000, which can be treated as a transitional link between the vegetation maps at 1:500,000 and 1:7,500,000, was developed for the area.

The first level of subdivision is the subzone: one can distinguish between the southern polar deserts, the arctic tundras, and the northern, the middle, and the southern subarctic tundras. The 2nd level of the legend structure is that of geobotanical areas which are singled-out as longitudinal sectors within each zone. The three units of mountain polar deserts are also distinguished within the arctic tundra subzone due to altitudinal zonation.

As a detailed example, the recognized units for the subarctic tundra subzones are given below:

The northern subarctic tundras occupy six million hectares (7.3% of the whole Taimyr area). Among the dominant species are arctic-alpine, meta-arctic (*Dryas punctata, Carex ensifolia* subsp. *arctisibirica*) and hypoarctic (*Vaccinium uliginosum, Ledum decumbens*) species. The sedge-dryad-moss frost-boil arctic tundras prevail (25.3%) in the western part of the subzone (area 6). In the eastern part, the dryad-moss subarctic tundras are typical (20.7%) for the places less subject to the northern wind influence. Here the characteristic species are *Vaccinium uliginosum*, *Betula nana*, and *B. exilis* (area 7).

The middle subarctic tundras cover 9.6 million hectares (11.2% of the whole Taimyr area) and stretch for 1100 km from west to east. *Vaccinium uliginosum* and *Ledum decumbens* are abundant. Species of dwarf birch are constantly present, but willows (*Salix reptans, S. lanata*) are much more abundant. *Alnus fruticosa* also appears.

The western part of the subzone is distinguished by a widespread distribution of shrub communities (36.0%); willow scrub occupies 2.5 times more area than dwarf birch thickets. *Cassiope-dryad*-moss and willow *Cassiope-dryad*-sedge-moss subarctic tundras prevail (area 8). The complex mire communities occupy 27.0% of the area in the central part of the subzone, but the sedge-cottongrass-moss tussock tundras with *Carex stans* and *Eriophorum vaginatum* are even more typical here (39.0%). Willow sedge-moss and dwarf birch dwarf shrub-moss tundras are also present (area 9).

The eastern, more continental, part of the subzone tundras are typically enriched in arctic and arctic-alpine species; these are mostly *Cassiope-dryad*-moss (30.0%) and willow-dwarf-birch-dryad-moss (22.0%) tundras (area 10).

The southern subarctic tundras occupy 15.9 million ha (18.6% of the whole Taimyr area) and stretch for 1075 km from west to east. The dominance belongs to hypoarctic species (*Salix lanata, S. glauca, Betula nana, B. exilis, Alnus fruticosa*), and the admixture of boreal species is observed (*Larix cajanderi* and *L. gmelinii* penetrate into the river valleys).

A mixed vegetation pattern is typical for the western part of the subzone. Here shrub communities dominated by *Salix lanata, S. glauca, Betula nana* and *Alnus fruticosa* prevail (48.1%), but an important role also belongs to dwarf shrub-moss frost-boil tundras (34.5%), like willow-dwarf birch-dryad-moss (with low shrubs of both willow and dwarf-birch) and Cassiope-*dryad*-moss ones (area 11). In the central part, sedge-cottongrass tussock tundras which dominate the area (57.0%) but are replaced with dwarf birch tundras with thickets of *Betula exilis* and *Salix* spp. (less often *Alnus fruticosa*) to the east (area 12).

The severe continental climate in the eastern part of the subzone promotes the thorough development of dryad-blueberry-lichen-moss tundras (40.1%) and polygonal mires (26.0%), where from 20 to 40 percent of the plant cover on rims belongs to *Cetraria cucullata* and *Cladina rangiferina* (area 13).

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THE DRAFT VEGETATION LEGEND FOR THE YAKUTIAN SECTOR OF THE TUNDRA ZONE (BY THE EXAMPLE OF THE ARCTIC GROUP OF SUBZONES)

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Within the limits of Yakutia the tundra zone occupies the New Siberian archipelago and the coastal belt from 40 to 300 km wide. The elevations of plains which cover 85% of the area are not more than 15-60 m above sea level, while mountains (15% of the area) rise from 130-600 m high. The climate is severe continental. Alevrite (loess) silts dominate among soils, and permafrost is observed throughout the area. Such large rivers as the Lena, the Yana, the Indigirka, and the Kolyma cross the tundra zone of Yakutia and form vast deltas. Fifty percent of the area to the east of the Lena is covered by lakes.

One can distinguish the two longitudinal sectors of the tundra zone of Yakutia, namely the West-Yakutian (WY), which also includes the Lena delta, and the East-Yakutian (EY) (Perfilyeva *et al.* 1991, Agricultural Atlas of the Yakut Autonomous Republic). Latitudinally, the two groups of subzones, the arctic and the hypoarctic, are present. Each group has a northern and the southern subzone, respectively. The altitudinal zonation of the vegetation is similar to the latitudinal one.

I. Northern arctic tundras (EY)

Ia. Plain tundras

1. Foxtail - ground willow (*Salix polaris, Alopecurus alpinus*) - moss (*Hylocomium splendens* var. *alaskanum, Aulacomnium turgidum, Dicranum* spp., *Racomitrium lanuginosum*) - low-hummock-- also forb-ground willow (*Salix polaris, Alopecurus alpinus, Papaver polare, Ranunculus* spp., *Saxifraga* spp., *Oxyria digyna, Potentilla hyparctica*) - moss (*Hylocomium splendens* var. *alaskanum, Tomenthypnum nitens, Drepanocladus uncinatus*)-- tundras of placors.

2. Vegetation complexes (VC) of hummocky ground: foxtail - ground willow - moss; low-hummock; forb - ground willow; and moss frost-boil (see above); also meadow (*Alopecurus alpinus, Poa alpigena, Luzula confusa, Oxyria digyna*) tundras; pioneer vegetation of eroded mounds (*Puccinellia angustata, Phippsia algida, P. concinna, Cochlearia groenlandica, Draba* spp., crustose lichens, liverworts); and grass (*Alopecurus alpinus, Dupontia fisheri, Pleuropogon sabinii*) vegetation of shallow-water thermokarst lakes.

3. Low-centered polygonal mires in vast depressions (described separately as an independent vegetation unit or as an element of community combination).

4. Patchy pioneer vegetation of sea banks and dunes: grass (*Deschampsia brevifolia, Poa alpigena*) and algal-liverwort.

Ib. Mountain calciphyte tundras, with no altitudinal zonation

5. Forb-ground willow (*Salix polaris, Alopecurus alpinus, Papaver polare, Saxifraga oppositifolia* subsp. *oppositifolia*) - moss (*Ditrichum flexicaule*); and foxtail - ground willow (*Salix polaris, Alopecurus alpinus*) - moss (*Ditrichum flexicaule, Ortothecium chryseum*) frost-boil and hollow VC.

Ic. Mountain acidophyte tundras, with altitudinal zonation

6. Lower elevations: montane variant of Ia. 1. Upper elevations: moss (*Racomitrium lanuginosum* with *Dicranoweisia crispula*, or else *Schistidium* spp.) and fruticose-lichen patchy tundras and fellfields, epilithic lichen boulder-field communities.

II. Southern arctic tundras

IIa. Plain tundras

7. Cottongrass - sedge - ground willow (*Carex stans, Eriophorum polystachion, Salix polaris*) - moss (*Aulacomnium turgidum, Hylocomium splendens* var. *alaskanum, Tomenthypnum nitens, Dicranum* spp., *Polytrichum* spp.).

III. Tundras of placors (WY)

8. Sedge - dwarf shrub (*Carex stans, Cassiope tetragona, Salix nummullaria, S. polaris*) - moss (*Aulacomnium turgidum, Dicranum* spp., *Polytrichum* spp., *Oncophorus wahlenbergii, Racomitrium lanuginosum*); sedge - ground willow (*Carex stans, Salix polaris*) - lichen (*Cladonia uncialis, Cladina* spp., *Asahinea chrysantha*); dwarf shrub (*Salix nummullaria, Cassiope tetragona, Diapensia obovata*) - moss (*Dicranum* spp., *Polytrichum* spp., *Aulacomnium turgidum, Racomitrium lanuginosum*)- frost-boil psammophytic tundras in combination with desiccated low-centered polygonal VC, sedge (*Carex stans*) mires, and pioneer algal and algal - lichen open communities (WY; high sandy terraces in the NW of the Lena delta).

9. Ground willow - dryad (*Dryas punctata, Salix polaris*) - moss (*Aulacomnium turgidum, Hylocomium splendens* var. *alaskanum, Dicranum* spp., *Polytrichum* spp.) low-hummock tundras of placors (EY).

10. Low-centered polygonal VC: sedge (*Carex stans*) - moss (*Hylocomium splendens* var. *alaskanum, Aulacomnium turgidum*) tundras; planktonic algal communities of cryogenic lakes; shallow-water communities of *Arctophila fulva* and *Carex stans*; sedge (*Carex stans*) - brown moss mires (WY; the lower peaty-and-sandy terraces of the Lena delta).

11. Low-centered polygonal and trough polygonal VC: sedge (*Carex stans*) - moss-lichen (*Cladina* spp., *Cladonia uncialis, Alectoria* spp., *Dicranum elongatum, Polytrichum juniperinum,*

Racomitrium lanuginosum) psammophytic tundras; pioneer algal and algal-crustose lichen - moss open communities; grass (*Arctophila fulva*) - moss (*Drepanocladus exannulatus*); grass (*Dupontia fisheri*) - liverwort, and other mires; shallow-water communities of *Carex stans* (WY, NW coast of the Lena delta).

12. Low-centered polygonal VC: cottongrass-sedge (*Carex stans, Eriophorum polystachion*) - peat moss; moss - peat moss (*Sphagnum fimbriatum, Aulacomnium turgidum*) tundras; sedge-cottongrass (*Eriophorum polystachion, Carex stans*)-moss (*Drepanocladus exannulatus*); - peatmoss (*Sphagnum squarrosum*) mires and shallow-water communities in microrelief depressions (EY).

13. Moss (*Drepanocladus exannulatus*) and peatmoss (*Sphagnum squarrosum*) mires with *Carex stans, Eriophorum polystachion*, and *E. scheuchzeri* on low coastal terraces (EY).

14. Seashore halophyte communities with *Puccinellia phryganodes, Carex subspathacea, Dupontia fisheri.*

References

Perfilyeva V.I., Teterina L.V., and Karpov N.S., 1991: *Plant Cover of the Tundra Zone of Yakutia*. Yakutsk: Yacut Science Center, Russian Academy of Science, Siberian Dept. 194 pp. (In Russian)

VEGETATION MAP OF THE FAR-EASTERN SECTOR OF THE ARCTIC

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A vegetation map of the Far-Eastern sector of the Arctic (except Korjakia) was created in GIS Arc/INFO format for DOS. 1900 polygons with vegetation at 3 levels are shown on the map. One type of vegetation prevails (50%) in vegetation units of the first level. Vegetation units of the second level are represented by an approximately equal (25% to 50%) combination of two types of vegetation; vegetation units of the third level have a complex number of vegetation types in each polygon. Two variants of vegetation units of the third level are distinguished: (a) with 25% to 50% presence of one type of vegetation among others; and (b) with an approximately equal (10% to 25%) presence of types of vegetation in the polygon.

The legend of the map is prepared in accordance with recommendations of the Second Circumpolar Arctic Vegetation Mapping Workshop. It contains 70 items divided into two subdivisions. The first subdivision includes zonal vegetation of low watersheds, gentle slopes, sea shores and river valleys. The second subdivision includes vegetation of mountain territories. The names of units reflect the characteristics of the vegetation itself: dominant or characteristic biomorphs, dominant or characteristic species, vertical structure and combinations of communities.

Arctic vegetation is represented on the map by: arctic tundras (2 units), northern subarctic tundras (5 units), southern subarctic tundras (5 units). Tundra bogs and tundra-boggy complexes are divided into arctic, northern subarctic (6 units) and southern subarctic (5 units). Boreal vegetation is represented on the map by: shrub thickets (*Alnus fruticosa*) (3 units), and Siberian dwarf pine (*Pinus pumila*) thickets (7 units). Northern taiga open-larch forests (*Larix gmelinii*) are represented by four units. Boreal bogs and vegetation of river valleys include three units. Mountain vegetation is represented on the map by stone deserts (7 units), hekistothermic mountain tundra meadow and nival vegetation (1 unit). Combinations and complexes of stone deserts, mountain tundras, plain tundras, shrub thickets and Siberian dwarf-pine prostrate thickets are represented by 13 units. The vegetation map in Arc/INFO format is supplemented by a database where each polygon has a number, zonal relevance, number of the geobotanic district (which is included in the polygon), vegetation type and map legend number. Presence of communities with *Betula exilis, Salix* sp., *Alnus fruticosa, Pinus pumila*, and *Larix gmelinii* is shown if they occur outside of continuous distribution.

The Draft Three-Level Legend of the Chukotka Peninsula Vegetation Map at Scale 1:7,500,000

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Three items are marked out at the first level of the legend (Table 1, Figure 1): the northern hypoarctic (NHT) subzone, the southern hypoarctic tundra (SHT) subzone, and the interzonal vegetation.

The arctic tundra subzone is absent on the Chukotka Peninsula. The northern hypoarctic tundra subzone is represented as a belt, while the southern (shrubs) hypoarctic tundra subzone is not expressed. On the plains of the Chukotka Peninsula and in its seashore mountains, the maritime climate depresses shrub growth and shrub communities which are typical of the SHT. However, the small "islands" of the plain SHT occur is some parts of the peninsula, where the shrub (willow) forb-moss communities are adjusted to the oval depressions and hollows on drained loamy watersheds (placors). Rather often, the south-tundra variant of the altitudinal zonation system is expressed in the mountains where the subalpine belt with shrub (willow and alder) communities is found on the mountain aprons and on lower slopes. These fragments of the SHT occur in locations where the plants are not depressed by the influence of the wind from the Pacific Ocean.

Three items are marked out at the second level of the legend. Vegetation cover of the Chukotka Peninsula is divided into the three meridional sectors according to the pecularities of their flora, climate and orography: Western, Central, and Eastern (see B.A. Yurtsev's Amguemsky, Koljuchinsky and Extreme Eastern districts of the Chukotka floristic province).

The Western sector is characterized by a large amount of Asian and Western-Chukotka species and by continental climate, as well as by prevalence of the middle height mountains in the south, intermountain depressions in the center, and low mountains and plains in the north. Kresta Bay and the Iskaten Range separate the plains of Western and Central sectors from the Anadyr lowland where the SHT is widely distributed.

In the Central sector, the low mountains prevail. From the east and the north two bays run deep into it, promoting the transit of the air masses from the Pacific and Arctic Oceans over the territory of this sector.

TABLE 1

Legend of vegetation zones

I. Vegetation of the Northern Hypoarctic Tundra (NHT) Subzone

A. The Western Sector
1. Vegetation of NHT subzone on the plains
2. NHT variant of the altitudinal zonation in middle height noncalcareous mountains
3. NHT variant of the altitudinal zonation in low noncalcareous mountains

B. The Central Sector
4. Vegetation of the NHT subzone on the plains
5. NHT variant of the altitudinal zonation in middle height noncalcareous mountains
6. NHT variant of the altitudinal zonation in low noncalcareous mountains

C. The Eastern Sector
7. Vegetation of NHT subzone on the plains
8. NHT variant of the altitudinal zonation in middle height noncalcareous mountains
9. NHT variant of altitudinal zonation in low noncalcareous mountains
10. NHT variant of altitudinal zonation in low calcareous mountains

II. Vegetation of the "islands" of southern hypoarctic tundra (SHT) within NHT subzone

A. The Western Sector
11. SHT variant of the altitudinal zonation in low noncalcareous mountains

B. The Central Sector
12. Vegetation of SHT subzone on the plains
13. SHT variant of altitudinal zonation in low noncalcareous mountains

C. The Eastern Sector
14. SHT variant of altitudinal zonation in middle height noncalcareous mountains
15. SHT variant of altitudinal zonation in low noncalcareous mountains
16. SHT variant of altitudinal zonation in low calcareous mountains

III. Interzonal Vegetation
17. Coastal halophytous vegetation

	I	II	III
A	1 2 3	11	
B	4 5 6	12 13	
C	7 8 9 10	14 15 16	17

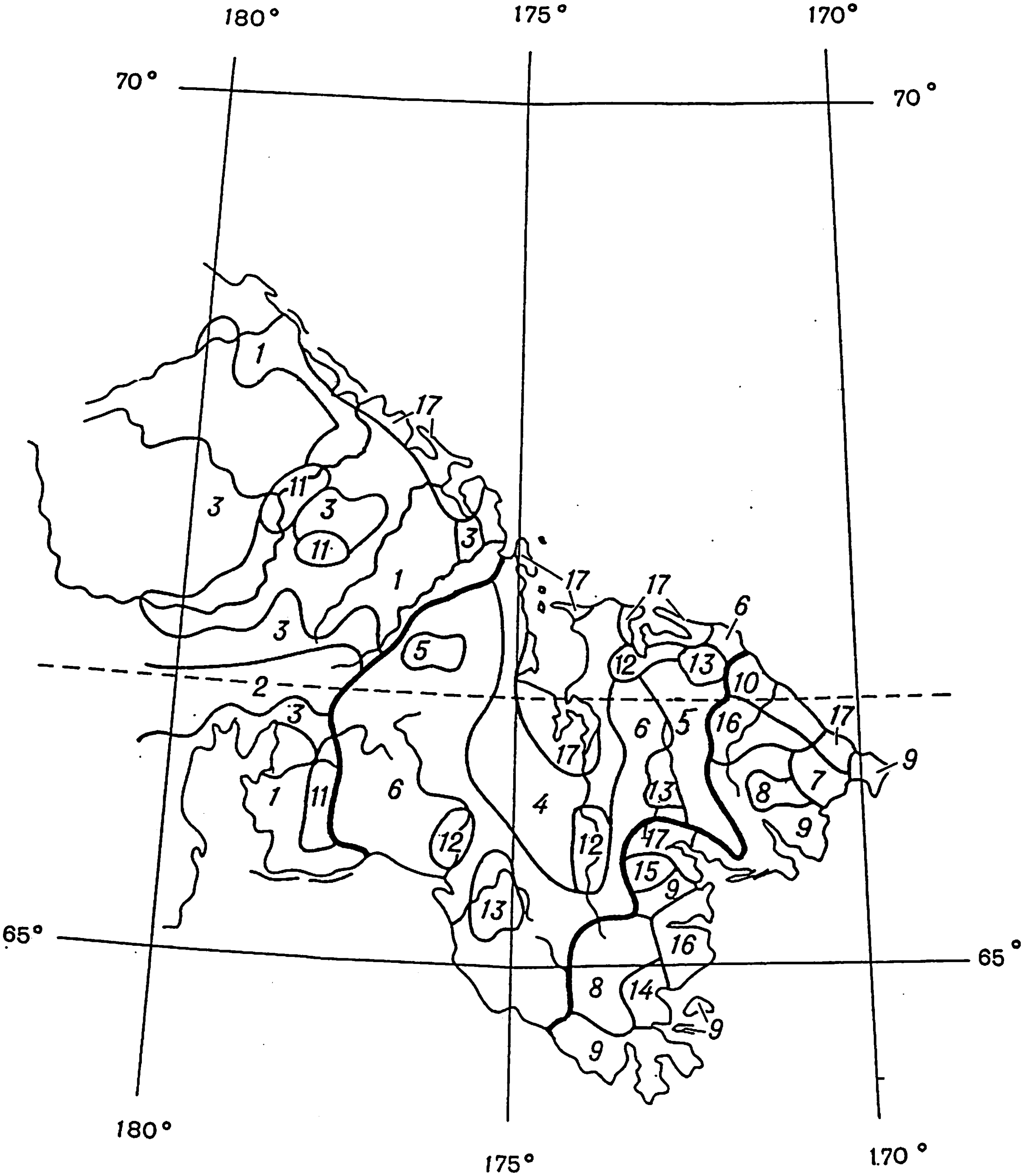

FIGURE 1. Map of vegetation zones.

Almost the whole area of the Eastern sector is occupied by the low and middle height mountains. Among the low mountains, many are formed by limestone. Numerous in this sector, Alaskan plant species hardly penetrate into the Central sector, apparently because of the high mountains formed by acidic rocks and restricted to the west boundary of the Eastern sector.

The subdivisions of the second level of the legend are based mostly not on floristic differences, but on the heterogeneity of Chukotka relief and climate. The second level of the legend is weakly expressed and it is not clearly divided from the third level, based on the relief's heterogeneity and the composition of the rock.

The heterogeneity of the relief of the three parts of the Chukotka Peninsula -- Western (with middle-high mountains), Central (with plains and low mountains), and Eastern (with middle-high mountains) -- intensifies the distinctions of their various flora and vegetation, resulting from historical and geographical floral diversity. Floristic and vegetation distinctions of these three sectors are caused also by differences in the chemical composition of their respective rock structures-- mainly acidic in the Western sector and calcareous in the Eastern one. All these factors intensify the floristic distinctions between the Western and Eastern sectors, while the Central sector occupies the intermediate position with respect to climate, relief and floristic composition.

The distinctions in the vegetation of the three sectors unequally reveal themselves in the vegetation of different elements of the relief. The most similar vegetation is restricted to placors in all three sectors. On the plains the vegetation distinctions of shallow and deep snow locations and river valleys are expressed most strongly. The montane vegetation of all the sectors also differs strongly and reflects the pecularities of the floristic districts. The coastal vegetation of the Chukotka Peninsula does not differ strongly.

The third level of the legend reflects the correlation of vegetation with relief and soil chemistry. Here the vegetation of the plains, of the middle-high mountains (800-1500 m), of the low mountains (up to 800 m), and the large areas of the low coastal plains are distinguished. Mountains differ from one another by the presence of either acidic or calcareous rocks.

The plain vegetation is characterized by drained loamy watersheds (placors), weakly snowy uprisings, heavy moisture locations around watersheds, river valleys, and snow-bed vegetation.

The altitudinal zonation is peculiar to the montane vegetation: the lower (sometimes an apron), the middle, and the upper (crest or plateau) belts. The vegetation of more or less flat strips with fine-grained immobile substrata is described by characteristics of montane belt vegetation.

The vegetation of the low coastal plains is represented by saline low lagoon shores, spits, sandy banks, and beaches.

Five items are marked out on the third level, but not all of them have their reflection in all subzones and sectors. This level includes seventeen numbers.

A Terrestrial Wildlife Habitat Map of Russian Tundra

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An animal habitat map of the Russian tundra was created on the basis of vegetation and landscape maps. Regional, typological principles, and ecological characteristics of species were taken into account. Every polygon of the map was characterized by the features important for animals: vegetation, humidity, geomorphology, and ground structure. For each polygon an estimate of animal species occurring in the region was given. An ARC/INFO GIS system was used for data management. For primary information a 1:4,000,000 map was created. It can be used to describe ecosystems, animal communities, and the distribution of single species.

Distribution of 200 vertebrate animal species was included in the database. The database for animal habitats was created for analysis of biodiversity in the Russian Arctic. It can be used to describe ecosystems, animal communities, and distribution of single species. The habitats map is necessary as a base for estimation of biodiversity and planning of a protected areas network in the Arctic.

Mapping of Industrially-Damaged Northern Vegetation by Space Images: Test Large-Scale Examples in Addition to Circumpolar Map

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A new circumpolar vegetation map will show the modern state of arctic vegetation with special attention to anthropogenic influences. There are some local areas in arctic regions with particularly strong industrial damage. Within the Russian part of the Arctic they are: Pechenga-Nickel, Monchegorsk, Vorkuta, Yamal, Norilsk, and others. It is very important to combine the circumpolar map vegetation characteristics with some examples of large-scale maps for these damaged areas. Remote-sensing is the best way to monitor them and to provide for the compiling of test maps.

In this paper we show one example for the Monchegorsk area in the central part of the Kola Peninsula. The ecosystems of the area are very sensitive to industrial impact and recover with difficulty. The copper and nickel processing plant in Monchegorsk, which recently started to use imported ore with high sulfur content, is emitting large quantities of sulfur dioxide and heavy metals into the atmosphere. This produces serious harm to the environment, and has so far resulted in the creation of desert areas and damaged forests around the plant. Their monitoring and mapping is necessary, and it must, at least partially, be based on satellite data.

In our investigations, carried out by a joint project of Moscow State University, the Scott Polar Research Institute, and the World Conservation Monitoring Centre, we have suggested methods for the interpretation of multi-band space images to detect human impact on the environment reflected in the state of vegetation cover.

The investigation includes:

• visual interpretation of LANDSAT (US) and KOSMOS (USSR) images, using the results of previous field work,

• computer-based derivation of the spectral signatures for main land cover classes, including the classes of variously-damaged vegetation,

• analysis of spectral signatures and development of automatic classification algorithms,

• visual and automated compiling of thematic maps of damage to vegetation,

• multi-temporal analysis of LANDSAT and KOSMOS images, with derivation of multi-temporal maps of damage to vegetation.

The "pre-computer" (visual) interpretation was first made based on the data from previously-held field studies (Fig. 1).

Twenty-four classes were based on visual interpretation, including industrial areas and settlement, technogenious deserts in the three areas of industrial impact, damaged and healthy tundra, and forest vegetation (with forests divided into four degrees of damage. The full list of these classes is presented in Table 1). Spectral signatures were derived for these classes from digital multiband data (Figure 2).

The spectral signature curves derived for more than one hundred locations were then assigned to these classes and examined. As useful tools for the screen assessment of both the distribution and the state of vegetation, a number of indices was computed, including: standard vegetation index (normalized difference - NDVI), and a color composite image of the principal components. The optimal parameters for computer classification of the analysis were: (1) a color composite image of the principal components and NDVI - for outlining and separating such classes as urban and industrial areas, technogenious deserts, stony deserts, damaged and healthy tundra vegetation, significantly damage forest with different shares of dead trees; (2) NDVI - for distin-guishing between different species of slightly-damaged forest vegetation.

A computer program for the supervised classification runs with GIS EPPL7. The program makes use of a box classification approach, an analysis of vegetation index and color composite images of principal components as classification features, and shapes of spectral signatures' curves. The threshold classification feature levels were determined by the consequent analysis and interactive brightness quantization of screen images for these parameters based on analysis of their histograms. These threshold levels are presented in Table 2.

The results of this work-- the maps of damage to vegetation-- may be used to form a scientific basis for environmental management and conservation strategies in the North. We hope, also, that they will be a good addition to the Circumpolar Arctic Vegetation Map. Such large-scale information is useful also for the Arctic Environmental Database.

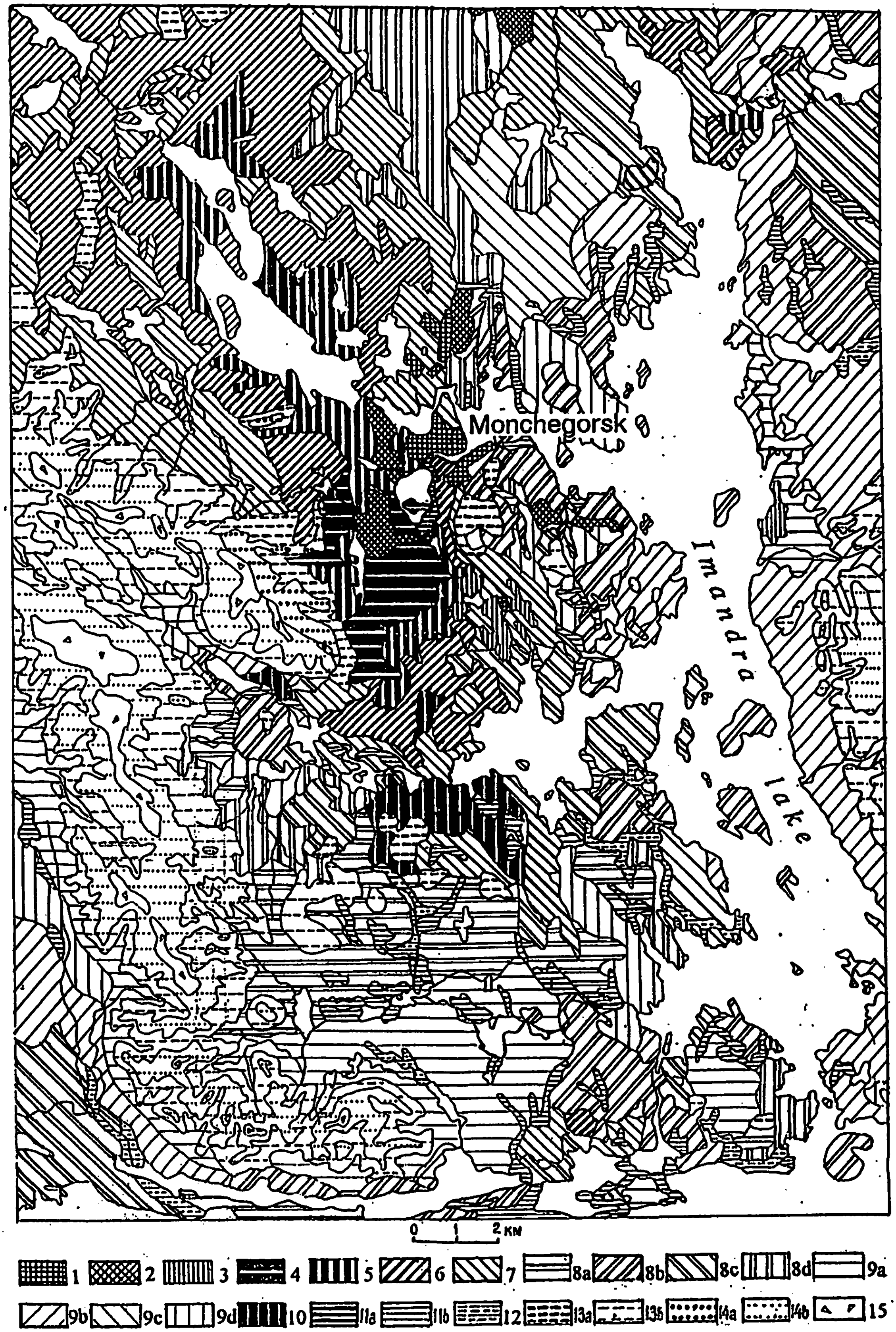

FIGURE 1. *Map of damaged vegetation for Monchegorsk area (See legend in Table 1).*

TABLE 1

Legend for map of damaged vegetation for Monchegorsk Area

I. Urban Areas, Settlements, and Agricultural Lands
- 1. Housing areas
- 2. Industrial areas, quarries, tailing ponds
- 3. Agricultural lands

II. Technogenious Deserts in the Areas of Industrial Impact
- 4. Completely destroyed by soil and vegetation cover
- 5. Severely damaged soil and vegetation cover

III. Forest Vegetation Affected by Industrial Pollution
- 6. Severely damaged forests (80% - 100% dead trees): dead spruce and pine dry forests, birch-shrub sobole on soils with exposed mineral layers
- 7. Significantly damaged forests (60% - 80% dead trees): North-taiga forests transformed into oppressed Arctic birch/spruce woodlands, with large proportion of dying or dead trees, with the absence of herb/dwarf-shrub layer and of moss cover
- 8. Partially damaged forests (40% - 60% dead trees), including:
  - 8a. Spruce forests
  - 8b. Birch/pine/spruce forests
  - 8c. Birch/spruce forests
  - 8d. Spruce/birch forests
- 9. Slightly damaged forests (up to 40% dead trees), including:
  - 9a. Spruce forests
  - 9b. Birch/pine/spruce forests
  - 9c. Birch/spruce forests
  - 9d. Spruce/birch forests
- 10. Fires

IV. Wetlands Vegetation
- 11. Lowlands dwarf-shrub/moss swamps
  - 11a. Areas damaged by industrial pollution
  - 11b. Not damaged areas
- 12. Combination of lowlands moss swamps with spruce forests

V. Tundra Vegetation
- 13. Stone dwarf-shrub/lichen mountain tundra, including:
  - 13a. Areas damaged by industrial pollution
  - 13b. Undamaged areas
- 14. Combination of stone dwarf-shrub/lichen mountain tundra with stone deserts of nival zone, including:
  - 14a. Areas damaged by industrial pollution
  - 14b. Undamaged areas
- 15. Stone deserts of nival zone

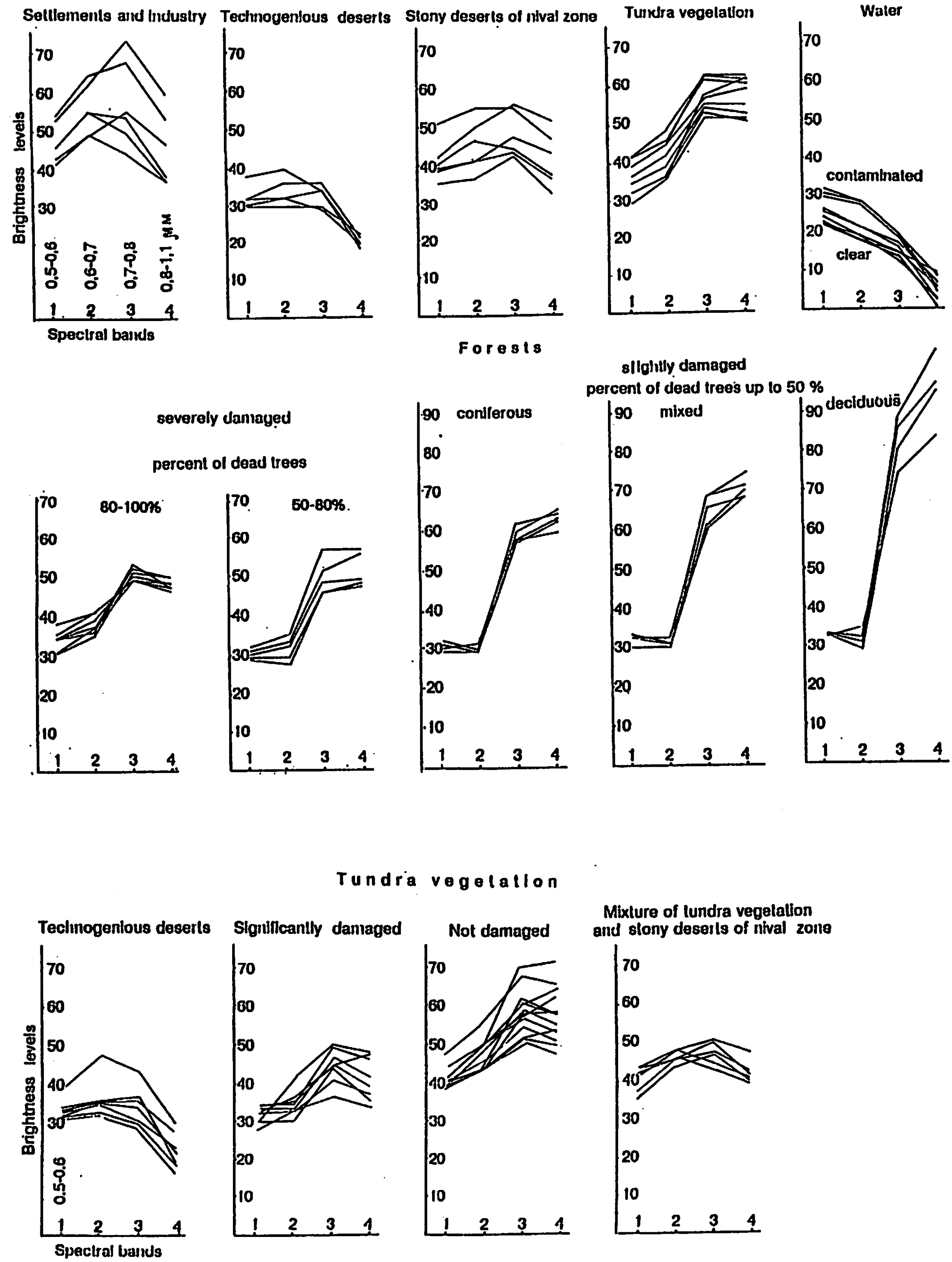

FIGURE 2. *Spectral signature curves of investigated objects.*

Table 2

*The threshold classification feature levels /**

VI=255 and 48<=SINT<=79	completely destroyed soil and vegetation cover / industrial areas
VI=255 or 0<=VI<=48 and 80<=SINT<=107	- severely damaged soil and vegetation cover / quarries / stone deserts
(VI=255 or 0<=VI<=48) and (126<=SINT<=143 or 87<=SINT<=215)	severely damaged soil and vegetation cover / quarries / housing / mixture of stone deserts and tundra vegetation
0<=VI<=48 and 120<=SINT<=125	damaged tundra vegetation / significantly damaged forests, share of dead trees 80-100%
157<=SINT<=175	healthy tundra vegetation / housing
49<=VI<=72 and (SINT<157 or SINT>175)	significantly damaged forests, share of dead trees 50-80%
	slightly damaged forests:
73<=VI<=89	predominantly coniferous
90<=VI<=103	mixed
104<=VI<=255	predominantly deciduous
B4<=12	water bodies

/* KEY : SINT - color composite image of the principal components, VI=(B4--B2)*255/(B4+B2), B2 and B4 - brightness values for bands 0.5-0.6 mkm and 0.8-1.1 mkm

PART II

CAVM-NORTH AMERICA WORKSHOP

ANCHORAGE, ALASKA, US, 14-16 JANUARY 1997

I. SUMMARY OF PROCEEDINGS OF THE NORTH AMERICAN CAVM WORKSHOP, USGS EROS ALASKA FIELD OFFICE, 14-16 JAN 1997

Derived from notes taken by Carl Markon
USGS EROS Alaska Field Office

Participants and funding

The participants at the workshop included Christian Bay and Fred Daniëls (Greenland), Larry Bliss and Steve Zoltai (Canada), Mark Shasby, Mike Fleming, Carl Markon, Steve Talbot and Skip Walker (US). Funds for the Anchorage workshop were provided by the Alaska Science Center, Biological Resources Division, US Geological Survey, Anchorage. Other funding came from an Interagency Agreement between the Alaska Region US Fish and Wildlife Service, Anchorage, and the Alaska EROS Field Office, US Geological Survey, Anchorage, through an Interagency Agreement between the Alaska State Office, Bureau of Land Management, Anchorage, and the Alaska Region US Fish and Wildlife Service, Anchorage.

Presentations

- Mark Shasby: Welcome and introductions.
- Steve Talbot: Welcome and acknowledgments.
- Skip Walker: Overview and schedule.
- Mike Fleming: Progress on the CIR and NDVI base maps.
- Skip Walker: Methodology for mapping in northern Alaska.
- Christian Bay: Progress in Greenland.
- Steve Zoltai/ Larry Bliss: Progress in Canada.
- Steve Talbot/Carl Markon: Progress in western and southwestern Alaska.
- Fred Daniëls: Community nomenclature.

Presentations were made by each of the participants summarizing the progress in each of the North American countries. Most of the workshop focused on developing a mapping approach for the CAVM. The discussion focused on a prototype legend and integrated map for northern Alaska, presented by Skip Walker.

Summary of results

During development of a prototype map for northern Alaska, the multi-factoral vegetation coding procedure suggested at Arendal was replaced by an integrated mapping method. This approach is described in the attached abstract which also contains the legends agreed to for North America. This paper contains the final legend, and a full description of the integrated mapping methods and GIS methods.

During the first phase of the North American mapping, the integrated mapping approach will be applied to seven prototype areas in North America where we have the best information: Alaska North Slope, Yukon-Kuskokwim River Delta, Alaska, Ellesmere Island, Banks Island, Melville Hills vicinity, Ammassalik District, Southeast Greenland; Jameson Land, East Greenland and Kronprins Christian Land, Eastern North Greenland.

The 3rd International CAVM Workshop

Another international workshop was proposed for GRID-Arendal in early 1998 pending funding. Key participants from each country will be invited. The primary purpose of the workshop will be to review the prototype maps from North America and finalize the plans for each region.

METHOD FOR MAKING AN INTEGRATED VEGETATION MAP OF NORTHERN ALASKA (1:4,000,000-SCALE)

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Abstract

This method consists of making several separate maps portraying different themes (e.g., landscape units, soils, bedrock geology, percent

lake cover, and vegetation complexes). The landscape units are defined by characteristics that can be observed on AVHRR imagery (mountains, hills, floodplains, etc.). The landscape-unit boundaries are used to guide the boundaries on the other thematic maps. The polygon boundaries on several of the separate thematic maps, or layers, are then integrated onto a single map sheet (the integrated terrain-unit map), which contains all the polygon boundaries. This map is then digitized and each polygon is given a unique polygon identification number. The GIS database consists of two principal files, one containing the 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. The look-up tables contain additional information regarding principal plant communities, and vegetation properties (dominant growth forms, dominant species, horizontal structure, production, and biomass) within each vegetation complex for each floristic subprovince/ phytogeographic zone combination.

Introduction

This document contains a brief description of a GIS and remote sensing-based approach used for mapping the tundra region of northern Alaska at a scale of 1:4,000,000. The contribution is toward the development of a comprehensive method for making a circumpolar arctic vegetation (Walker 1995, Walker *et al.* 1995, map). Rather than aiming toward a single vegetation map, the goal of the integrated vegetation mapping approach described here is a vegetation database that can be used to derive a wide variety of map products and spatial analyses of the arctic region.

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 most clearly presented by Dangermond and Harnden (1990) as the integrated terrain unit mapping (ITUM) approach used by the Environmental Systems Research Institute (ESRI). The approach uses the philosophy that most soil and vegetation boundaries on maps are controlled 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 landscape units first be defined and mapped. Boundaries of other geobotanical elements of the landscapes, such as soils and vegetation, are then guided by the boundaries of these basic landscape units.

Components of the integrated vegetation map

The final integrated terrain unit map (ITUM) is based on several map layers which are described below. The legend for each layer is presented in Table 1.

Layer 1. AVHRR CIR composite

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 developed by Fleming (this volume). It displays the maximum relfectance of the vegetation for each 1x1-km pixel during the summer of 1991.

Layer 2. Topography/hydrology.

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.

Layer 3. Boundary of the study area and locations of intensive study sites.

a. Map boundary. This layer defines the total boundary of the study area. The position of the northern treeline was obtained from the *Major Ecosystems of Alaska* (Joint Federal-State Land Use Planning Commission for Alaska, 1973). The final map will utilize the shoreline boundary defined in the Digital Chart of the World.

b. Location of major study sites. This layer also portrays points of major vegetation and soil study sites in northern Alaska described in the literature. This information is important because it is used to determine the dominant communities described in the literature for each vegetation complex with the floristic subprovince/phyto-geographic zone combinations of Yurtsev (1994).

Layer 4. Floristic subprovinces and phytogeographic subzones.

This layer was not used in defining the final ITUM polygon boundaries. Because of disagreement among the CAVM working group regarding the position and validity of the these boundaries, it is suggested that these boundaries be contained in a separate overlay where they can be readily modified and overlaid on the final ITUM to help in characterizing the floristic nature of the final map. The layer shown here portrays the approximate location of Yurtsev's (1994) floristic boundaries in northern Alaska.

Layer 5. Landscape units.

The landscape unit layer is the basic element of the integrated terrain unit map, and the boundaries on this map are used to guide the boundaries on the other layers. This layer displays basic landscape units that can be recognized on the AVHRR-derived base map. These include lakes, ocean, plains, plateaus, hills (without altitudinal vegetation belts), mountains (with altitudinal belts), floodplains and deltas, glaciers, and mountain valleys. In some cases the position of mountain valleys and floodplains was 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 (USGS 1978, USGS EROS Data Center no date). The position of these boundaries would be further aided by including the river network and the major topographic isolines on Layer 2.

Layer 6. Percentage cover of 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 no date) and Sellman *et al.* (1975), who mapped the percent cover of water on the North Slope. This layer will probably be useful for helping to develop classifications based on AVHRR imagery.

Layer 7. 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. Our studies in northern Alaska have shown that the contrast in vegetation between acidic and nonacidic substrates is striking and that there are major differences in a wide variety of important ecosystem properties and functions, including biodiversity, primary production, heat flux, and trace-gas production (Walker *et al.* submitted). 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 generalizes the bedrock portrayed on 1:2,500,000-scale geology map of Alaska (Beikman 1980) into four categories based primarily on the pH of the soil to which these bedrock types weather. It may be desirable to add other categories [e.g. surficial geology, (Karlstrom and others 1964)] for extensive geologic formations that weather to substrates supporting unique vegetation (e.g. serpentine).

Layer 8. Soil associations.

Like the bedrock, soil maps can help in defining the location of vegetation complexes. 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. This layer is derived from the *Exploratory Soil Survey of Alaska* (Rieger *et al.* 1979) and modified based on information from a wide variety of sources including surficial deposit maps of the National Petroleum Reserve in Alaska (Gryc 1985, Hamilton 1986, Hamilton and Porter 1975), maps of the landscape units in the Arctic National Wildlife Refuge (USDI 1982), and personal unpublished data from numerous surveys.

Layer 9. Maximum NDVI.

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 polar desert regions, or areas with high biomass such as shrublands. This layer portrays the maximum NDVI for each pixel during the summer of 1991. It was particularly useful for defining the boundaries of shrubland vegetation near treeline, in the mountains, areas of northwestern Alaska, and a few areas in warmer portions of the North Slope.

Layer 10. Vegetation complexes.

At 1:4,000,000 scale, the vegetation patterns are strongly related to terrain features that contain mosaics of characteristic plant communities. It is impossible to map the boundaries of individual plant communities at this scale, but it is possible to map vegetation complexes and list the typical plant communities that occur in common elements of each vegetation complex, similar to the approach used for the European vegetation map (Bohn this volume) and several Russian vegetation maps (e.g., Perfilieva this volume)).

Delineation of vegetation boundaries.

The vegetation complexes for Layer 10 (see Table 1) are derived from a variety of geobotanical information in the previous layers. The boundaries are, for the most part, an amalgamation of boundaries for Landscape Units (Layer 5), Generalized Bedrock Geology (Layer 7), Soil Associations (Layer 8), and Maximum NDVI (layer 9). The information used to delineate the vegetation information depends on the vegetation type, and may include various combinations of bedrock geology, substrate pH, soil texture, extent of cryoturbation, surface area covered by water, and NDVI.

Dominant and characteristic plant communities in each vegetation complex.

Table 2 (not shown here) presents the suite of dominant and characteristic plant communities for each vegetation complex within Yurtsev's (1994) floristic subprovinces and phytogeographic zones in northern Alaska. The table presented at the Anchorage meeting contained only the information for Subzones II and IV within the northern Alaska subprovince, and will be expanded for the other three floristic regions in northern Alaska at a later date. Wherever possible information in Table 2 is derived from vegetation studies from within the relevant subregion and subzone (Layer 3).

Community names.

The names of the communities are standardized. If a published Braun-Blanquet association name is available, it takes precedence over all other descriptions because this name is readily recognized by phytosociologists and contains a great deal of inherent information regarding species composition, geographic location, and habitat. If no Braun-Blanquet epithet is available, the best available description is selected as the reference plant community. The best 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 name should contain only two species names, the dominant and a characteristic plant, preferably one that is characteristic of the floristic subregion in which the community occurs. The plant names are italicized and separated by a dash. The name is followed by the author(s) of the article in which the community is described and the date of publication. The terrain element or habitat is briefly described in parentheses.

Layer 11. Integrated terrain unit map.

A full explanation of the advantages of creating an integrated map for GIS applications are 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.

Although the process of integration sounds somewhat mysterious, it is actually straight-forward as long as a systematic procedure is followed. The landscape unit boundaries in Layer 5 are used as the basic set of boundaries and are carried through wherever possible by tracing them onto other layers where appropriate. New boundaries are added for other layers only where needed to properly map the information. In this way, only the minimum number of lines and polygon boundaries are used in the final ITUM.

It is recommended that the final ITUM be produced by first tracing the boundaries of the vegetation complex map (Layer 10) since this layer is already an integration of several other layers. After these boundaries are drawn, other boundaries appearing on the other layers are added. The ITUM for the northern Alaska prototype map includes information from landscape units (Layer 5); percent cover of lakes (Layer 6); bedrock geology (Layer 7); soils (Layer 7); and vegetation complexes (Layer 10).

The final ITUM should be checked to make sure that all polygons are closed.

Layer 12. Point map for off-scale units

This map contains points identifying known important off-scale units, including polar oases, balsam poplar groves, and spring communities. This layer is also not part of the ITUM.

Layer 13. Polygon ID map.

The ITUM is then digitized. This results in a raster-format file, that is then converted to a vector (or line) format using GIS software. Unique polygon ID labels are added to each polygon either automatically using GIS software or by manually creating centroids in each polygon and attaching the ID number. A final polygon ID map is then produced that shows the polygon boundaries, centroids, and polygon ID numbers. (The map at the Anchorage workshop had only five polygons with ID numbers near Point Barrow for demonstration purposes. Normally every polygon on the map would have an ID number.)

Geobotanical attribute coding sheet

The geobotanical attributes for each polygon are then recorded on a coding sheet. The polygon ID map (Layer 13) is overlaid on a given thematic map (e.g. landscape units) and thematic code for each polygon is recorded. This procedure is repeated for all the map attributes (landscape unit, % lakes, bedrock, soil association, and vegetation complex). 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.

Editing

Separate maps are then produced for each theme and checked against the original information. A variety of consistency checks should also be made to make sure that inappropriate combinations of codes (for example, moist tundra occurring within lakes) do not occur.

"Look-up" tables to produce derivative maps

The relatively small set of soil and vegetation complexes can be linked to "look-up" tables that contain a wide variety of information for each soil or vegetation unit. For example, information regarding biomass, primary production, plant growth forms, horizontal structure, and dominant species could be contained in a look-up table linked to the dominant plant community of each vegetation complex (Table 4). Similarly, the soil properties, such as texture, depth of organic horizons, and pH, could be contained in a soil look-up table.

Technical aspects

1. The AVHRR base image (Layer 1) should have 3 or 4 registration marks that are aligned with registration marks on Layer 10 (the ITUM). 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 made by Burton Ternes, and the registration tabs are Pako 0.25 in. round, self-adhesive, package of 250, Part No. 750-18102.

3. Coding the polygons appearing on each layer should be done such that a dot is placed 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.

Concluding remarks

It may be possible to reduce the number of vegetation complexes for the final map. 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.

We need to thoroughly discuss whether this method is feasible for all members of the CAVM working group. There are potential pitfalls to a group that is largely unfamiliar with GIS methods. There are also overriding benefits including the ability to produce a wide variety of derived maps and the flexibility of the database for modeling purposes. Above all, it allows 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.

The use of "look-up" tables is also being used to resolve classification differences among countries involved in the circumpolar soils map. Charles Tarnocai, at an International Permafrost Association meeting in Boulder, noted that by using look-up tables, each country can go ahead and proceed with mapping using their own local classification. The properties of soils, which is what most users will be interested in, are contained in a separate look-up table. It is then possible to relate these properties to the various soil units and produce maps of these properties. Similarly, the plant communities are the basic units that make up the mosaic of vegetation. There are many ways to name these communities, but the basic properties are relatively easy upon which to agree. By relating the various plant community names to a few landscape units that we can recognize on satellite imagery and then describing the communities in terms of a few basic properties such as biomass, productivity, composition and structure, we can easily produce maps of vegetation properties, in which most users are interested.

Table 1. Northern Alaska Tundra: Integrated Terrain Unit Map Legends.

Layer 1. AVHRR CIR composite (1:4,000,000 scale) (Fleming, this volume).

Layer 2. Topography/ hydrology (Fleming, this volume).

Layer 3. (a) Boundary of study area. Treeline is derived from the Major Ecosystems of Alaska (Joint Federal-State Land Use Planning Commission for Alaska 1973). (b) Locations of intensive vegetation and soil studies. These sites generally have detailed vegetation descriptions with complete species lists and/or good vegetation maps derived from photointerpretation.

Map code	*Location*	*References*
1	Barrow	Webber 1978, 1980; Gersper 1978; Walker et al. 1995
2	Fish Creek	Lawson et al. 1978
3	Kuparuk Oil Field	Everett and Walker 1982 unpub.
4	Prudhoe Bay Oil Field	Everett and Parkinson 1977; Walker 1985; Walker and Acevedo 1987; Walker and Everett 1991
5	Barter Island	Walker et al. 1995
6	Meade River	Komarkova and Webber 1980; Everett 1980
7	West Oumalik	Ebersole 1985
8	Umiat	Churchill 1955; Bliss and Cantlon 1957
9	Sagwon Upland	Walker 1995, unpub.
10	Happy Valley	Walker 1994, unpub.
11	Arctic National Wildlife Refuge	Walker et al. 1992, Jorgenson et al. 1994; Hettinger and Janz 1974
12	Cape Thompson	Everett 1966; Johnson et al. 1966
13	Arrigetch Mountains	Cooper 1986
14	Toolik Lake	Walker et al. 1994
15	Imnavait Creek	Walker et al. 1987; Walker and Walker 1996
16	Kobuk River Valley	Racine 1976; Melchoir 1976
17	Lake Peters	Battan 1977
18	Noatak River	Young 19873
19	Killik River	Murray 1974

Layer 4. Floristic subprovinces and phytogeographic subzones. Based on Yurtsev (1994).

Map code	*Floristic subprovince and phytogeographic subzone*
11	Northern Alaska subprovince, arctic tundra (=southern high arctic) subzone
12	Northern Alaska subprovince, northern hypoarctic (=northern low arctic) subzone
13	Northern Alaska subprovince, southern hypoarctic (=southern low arctic) subzone
21	Beringian Alaska subprovince, northern hypoarctic (=northern low arctic) subzone
22	Beringian Alaska subprovince, southern hypoarctic (=southern low arctic) subzone

Layer 5. Landscape units. Based on photo interpretation of AVHRR CIR composite image 1:4,000,000 (Fleming, this volume) with reference to standard false-color controlled Landsat mosaic of mainland Alaska, Scale 1:1,000,000 (USGS, Branch of Alaska Geology 1978).

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

Layer 6. Percentage land cover by lakes. Based on Sellman *et al.* 1975. Percentages reflect only lakes and do not include marshes and drained lake basins.

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

Layer 7. Generalized bedrock geology. Based on Beikman, H.M. (1980). Geologic map of Alaska. Scale 1:2,500,000. State of Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys. 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	IPM, DS, IPz, IPzpC,	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.

Layer 8. Soil associations. Based on Rieger *et al.* (1979) and photointerpretation of AVHRR false CIR composite (Fleming, this volume) and modified with information from numerous sources including Gryc (1985), Hamilton and Porter (1975), Hamilton (1986), US Dept. of Interior (1982).

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

Layer 9. Maximum NDVI. Hard-copy image at 1:4,000,000 scale derived from AVHRR composite of maximum NDVI values for each pixel. (Fleming, this volume)

Layer 10. Vegetation complexes. Refer to attached look-up table for dominant and characteristic vegetation communities in each complex and within each of Yurtsev's (1994) floristic provinces and phytogeographic zone in northern Alaska.

Map code	*Vegetation complex*
1	Acidic high mountain complex with vertical zonation
2	Circumneutral high-mountain complex with vertical zonation
3	Circumneutral plateau complex
4	Mountain valley 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

Layer 11. Integrated terrain unit map. This map contains all the polygon boundaries from all the overlays. This map is digitized and each polygon assigned a unique polygon ID number.

Layer 12. Point map for off-scale units.

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

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OCCASIONAL PAPERS

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