Circumpolar Arctic Vegetation Mapping Workshop

By D.A.Walker and Carl J. Markon

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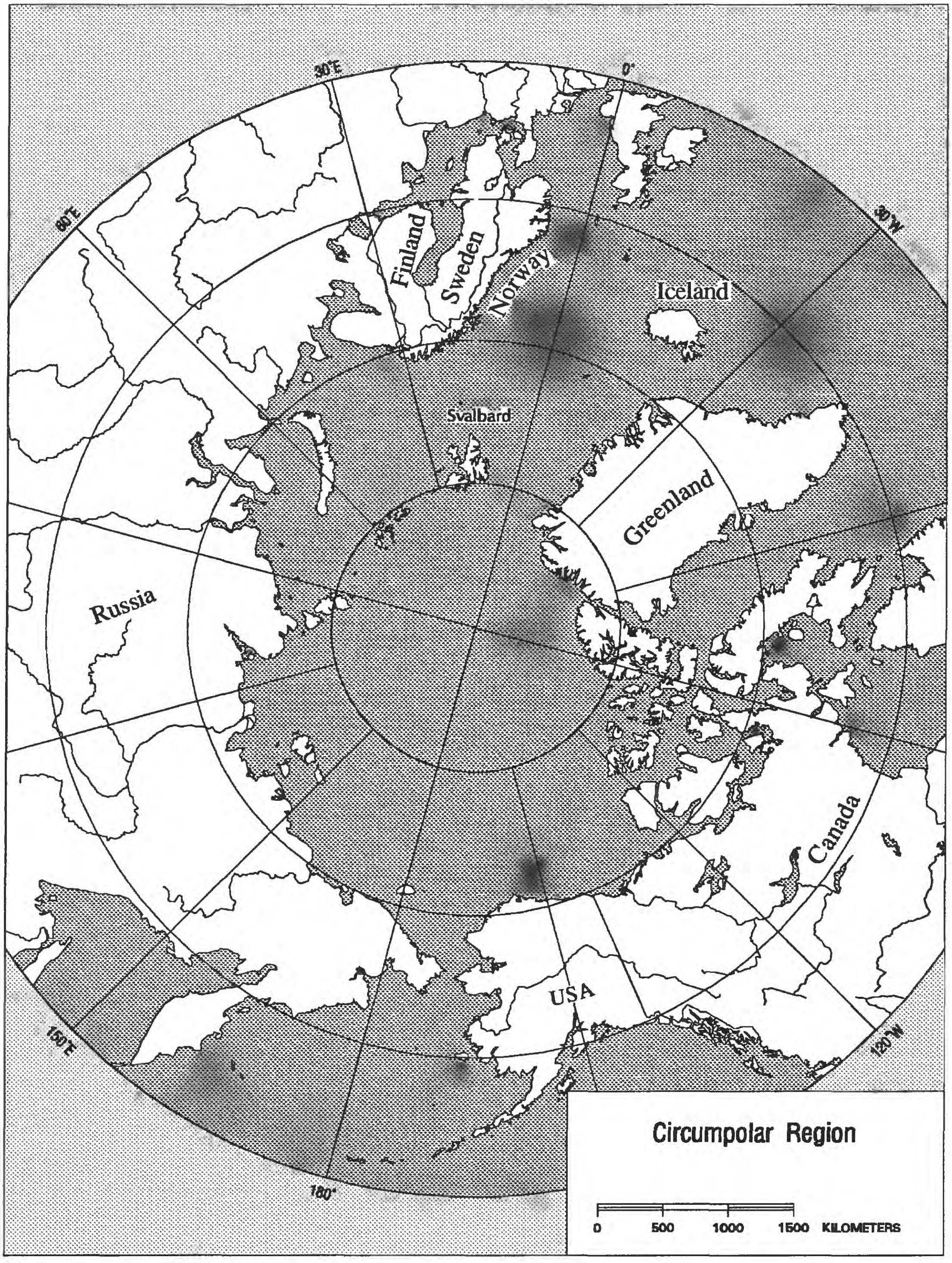
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CIRCUMPOLAR ARCTIC VEGETATION MAPPING WORKSHOP

Edited by: D. A. Walker [1] and C. J. Markon [2]

A compilation of abstracts and short papers presented at the
Komarov Botanical Institute
St. Petersburg, Russia
March 21-25, 1994

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[1] University of Colorado, Boulder, Co.

[2] Hughes STX Corporation, Work performed under U.S. Geological Survey contract 1434-92-c-4004.

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Preface

The first Circumpolar Arctic Vegetation Mapping Workshop was held in the historic village of Lakta on the outskirts of St. Petersburg, Russia, March 21-25, 1994. The primary goals of the workshop were to: (1) review the status of arctic vegetation mapping in the circumpolar countries and (2) develop a strategy for synthesizing and updating the existing information into a new series of maps that portray the current state of knowledge. Such products are important for a number of purposes, such as the international effort to understand the consequences of global change in Arctic regions, to predict the direction of future changes, and for informed planning of resource development in the Arctic.

The invitees to the workshop were selected primarily for their expertise in producing vegetation maps of arctic regions or their involvment in large-scale arctic geobotanical mapping projects. Each came with a short paper or abstract in English summarizing their mapping activities. This volume contains the edited versions of these documents. The first six papers present the introductory comments and describe the background and goals of the workshop. The second section contains 14 papers that summarize the status of vegetation mapping in each of the major circumpolar regions, including Alaska, Canada, Greenland, Iceland, northern Fennoscandia, Svalbard, Western Siberia, Yakutia, Taimyr Peninsula, and Chukotka. In total, these presentations provided an excellent overview of vegetation mapping in the circumpolar region. The highlight of this section of the workshop was the review of colored vegetation maps from around the circumpolar region. Unfortunately, because of their large size and complex legends, it was not possible to reproduce these maps for this volume, and some of the abstracts are difficult to understand without the maps. The third section contains five papers that discuss the considerations for making the legend of a new circumpolar vegetation map. These papers were the focus of discussions during the next two days of the workshop. New vegetation maps of the Arctic will rely heavily on remote sensing technology and will be key components of circumpolar environmental information systems. The final section contains seven papers that discuss the status of remote sensing and geographic information systems in arctic regions, and several arctic database projects.

Two other publications resulted from the workshop. The first, published in Arctic and Alpine Research, is an appendix to this volume; it summarizes the overall objectives and resolutions of the workshop (Walker and others, 1995a, Appendix A). The second paper, published in the Journal of Vegetation Science, is a review of the existing maps in each of the circumpolar countries (Walker and others, 1995b, Appendix B). A followup workshop is planned for 1996 in Arendal, Norway. The major topics of this workshop will be to finalize the legend of the map and develop a funding strategy for completing the map.

The organizers of the workshop thank the Komarov Botanical Institute for hosting the workshop and all who participated for their contributions and lively discussions. Support for the workshop came from the National Science Foundation as part of the Arctic System Science Program (Grant No. DPP 93014-58) and the U.S. Department of State through the Fish and Wildlife Foundation (Grant No. 94-032a) as part of the Circumpolar Arctic Flora and Fauna (CAFF) program. The U.S. Geological Survey is supporting the U.S. effort to produce base maps and remote-sensing products of the circumpolar region; the first of which appears on the cover of this report.

A special thanks to Carl Markon for editing this report and coordinating its completion, to Dr. Sigmund Spielkavik and Sara Wesser for their technical reviews, Steve Finneran for digitizing many of the maps, and to Sablou Gabriel for all her assistance in initiating and shepherding this manuscript through the U.S. Geological Survey review process.

D.A. Walker, B.A. Yurtsev, and S.S. Talbot
August 28, 1995

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I. INTRODUCTORY COMMENTS

WELCOME

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(to the attention of Dr. B.A. Yurtsev)

Dear Colleagues and Friends!

I have the privilege of opening the Circumpolar Arctic Vegetation Mapping Workshop. I am happy to see and greet all of the participants and guests to this city. You have arrived from different countries and different cities of Russia and represent various agencies and institutions. Many of you have had to travel a long way to contribute to what is to become our joint work.

As you know, this conference is the realization of one of the initiatives born 2 years ago at the International Workshop on the Classification of Circumpolar Arctic Vegetation held in Boulder, Colo., USA. Since the potential participants of the creation of the map were represented in Boulder very incompletely, it was decided to hold a special workshop on Circumpolar Vegetation Mapping, involving key specialists.

It is a particular pleasure to me that this meeting occurs in Russia (the country possessing the most extensive arctic territories), and namely, in the largest scientific-botanical center of Russia (and one of the largest in the world) -- the Komarov Botanical Institute of the Russian Academy of Sciences. This is by no means accidental: the Institute possesses an excellent school in geobotanical cartography, very experienced, top-level specialists in this field, and good experience for creating survey maps of extensive areas, including arctic territories, and for the international cooperation in vegetation mapping. In this country an enormous body of information about the plant cover of the Arctic has been accumulated (but only partially processed!), and the survey vegetation maps on major sectors of the Russian Arctic have been created.

I would like to recognize the key contribution of American botanists to the organization of this meeting, particularly Dr. Skip Walker of the University of Colorado, the initiator and largest contributor of the project, as well as Dr. Steve Talbot of the U.S. Fish and Wildlife Service for securing our funding. Grants for this workshop were received from the U.S. Fish and Wildlife Service and the U.S. National Science Foundation.

I shall not be talking about the fundamental importance of the work to be started for arctic biology and ecology: it will be the topic of the next speaker, Dr. Skip Walker. However, I should emphasize that if we want to get the necessary funding for the realization of our plans, we have to make our points clear and evident to the decisionmaking agencies in the Nordic countries.

I also would like to emphasize that our joint work lies just on the crossing point of classical and the most modern approaches, methods, and technologies. The core of this work combines the advantages of the botanical-geographic schools, which have accumulated an enormous store of knowledge on the vegetation of specific parts of the Arctic, and the most modern scientific technologies (such as remote-sensing, GIS, the calculation of vegetation indexes for large areas and of its dynamics). If we harmonize both the approaches, our knowledge of arctic vegetation will rise to a new, higher level.

At present, our country is passing through a hard but necessary period of its history. These difficulties have impeded, to some extent, the preparations of the workshop, but I hope that all of you will feel comfortable here, and that the conference will be successful and fulfill all of its major goals. As is the case at all such meetings, one of the most important things ("the submerged part of an iceberg") is the personal contacts between the participants at the meeting. I also hope that you will have a chance to visit the Komarov Botanical Institute and, at least shortly, tour the city, show slides to one another, and set up new friendships without which it would be almost impossible to perform the planned joint work.

Once more, thank you all for coming and let us start!

BACKGROUND AND GOALS OF THE CIRCUMPOLAR ARCTIC VEGETATION MAPPING WORKSHOP

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Acknowledgments

I would first like to acknowledge the roles of many individuals who helped to make this workshop possible. First, I'd like to thank our hosts Boris Yurtsev and the Organizing Committee at the Komarov Institute for making the conference arrangements and performing the very difficult task of bringing together scientists from all over Russia. The reason we are holding this workshop here is that without our Russian colleagues, this would be a very hollow meeting indeed, and we recognize the difficulty for many of you to travel outside of Russia. I would like to dedicate this meeting to the long heritage of vegetation mapping research in Russia, which serves as an inspiration for the rest of the circumpolar countries. We are truly delighted that we could come and visit your beautiful city and see one of the great vegetation mapping centers in the world. In the U.S., we had a smaller, less formal committee who helped with many aspects of the meeting. Dr. Steve Talbot and Dr. Dave Murray are with us and I would like to thank them very much for their help and insights. I would like to particularly thank Steve Talbot, who was able to convince the U.S. Fish and Wildlife Service that this was a project worthy of funding as part of the Circumpolar Arctic Flora and Fauna (CAFF) initiative. Drs. Jerry Brown and Pat Webber could not attend, but they also provided much support and advice for this meeting.

I also would like to thank numerous people at the Institute of Arctic and Alpine Research who helped with the logistics of the meeting, including Nancy Auerbach, who was able to join us. Many others, including Kristi Rose, Margaret Ahlbrandt, and Fran Simpson, made major contributions to seeing that this meeting could happen. I'd like to also acknowledge the help of Dr. Marilyn Walker and particularly her role in hosting the very successful predecessor to this workshop at the International Workshop of the Classification of Circumpolar Arctic Vegetation, which was held in Boulder, Colo., and where the idea for this workshop was formed.

Finally, I would like to acknowledge the agencies that provided the funds for this workshop: The National Fish and Wildlife Foundation and the National Science Foundation. Dr. Steve Talbot will give some background regarding the CAFF initiative and I have a small letter from Dr. Pat Webber that explains National Science Foundation (NSF) interest in this workshop.

Introduction

The circumpolar arctic tundra region is experiencing rapid environmental change. Problems related to resource development are shared by all the circumpolar nations. These problems include cumulative impacts of development, wetland destruction, thawing of ice-rich permafrost, and increasing pressures on the flora and fauna and the native peoples. Coupled with these direct impacts are the indirect effects of global climate change.

Vegetation is the key element in understanding and predicting how these regions will respond and contribute to global change. Accurate maps of the extent of vegetation units are an essential component of preserving the biodiversity of the region. Arctic vegetation is in many ways a single natural ecological unit, and its study requires a vegetation classification system and a map that can be applied to any region and be adapted to many spatial scales.

Several coarse-scale (greater than 1:10,000,000) vegetation maps exist for the Arctic as part of global vegetation databases (for example, Matthews, 1982; Olson and others, 1983; Blasco, 1988). The scales of these maps are, however, too coarse for regional modeling efforts. Similarly, many detailed vegetation maps portray relatively small regions of the Arctic (for example, Edlund, 1990; Gribova, 1974; Walker and others, 1980). The weaknesses of this collection of maps are that the maps have various scales, classifications, are derived using different mapping techniques, and the base maps are often constrained by political boundaries, all of which frustrate attempts to do regional or global extrapolations. All the maps must be generalized to the lowest common denominator.

An important consideration, especially for land-use planning and modeling, is that the vegetation information be accurately located with reference to actual terrain features. The boundaries on existing coarse-scale maps of the Arctic are very general and of marginal use for global GIS databases. We must be able to tie the vegetation information to global satellite-derived spatial databases.

The following examples are important applications of vegetation maps to current questions in the Arctic:

* Studies of arctic biota and their diversity
* International studies of conservation
* Natural resource development
* Models of global trace-gas fluxes
* Planning for international parks
* International ecoregion mapping
* Circumpolar and global environmental databases.

Now is the time to begin making a comprehensive circumpolar arctic vegetation map. Three previous obstacles to this goal have been recently removed: (1) travel and communication between Russia and the other circumpolar countries are now relatively simple, (2) data are now available with sufficient resolution to develop a map at more than a very coarse scale, and (3) powerful remote-sensing techniques and geographic information systems (GIS) are now widely available to assist in developing the map and integrating it with other geobotanical information.

At the Circumpolar Arctic Vegetation Classification Workshop in Boulder in March, 1992 the attendees prepared the Resolution for Preparation of an Arctic Circumpolar Vegetation Map.

Goals of The Workshop

I see eight primary goals:

1. Review the status of arctic vegetation mapping in the circumpolar countries. This will be accomplished during the first day of the conference.

2. Review the current status of GIS databases, and remote sensing that is relevant to a vegetation map. This will be accomplished during the second day of the conference.

During the third and fourth days, we will break up into working sessions to address the following goals:

3. Define the purposes of making a new circumpolar vegetation map. How do we foresee it being used?

4. Define the type of vegetation legend that is feasible and which will serve the purposes for which it will be used. Do we want a "pure" vegetation map based solely on characteristics of the vegetation (physiognomy, floristics, growth forms)? Or do we want to consider a combination of vegetation and ecological criteria?

5. Define the type of approach that will be used. Do we start from scratch and use a photointerpretive approach, using AVHRR and Landsat images as the photobases? Do we attempt an automated remote sensing mapping approach using training areas where available? Or, do we synthesize and combine all the maps that have already been made into a single format where possible and use remote sensing and photointerpretation only where we have no previous maps?

6. Develop a legend that can be consistently applied across the arctic and that is amenable to the approach defined in #5. This will be the hardest objective to achieve.

7. Define a cooperative strategy for doing the mapping that will take advantage of the expertise in each of the circumpolar countries.

8. Develop a funding strategy.

These are simply my first impressions of what we should accomplish. I think we need to carefully consider these, reword them where necessary, add and delete, and agree on what it is that we are here to accomplish.

So, I would like to thank you all for coming and participating. I know we will all learn a lot from each other and that we will strive to obtain the goals of the workshop. We have a busy three days ahead of us.

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Resolution for Preparation of an Arctic Circumpolar Vegetation Map

Whereas the distribution, characteristics, and history of arctic flora and vegetation are of essential importance with regard to (1) knowledge of how circumpolar terrestrial ecosystems interact with and contribute to the earth system, (2) conservation of the biodiversity in these regions, and (3) plans for energy extraction and resource development in the circumpolar nations;

Whereas our knowledge of previously unknown regions and the distribution and environmental constraints on arctic vegetation has increased;

Whereas no single existing map accurately portrays the synthesis of existing knowledge of the vegetation of this region;

Therefore, be it resolved that the international community of arctic vegetation scientists undertakes the joint task of compiling, editing, and producing a circumpolar map depicting the distribution and boundaries of arctic vegetation north of the arctic tree line at a scale of approximately 1:7,500,000 and a legend that is accepted and understood by the international vegetation community;

Furthermore, the Man and Biosphere Northern Sciences Network (MAB/NSN) endorses such a project and announces that the cooperation, interest, and scientific expertise of the international community are welcome in the development of this map.

Finally, be it **resolved** that the undersigned scientists begin the task of developing the organizational mechanism to accomplish this task and a schedule that will produce a draft of this map for the International Botanical Congress in 1997.

Attendees at the *International Workshop* on
Classification of Circumpolar Arctic Vegetation,
Institute of Arctic and Alpine Research,
Boulder, Colorado, March 9, 1992

CONSERVATION OF ARCTIC FLORA AND FAUNA (CAFF) INITIATIVE

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Abstract -- The Conservation of Arctic Flora and Fauna (CAFF) program is a new initiative to foster international cooperation between eight Arctic nations. Its purpose is to provide a forum for information exchange on the circumpolar Arctic. Working groups meet annually to address issues of international concern regarding the status and trends of biological and human resources. These include issues such as habitat protection, flora and fauna conservation, modern human impact, and integration of indigenous peoples' knowledge. Active dialogue in the working groups stimulates the development of an interactive process where questions of international concern are addressed and resolved through the cooperative sharing and synthesis of data.

Introduction

Given the modern human impact on the Arctic and the considerable amount of information learned in the past 15-20 years regarding the use of ecological data in lessening the impact of human influence, an opportunity exists for Arctic countries to cooperate and share information (Bliss, 1983). To this end, CAFF is an ecosystem-based program with membership from natural resource agencies. The CAFF is part of the Arctic Environmental Protection Strategy (AEPS), adopted by ministerial declaration at Rovaniemi, Finland in 1991 by eight Arctic countries -- Canada, Finland, Greenland (Denmark), Iceland, Norway, Russia, Sweden, and the United States. The purpose of CAFF is to further the goals and objectives of AEPS aimed at protecting the Arctic environment from identified threats and at seeking the development of more effective laws and conservation practices in close cooperation with indigenous peoples in the Arctic.

The CAFF represents an innovative and distinct forum for scientists, resource managers, indigenous peoples, and conservationists sharing information on Arctic species and habitats. Traditional approaches to nature conservation focus primarily on local or regional issues but may miss the broader, circumpolar perspective. The CAFF offers a unique national and international forum to address questions from a circumpolar view. Member countries collaborate, as appropriate, for more effective research, conservation management, and sustainable use of Arctic resources. The CAFF meets to exchange scientific data and information, including traditional knowledge of indigenous peoples on Arctic flora, fauna, their habitats, and diversity.

The goal of this overview is to demonstrate the role of the CAFF as a tool to resolve circumpolar questions through concrete examples.

Methods

The CAFF Working Groups meet annually in host countries, Canada and the United States in the past, and Iceland in September 1994. Annual work plans with action items address specific conservation issues.

Lead countries select action items and gather, analyze, and synthesize data from the eight CAFF member countries. For example, Norway addressed the status of habitat protection in the Arctic as it regards circumpolar threats. To find out if circumpolar habitat protection gaps exist, Norway used an international system of classification (IUCN, 1990) in conjunction with computer-generated maps to identify and map the location, extent, and levels of protection given to areas such as refuges, parks, and reserves within each Arctic country. Through a questionnaire, Norway also identified a number of potential disturbances related to human activities in the Arctic habitats such as exploitation of hydropower, petroleum, minerals, and forests.

In another example, Canada, as lead country for a murre conservation strategy, sought to provide a comprehensive international approach to protecting murre populations from anthropogenic sources of mortality using an international team of scientists.

The U.S. Fish and Wildlife Service, as lead agency for the United States, proposed two major initiatives to address circumpolar conservation issues that foster the rational understanding of high-latitude resources: (1) international activity support for a circumpolar mapping program through the Institute for Arctic and Alpine Research, University of Colorado, to prepare a vegetation map for a unified approach to understanding Arctic ecosystems, and (2) development of a prototype information database system for Alaska through the U.S. Geological Survey, EROS Alaska Field Office to demonstrate the feasibility of regional and circumpolar databases.

Results and Discussion

The Second Ministerial Conference on the Arctic Environment held in Nuuk, Greenland, in September 1993, endorsed the direction, thrust, and progress achieved in the CAFF work plan in its first two years. The CAFF serves as a demonstration of international cooperation for conservation and sustainable use of Arctic resources using an ecosystem approach as evidenced by:

(1) The practical approach taken by the CAFF to focus on specific issues through the work plans, as exemplified in the "State of the Habitat Protection in the Arctic" report (CAFF, 1994). The report includes the following subjects -- (a) mapping of protected areas in the Arctic, (b) review of management practices and regulations pertaining to those protected areas, (c) assessment of gaps in the protected area system, and (d) examples of habitat protection measures outside the protected areas in the Arctic. In addition to the report, a plan is being prepared for developing a network of Arctic protected areas that will ensure necessary protection of Arctic ecosystems, recognize the role of indigenous cultures, and provide a common process by which Arctic countries may advance information of circumpolar areas.

(2) The concrete example CAFF portrays of cooperation to implement the conservation measures called for in the Convention on Biological Diversity.

(3) The initiatives undertaken by CAFF to link conservation and wise use of flora and

fauna to other components of the AEPS, for example, through intensified cooperation with the Arctic Monitoring and Assessment Program (AMAP). The CAFF Working Group and the AMAP Task Force will collaborate to ensure compatibility between the two programs. Other joint initiatives such as species lists for monitoring activities and compatible databases will be identified.

(4) The development of appropriate conservation strategies, as exemplified by the Circumpolar Murre Conservation Strategy.

(5) The support of a proposal to produce a 1:7.5 million-scale vegetation map using advanced very high resolution radiometer (AVHRR) satellite images as a base for a landscape-guided mapping approach and a combined floristic-physiognomic legend. The first step toward this is the convocation of this international workshop in St. Petersburg, Russia with the following major goals: (a) thoroughly review existing maps for the circumpolar region, (b) develop a map format and legend, and (c) define the approach. The map will be useful for addressing major issues related to global change, biodiversity of Arctic ecosystems, large-scale resource development in Arctic regions, and the use of Arctic regions by indigenous people.

(6) Finally, the CAFF is supporting the development of a prototype database for Alaska to be produced by the U.S. Geological Survey, EROS Alaska Field Office. The system will address issues related to the conservation of Arctic flora and fauna and seek to demonstrate the feasibility of regional and circumpolar databases. The land characterization database will include attributes such as vegetation, elevation, slope, aspect, soils, geology, permafrost, climatic data, and AVHRR composites. The power of the land characterization database will be demonstrated for the identification and study of discrete landscape units and patterns, a process that will be repeatable upon the establishment of a similar database for the entire circumpolar Arctic region.

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LETTER FROM THE NATIONAL SCIENCE FOUNDATION

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Letter to Delegates to the Circumpolar Arctic Vegetation Mapping Workshop, St.Petersburg, Russia

11 March 1994

My Dear Friends and Colleagues:

I send my best wishes for a successful workshop. I hope that you leave the meeting with a clear set of goals and a firm resolution and commitment to create a series of sorely needed maps of Arctic vegetation and related phenomena.

The U.S. National Science Foundation is pleased to join The Komarov Botanical Institute and the U.S. Fish and Wildlife Service in being able to provide some funding to assist this workshop.

I am sad that I cannot be with you. I am afraid that my new bureaucratic responsibilities prevent me from coming. I had looked forward to what would have been my third visit to St. Petersburg, and the chance of seeing old friends and making new ones and of telling you that the U.S. National Science Foundation is ready to continue its partial support of your effort.

Before I say anymore I wish to thank Dr. Boris Yurtsev and his colleagues at The Komarov Botanical Institute for hosting the meeting. There is no better place in the world to hold such a meeting. Where else is there more knowledge of polar vegetation than at The Komarov?

I also wish to congratulate the co-organizers of the program, Drs. Skip Walker, Steve Talbot, and Boris Yurtsev. Congratulations to you for having the vision, faith, and fortitude to make the meeting a reality.

As Director of the only program in the U.S. Global Change Research Program which is focussed solely on the Arctic, I am aware how much a new, appropriately scaled series of surface and near-surface maps are needed to assess the effect of global change in the Arctic. These maps are needed to provide state variables for the climate models, to inventory living and other carbon-based resources, to predict and assess change and as a basis for ensuring good stewardship of the land and the biota. I believe that you are the best group to carry out this important task.

The program which I direct is called Arctic System Science (ARCSS). ARCSS is a program developed by the Office of Polar Programs in the U.S. National Science Foundation in order to fund research which would gather the knowledge that is needed to assess the effects of global change, including climate change, on the Arctic and the Earth System within which it is a component. It is this knowledge which is necessary to develop policy and management options for sustaining the Biosphere.

ARCSS supports interdisciplinary systems research, which usually involves the team approach. For example, the GISP-2 (Greenland Ice Sheet Project) and the NEWP (North East Water Polynya) projects are funded by ARCSS. The U.S. component of ITEX (International Tundra Experiment), which you may wish to regard as a sister project to your Circumpolar Vegetation Mapping Project is also funded by ARCSS. Since there will be colleagues among you that have attended the recent ITEX workshop you might consider exploring links with ITEX.

While NSF almost never directly funds foreign institutions it is able to support overseas workshops and secretariats through awards to US-based institutions and investigators. Therefore you may wish to submit proposals in collaboration with some US-based scientists for the NSF to consider. Of course there is only a limited supply of funds and since all our funding is awarded on a competitive, merit, and peer review basis there are no guarantees. Nevertheless you have the skills to meet the needs and goals of ARCSS and I encourage you to consider this opportunity.

I recommend that you consider developing a phased program and have as a first modest, short-term goal the production of a new map at a scale appropriate for input into the next generation of Global Climate Models. This will prove your talents and organization and open the door for support of more demanding and longer-term tasks. You may wish to report your progress at the IGBP/GCTE meeting in Woods Hole, Massachusetts towards the end of this May!

I look forward to seeing the report of your workshop.

Work hard and enjoy yourselves.

My sincere best wishes to you all,

Patrick John Webber
Program Director

PANARCTIC FLORA PROJECT

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Abstract -- The Panarctic Flora Project (PAF) is one-half of the Panarctic Biota Project, which was formally established at workshops held in Moscow (1991) and St. Petersburg (1992). There are two parallel objectives: (1) development of electronic databases as a means to assess arctic biodiversity, and (2) production directly from the databases of hardcopy manuals and monographs. Information on the arctic flora will come from herbarium specimens and libraries in addition to field work to fill gaps in our information.

Working groups and group coordinators have been named for both vascular and nonvascular plants at two centers: David F. Murray and Barbara M. Murray, University of Alaska Museum, University of Alaska Fairbanks, and Boris A. Yurtsev and Nina S. Golubkova, the Komarov Botanical Institute, Russian Academy of Science, St. Petersburg. We are now arranging for wider collaboration from Canada and the Nordic countries. Because of the obvious relationship of PAF to vegetation mapping and GIS, Marilyn Walker (University of Colorado at Boulder, USA) has been part of the project from the beginning. A subcommittee to study anthropogenic plants is being established by Bruce Forbes (Canada).

The database of the Northern Plant Documentation Center (University of Alaska Museum), developed by Alan Batten and Barbara Murray, has been taken as the standard for database structure and data dictionaries. Vladimir Razzhivin (Komarov Botanical Institute) is the database manager for the Russian side. Authority files for plant names, collecting localities, collectors, geographic and floristic sectors, and habitats are among the many files of data being jointly compiled. Data are cross-referenced to a bibliographic database. The Russian language literature is recorded in its original Russian, transliterated Russian, and English translated forms. Annotated checklists produced from the authority files document plant diversity and the conservation status for rare plants.

In collaboration with the National Park Service (USA), a team of PAF botanists from the University of Alaska Museum, University of Colorado, Boulder, Colo., and the Komarov Botanical Institute has engaged in field work on the Seward Peninsula, Alaska, to inventory the vascular plants, bryophytes, and lichens of the Bering Land Bridge National Preserve. An emphasis for PAF in the near term will be an atlas of plants endemic to Beringia. The PAF botanists are contributing information on rare plants to the consortium of eight arctic countries for the Conservation of Arctic Flora and Fauna initiative of the Arctic Environmental Protection Strategy. Bente Eriksen (University of Gothenburg, Sweden) is beginning research on the systematics of some arctic species of the genus *Potentilla*, which provides an important link between the activities of PAF, Flora of North America, and Flora Nordica.

At the inaugural meeting of the Circumpolar Arctic Vegetation Mapping Project in Boulder, Colo., in 1992, PAF agreed to provide the Alaskan plant names file from the Northern Plant Documentation Center, and now we are ready to enlarge this contribution.

Vegetation units of map legends are necessarily abstractions of a myriad of floristic details, which are subsumed by the names for types of plant cover. Nevertheless, local and regional variation of the flora can be made available through the PAF database, which is being compiled from both specimens and reliable sight records.

Eriophorum sp.

Arctophila fulva

Poa sp. /Carex sp.

INTERNATIONAL TUNDRA EXPERIMENT AT PRESENT

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Abstract -- The goal of the International Tundra Experiment (ITEX) is to understand the response of tundra plant species to climate change through simple manipulation and transplantation experiments conducted at multiple arctic and alpine sites. The ITEX was created as a Man-And-the-Biosphere, Northern Sciences Network (MAB-NSN) initiative during a meeting at the Kellogg Biological Station, Michigan, USA, in 1990. The 5th International ITEX Workshop, which just closed in St. Petersburg, revealed the first results of the programme.

The ITEX is unique among international programmes relating to global change in that it has been operating in the field for several years, and is now at more than 20 field stations in 10 countries (Canada, Finland, Greenland [Denmark], Iceland, Japan, Norway, Russia, Sweden, Switzerland, and the USA). Our preliminary results indicate that experimental warming induces quite different short-term responses in different plant species. Deciduous species respond dramatically in vegetative growth, for example, leaf area and standing crop, whereas evergreen species show little or no such response. Speeding-up of the flowering and fruiting phenology, on the other hand, is significant in most evergreen species, but less so (or absent) in deciduous ones. In most, but not all, species, experimental warming in the range of 2-3°C in open-top chambers yields significantly higher seed weight and germinability. Thus, in an anticipated warmer climate, we should not expect a movement of entire plant communities "en bloc," but rather a decomposition of known plant communities. The Circumpolar Arctic Vegetation Map will provide an extremely important source of baseline data for modeling of climate change impacts, as well as for comparisons and assessment of climate change impacts in the Arctic in the next century.

The ITEX has established collaboration with three other major programmes: The International Permafrost Association, the Panarctic Flora, and the Circumpolar Arctic Vegetation Mapping Project, each of which is represented during the 1994 St. Petersburg meeting. An important question that ITEX addresses to the delegates of the workshop is: How widespread and representative are the vegetation types and plant communities that are subjected to monitoring and manipulation at the various ITEX sites?

II. STATUS OF CIRCUMPOLAR MAPS

REVIEW OF VEGETATION MAPPING IN ARCTIC ALASKA

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Introduction

Information on Arctic vegetation has increased markedly in recent years (Walker and others, 1995). At an International Workshop on the Classification of Circumpolar Arctic Vegetation at Boulder, Colo., in March 1992, the participants recognized that no single existing classification or map portrayed the synthesis of current knowledge. From this recognition, the participants agreed to undertake the tasks of compiling, editing, and publishing an Arctic circumpolar map database. Realizing the value of this endeavor, the Conservation of Arctic Flora and Fauna (CAFF) Program, a component of the Arctic Environmental Protection Strategy (AEPS), collaborated with the Institute of Arctic and Alpine Research, University of Colorado, Boulder, to initiate this task.

Toward these objectives, the first Circumpolar Arctic Vegetation Mapping Workshop was held in St. Petersburg, Russia, March 21-25, 1994 to (1) review the status of maps for the Arctic tundra regions, (2) formulate a strategy for making a vegetation map database, and (3) develop a framework for the vegetation legends. The results of this workshop are summarized in the Journal of Vegetation Science (Walker and others, 1995). One resolution of the workshop was to produce a bibliography of vegetation maps for the circumpolar Arctic. Accordingly, the objectives of this paper are to (1) compile a list of references for Alaskan arctic vegetation maps, and (2) review vegetation mapping in Arctic Alaska.

The process of inventorying available vegetation maps is a logical first stage in vegetation mapping. In this first step, Gribova and Isachenko (1972) stated that it is necessary to determine the number and kind of plant cover units that are mappable at a given scale and the area they occupy.

The term Arctic has been variously defined. As used here the Arctic is equivalent to tundra, or treeless lands beyond the latitudinal treeline. The tundra area is shown on the map "Major Ecosystems of Alaska" (Joint Federal-State Planning Commission for Alaska, 1973; 1:2,500,000 scale). This demarcation generally corresponds with that of Bliss and Matveyana (1991), Knapp (1965), and Yurtsev (1994). The literature search was restricted to vegetation mapping studies conducted in tundra areas. The Alaskan Arctic includes approximately 590,553 km^2 (Conservation of Arctic Flora and Fauna, 1994). It encompasses the Aleutian Islands, Alaska Peninsula, southern Kodiak Island, Yukon-Kuskokwim Deltas, Seward Peninsula, and the region north of the southern slope of the Brooks Range.

A literature survey shows that only one map, 1:2,500,000 scale (Spetzman, 1963), covers all of arctic Alaska; variations of this map by others are available at similar scales (Küchler, 1966; Selkrigg, 1975; Joint Federal-State Planning Commission for Alaska, 1973; Viereck and

Little, 1972). Until the late 1970's there were relatively few maps of larger scale. In response to factors such as increasing resource development, planning mandates, and wildlife-habitat relationships, Federal and State agencies sought efficient vegetation mapping methods to inventory regions within the arctic at higher resolution.

Conventional photointerpretation was used in western Alaska for range surveys (scale 1:60,000) of Hagemeister Island (Swanson and LaPlant, 1987), Nunivak Island (Swanson and others, 1986; see also, Bos [1967] and Fries [1977]), Seward Peninsula (Swanson and others, 1985), and for habitat analysis in the Hazen Bay, Yukon Delta National Wildlife Refuge (Tande and Jennings, 1986) and in northwest Alaska (Becia, 1987). Concurrently, satellite multispectral-scanner data became available, influencing the direction of research by providing a new tool to inventory large areas of public lands (Markon, 1995).

Vast arctic landscapes were mapped using satellite images at intermediate, 1:250,000 scales. Consequently, maps covering the greatest portions of arctic Alaska are of this scale. Two major approaches were used: visual-interpretation and computer classification. Visually-interpreted Landsat maps were prepared for several National Parks: Kobuk Valley (Racine, 1976), Chukchi-Imuruk area (Racine and Anderson, 1979), Lake Clark (Racine and Young, 1976) and Katmai western extension (Young and Racine, 1978); and Kodiak National Wildlife Refuge (Northern Technical Services, 1984). Computer classification of digital data included several portions of western Alaska -- Alaska Peninsula and Bristol Bay area (Wibbenmeyer and others, 1982), Dillingham Quadrangle (U.S. Geological Survey, 1987), Togiak (Fleming and Talbot, 1982) and Yukon Delta National Wildlife Refuges (Talbot and others, 1986); portions of northwestern Alaska -- (Craighead and others, 1988, Nodler and others, 1978), Anvik/Bonasila (Osborne and others, 1986), Buckland area (Adams and Connery, 1983), Cape Krusenstern (Faeo, 1993), Gates of the Arctic (Wesser, in preparation), Nulato Hills (Meyer and Spencer, 1983), Kobuk Valley (Wesser and Piercy, 1994), Selawik National Wildlife Refuge (Markon, 1988); and northern Alaska -- Arctic National Wildlife Refuge (Acevedo and others, 1982; Jorgenson and others, 1993; Markon, 1989; Walker and Acevedo, 1987; Walker and others, 1982), Coville River delta (Markon and others, 198?), the National Petroleum Reserve (Morrisey and Ennis, 1981, see also, Spencer and Krebs, 1982), and Prudhoe Bay area (Walker and others, 1980).

Other large scale studies of rather small areas are scattered throughout the arctic. For the Aleutian Islands, vegetation maps exist only for Bogoslof Island, in part (Byrd and others, 1980), Buldir Island (Byrd, 1984), Amchitka Island (Amundsen, 1972), Atka Island, in part (Friedman, 1984), and Simeonof Island (Talbot and others, 1984), and for the Pribilof Islands, Byrd and Norvell (1988) sketched the vegetation of St. Paul Island. For western Alaska, portions of the Unalakleet area were mapped (McKendrick, 1981; Palmer and Rouse, 1945). For northern Alaska, vegetation mappers from the University of Colorado (V. Komarkova, D. A. Walker, M. D. Walker, and P. J. Webber) concentrated their efforts on mapping portions of the coastal plain at large scales with detailed maps showing dominant species, physiognomy, soils, and landforms. Other studies of this area include the Teshekpuk Lake area (Derksen and others, 1982; Markon, 1992), Toolik Lake (Jorgenson, 1984), Firth-Mancha (Mouton and Spindler, 1980), and Opilak River delta (Spindler, 1978).

Most of the intermediate scale maps, and many of the large-scale maps, are physiognomic-ecological classifications. Map units reflect the structure of the vegetation and are sometimes supplemented with ecological information. The most frequently used descriptor is moisture with terms such as wet, moist, and dry. Other map unit characteristics include terms such as riparian, dune, and marsh. Dominant species are occasionally included but their use is often inconsistent, even within a map legend.

There is no consistent mapping system for the Alaskan arctic and there is an unevenness in coverage and mapping scale. Despite these shortcomings, it may be possible to use intermediate-scale maps of large areas and large scale maps of small areas as guides to interpret AVHRR digital data for production of a circumpolar map.

The list of Alaskan arctic vegetation maps includes both published and unpublished manuscript materials. It excludes vegetation studies without vegetation maps. Individuals interested in the latter are referred to the wealth of references provided by Viereck and others (1992). Libraries and institutions maintaining map materials are listed in Appendix A.

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APPENDIX A.

List of libraries and institutions

Alaska Dept. of Fish and Game
Habitat Division Library
333 Raspberry Rd.
Anchorage, AK 99518-1599
907-267-1723

Alaska Natural Heritage Program
Plant Ecology Library
707 A St., Suite 208
Anchorage, AK 99501
907-279-4549

Alaska Resources Library
U.S. Bureau of Land Management
222 West 7th, No. 36
Anchorage, AK 99513-7589
(907) 271-5425

EROS Alaska Field Office
U.S. Geological Survey
4230 University Dr.
Anchorage, AK 99508
907-786-7022

Institute of Northern Forestry
U.S. Department of Agriculture
U.S. Forest Service
Fairbanks, Alaska 99775
907-474-8163

U.S. Fish and Wildlife Service Library
1011 East Tudor Rd.
Anchorage, AK 99503
907-786-3358

National Park Service
Alaska Regional Office
2525 Gambell St.
Anchorage, AK 99503
907-257-2557

STATUS OF ARCTIC VEGETATION MAPPING IN CANADA

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Mapping of the vegetation of arctic Canada has not been pursued on a systematic basis. This may be because no single government agency is responsible for inventorying the knowledge of natural vegetation. The research granting agencies have supported local studies but have not funded systematic vegetation mapping projects. This has resulted in a large number of botanical or floristic studies in small areas scattered throughout the arctic without any effort to pull them together in vegetation maps, except on a very broad, general level (Advisory Committee on the Development of Government in the Northwest Territories, 1966; Department of Indian Affairs and Northern Development, 1971). Broad-scale generalizations were based on such regional studies (Polunin, 1951; Bliss, 1979; Edlund, 1983).

In the absence of a systematic effort, vegetation mapping was pursued, based on an opportunity basis. Botanists working with the Geological Survey of Canada field crews have produced a number of vegetation maps (Barnett and others, 1975; Tarnocai and others, 1976; Woo and Zoltai, 1977; Vincent and Edlund, 1978; Thomas and others, 1979). As a first step in evaluating selected areas as potential national parks, vegetation maps were prepared for Parks Canada, mainly as unpublished reports (Kelsall and others, 1970; Zoltai and others, 1979, 1980a, 1980b, 1981, 1983), or as publications by the Canada Wildlife Service (Zoltai and others, 1987, 1992).

Environment Canada instituted a program of landscape and vegetation mapping, but this initiative was not pursued. A landscape-vegetation map of Labrador was prepared by Lands Directorate (Lopoukhine and others, 1977), which includes the arctic-alpine part of Labrador.

Other mapping projects were carried out by universities (Ritchie, 1962; Muller, 1963; Beschel, 1970; Arkay, 1972; Muc and Bliss, 1977), resulting in the mapping of limited areas. During the 1970's and 1980's, proposed pipeline developments initiated a number of vegetation studies, but these did not result in mapping projects.

As most of the vegetation maps were created to describe specific areas, there was little effort made to develop a common vegetation mapping system. The detail of the vegetation units was dictated by the scale of mapping; most units combined vegetation morphology and common species into their legend. Such terms as high shrubs, low shrubs, dwarf (prostrate) shrubs, graminiods, and wet meadows were commonly used alone or in combination with species. The amount of bare soil, when created by cryoturbation or desert processes, were often indicated.

The lack of vegetation maps of Canada's Arctic does not indicate a lack of knowledge. In addition to the mapped areas, there are dozens of small areas where the vegetation was analyzed and classified. Such information, along with the already mapped areas, could be used for ground truthing satellite-derived images for creating a small scale vegetation map.

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LEGEND FOR VEGETATION MAP OF CANADIAN ARCTIC ISLANDS AND ADJACENT MAINLAND

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Letter to Delegates to the Circumpolar Arctic Vegetation Mapping Workshop, St.Petersburg, Russia

My warmest greetings are extended to the scientists at the Circumpolar Arctic Vegetation mapping Workshop. I am sorry that I cannot be with you this year, but I am still recovering from last year's serious illness and have not yet received clearance for international travel. The prognosis for a complete recovery is good, but I have not achieved it yet. (Of course I want it now!) My thoughts will be with you during this workshop.

I am still keenly interested in helping to produce a Circumpolar Arctic Vegetation Map, and will do what I can to contribute to your effort. I am completing a map for the Canadian Arctic Islands and adjacent mainland for my own organization. I am sending examples of this along with Dr. Stephen Zoltai and Dr. Skip Walker [below].

I would urge that the meeting consider producing a 'pure' vegetation map that is based on the criteria of physiognomy, floristics, growth forms, and others. Such a map is already in high demand from a variety of users. We may also want to consider producing a second one based on ecological criteria.

The national Atlas of Canada has recently produced a vegetation cover map for all of Canada from AVHRR data. It is an attractive map, but it very poorly represents what is actually present in the Arctic. One of the major problems is that areas with dense lichen/moss cover, such as are found in Keewatin District, N.W.T., and parts of Baffin Island are treated as poorly vegetated areas or bedrock. They were not even able to distingish large wetlands, which should be quite accessible from satellite data.

I am particularly interested in developing a useful legend. If there is anything I can do to assist in this process, please do not hesitate to let me know.

Best wishes for a very successful meeting.

Warmest Regards,
Sylvia Edlund

LEGEND FOR VEGETATION MAP

Low, Erect Shrub Zone (L) - Roughly equivalent to parts of hemiarctic zone and low arctic. Includes zone from treeline to northern limit of low, erect shrub thickets. Low erect shrubs, when present, between 0.5 to 1.5 m high. This region roughly corresponds to the 10-7°C mean July isotherm.

1. Ericaceous shrub tundra
    a. Ericaceous shrubs with a dense lichen-moss understory, for example, *Ledum-Cassiope* tundra
    b. Prostrate ericaceous shrubs with herb and bryophyte understory, for example, *Cassiope-Cladonia/Cladina* tundra
2. Low, erect deciduous thicket tundra
    a. Willow-dwarf birch tundra, for example, *Salix lanata-Betula glandulosa* tundra
    b. Willow tundra, for example, *Salix richardsonii-Salix arctica* tundra
3. Tall shrub thickets (1.5 m high, locally 4-7 m high)
    a. Willow thickets, for example, tall *Salix alaxensis* thickets; *Alnus crispa* thickets
4. Graminoid meadows, fens and wetlands with scattered low, erect shrubs
    a. Tussock cottongrass-willow tundra or fens, for example, *Eriophorum vaginatum-Salix lanata* tundra
    b. Tall sedge meadows, for example, *Carex aquatilis*
    c. Sedge meadows, for example, *Carex stans-Eriophorum angustifolium* meadows
    d. Salt marshes, for example, *Carex ursina-Puccinellia* mats
5. Prostrate shrub barrens (less than 25 percent ground cover) on thin dry, exposed or nutrient poor soils
    a. Dwarf ericaeous heath barrens
    b. Dryas barrens, for example, *Dryas integrifolia*-legume barrens
    c. Prostrate willow barrens, for example, *Salix arctica* barrens
6. Early successional communities
    a. Scattered graminoids and herbs

Dwarf and Prostrate Shrub Zone (D) - Dominated by woody plants whose vertical height is generally less than 20 cm. This zone occurs from the northern limit of low, erect shrub tundra to the northern limit of low, erect shrub species in a compact or compressed growth form. This zone is similar to the northern low arctic and roughly corresponds to the 7-5°C mean July isotherm.

1. Evergreen heath shrub tundra
    a. *Cassiope*-lichen/moss tundra, for example, *Cassiope tetragona-Cladonia* tundra
    b. *Cassiope-Vaccinium* heath

2. Dwarf and prostrate deciduous shrub tundra
    a. Dwarf willow-legume tundra, for example, *Salix richardsonii-Oxytropis* tundra
    b. Low birch-willow tundra, for example, *Betula glandulosa-Salix* tundra
3. Prostrate shrub tundra
    a. Willow tundra, for example, *Salix arctica*-herb tundra
    b. *Dryas-Salix* tundra, for example, *Dryas integrifolia-Salix arctica* tundra
4. Graminoid meadows, fens and wetlands
    a. Tussock cottongrass-low shrub meadows, for example, *Eriophorum vaginatum-Salix arctica* meadows
    b. Tussock cottongrass meadows, for example, *Eriophorum vaginatum* tussock tundra
    c. Sedge-shrub meadows, for example, *Carex stans-Salix* wet meadow
    d. Sedge-herb meadows, for example, *Carex stans-Ranunculus* meadows
    e. Sedge meadows, for example, *Carex stans-Eriophorum triste* wet meadows
5. Early successional communities
    a. Herb and forb dominated sere
    b. Herb and forb sere with woody plants present

Prostrate Shrub Tundra (P) - This zone is found from the limit of dwarf shrubs to the northern limit of low shrub dominated communities. This is a "no frills zone" roughly equivalent to mid-arctic and in some cases, the southernmost high arctic zone. This zone roughly corresponds to the 6-4°C mean July isotherm.

1. Ericaceous shrub tundra
    a. Arctic heather shrub tundra, for example, *Cassiope-Dryas* tundra; *Cassiope-Salix* tundra
2. Deciduous and matted shrub tundra
    a. Willow tundra, for example, *Salix arctic-Saxifraga* tundra; *Salix arctica-Luzula* tundra
    b. Dryas-willow tundra, for example, *Dryas integrifolia-Salix arctica-Saxifraga oppositifolia* tundra; *Dryas-Papaver* tundra
3. Graminoid meadows, fens and wetlands
    a. Sedge-shrub meadows, for example, *Carex stans/Eriophorum tristie-Salix arctica* meadow
    b. Sedge-grass meadows, for example, *Carex stans-Dupontia/Alopecurus* wet meadow
    c. Grass meadow, for example, *Alopecurus-Carex* wet meadow
4. Prostrate and matted shrub barrens
    a. Dryas barrens, for example, *Dryas integrifolia-Saxifraga oppositifolia* barrens
    b. Willow barrens, for example, *Salix-Luzula* barrens

Herb-Prostrate Shrub Transition Zone (H-P) - Parts of middle high arctic, northern limit of shrub dominated communities to entirely herb dominated communities. This zone roughly corresponds to the 4-3°C mean July isotherm.

1. Forb tundra with a minor amount of woody plants
   a. *Saxifraga* sp. dominated communities, for example, *Saxifraga oppositifolia*-willow tundra; *Saxifraga oppositifolia*-lichen/moss tundra
   b. Mixed herb dominated communities, for example, *Papaver-Caryophyllaceae* tundra
2. Graminoid meadows, fens and wetlands
   a. *Luzula* dominated tundra, for example, *Luzula-willow* tundra
   b. Grass-dominated meadow, for example, *Alopecurus-Dupontia* meadow
   c. Grass-sedge dominated wetlands, for example, *Carex-Alopecurus* wetland
3. Forb barrens
   a. *Saxifraga* dominated barrens, for example, *Saxifraga*-lichen barrens
   b. Mixed herb barrens, for example, *Papaver* barrens
4. Graminoid barrens
   a. Grass dominated barrens, for example, *Puccinellia* barrens, *Phippsia* barrens
   b. *Luzula* dominated barrens, for example, *Luzula-Papaver* barrens, *Luzula-Alopecurus* barrens
5. Cyrptogam communities
   a. Moss and hepatic dominated communities, for example, *Racomitrium* communities, *Gymnomitrium* communities
   b. Lichen dominated communities, for example, *Cladina* communities, *Cetraria islandica* communities, *Rhizocarpon-Parmelia* communities

Herbaceous and Crytogam Communities (H) - This zone extends from the northern limit of woody plants to the northern limit of plant survival. Woody plants and sedges are absent. This zone roughly corresponds to the 3-1°C mean July isotherm.

1. Forb dominated
   a. *Saxifraga* dominated tundra, for example, *Saxifraga* tundra, *Saxifraga-Papaver* tundra
2. Graminoid meadows, fens and wetlands
   a. *Luzula* dominated tundra, for example, *Luzula-Papaver* tundra
   b. Grass-dominated meadow, *for example, Alopecurus-Dupontia* meadow
3. Forb barrens
   a. *Saxifraga* dominated barrens, for example, *Saxifraga*-lichen barrens
   b. Mixed herb barrens, for example, *Papaver* barrens
4. Graminoid barrens
   a. Grass dominated barrens, for example, *Puccinellia* barrens, *Phippsia* barrens
   b. *Luzula* dominated barrens, for example, *Luzula-Papaver* barrens, *Luzula-Alopecurus* barrens
5. Cryptogam communities
   a. Moss and hepatic dominated communities, for example, *Racomitrium* communities, *Gymnomitrium* communities

b. Lichen dominated communities, for example, *Cladina* communities, *Cetraria islandica* communities *Rhizocarpon-Parmelia* communities

REVIEW OF VEGETATION MAPPING IN GREENLAND

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Introduction

A few research institutions in Denmark, including the Greenland Botanical Survey (GBS), Greenland Environmental Research Institute (GERI), and Geographical Institute, University of Copenhagen have dealt with vegetation mapping, but no superior strategy for vegetation mapping of Greenland exists. However, in the last decade regional vegetation mapping has been carried out in different parts of Greenland. The vegetation mapping have been mainly a part of biological projects, which mostly have purposes other than vegetation mapping. These projects have been concerned with environmental monitoring of oil exploration, studies of vegetation and soil impacts caused by sheep farming, and studies of herbivore foraging dynamics. Different mapping techniques have been used by both biologists and geographers resulting in maps of different scales and sizes. False color aerial photos as well as satellite-based techniques have been used in subarctic, low, and high arctic Greenland. The NOAA satellite data have been used in South Greenland as well as in Northeast and North Greenland. False color aerial photos, Landsat, and SPOT satellite data have been used when more detailed information on the vegetation was required. In subarctic Greenland, these data were used in connection with management of sheep farming, in low arctic as a tool for monitoring habitats of reindeer and the rapidly increasing muskoxen population, and in different high arctic areas in connection with real vegetation mapping projects. In total, only a few percent of the vegetation covered areas in Greenland are mapped in a detailed way.

Floristic work is a prerequisite for vegetation classification and mapping. The present one-man institution of the Greenland Botanical Survey, University of Copenhagen, has carried out floristic work in different parts of Greenland for the past 30 years. Based on this substantial floristic work, phytogeographical studies in North and South Greenland have been carried out and published. An interadjacent area in West Greenland has been studied and the phytogeographical results will be published this year. A synoptic phytogeographical project including Southeast Greenland and all available data of distribution of the more than 500 species of vascular plants in Greenland is under preparation. This project will lead to a revision of the "Flora of Greenland" including the latest taxonomical results and the present distribution of the species. This may be an integrated part of the Panarctic Flora maps and a substantial background for working with detailed vegetation mapping in Greenland in the future.

Regional mapping: Northeast Greenland

In connection with a planned oil exploration in Jameson Land in central East Greenland, the Ministry for Greenland initiated environmental investigations in the early 1980's. One of the major jobs carried out by GERI was to map the vegetation of the western part of the

10,000 km² peninsula, which is the largest lowland in high arctic Greenland with large populations of muskoxen and geese. The vegetation was classified into 14 plant communities and 4 types of impediments based on floristics, life-forms, cover of the dominant species, and the relation of the species to physical parameters such as terrain, soil, and snow cover. Six main types were distinguished: fen, grassland, herb slope, dwarf shrub heath, copse, and snowbed. Based on ground truthing at 16 camp sites, 3-15 km² were mapped at each site using false color-infrared aerial photos. A total of 265 detailed maps at 1:25,000 scale, each covering 25 km² have been produced. This is the largest and most detailed vegetation mapping work ever carried out in Greenland. The maps have been used as a tool to monitor the activities of oil exploration to minimize the impact on the vegetation and soil caused by vehicle traffic and seismic work. Vulnerable habitats including fens, grasslands, and marshes, in addition to types that produce a substantial amount of forage to muskoxen and geese, have been protected by regulations minimizing human activities.

False colored aerial photos were used as they were the only tool available at the beginning of the project for producing vegetation maps at a scale giving detailed information on the distribution of vegetation types. Years later, SPOT and Landsat TM-based vegetation maps of selected areas in Jameson Land were produced to compare the methods. The conclusion was that satellite-based vegetation mapping was inadequate for mapping of vegetation classes covering less than a few hundred square meters, because they are close to the limit of 1 pixel. Consequently, the vegetation types herb slope, salt marsh, and copse were included in adjacent vegetation classes on the satellite-based vegetation map. It was possible to distinguish 10 vegetation classes using the satellite data compared to the 14 types recognized by the aerial photo-based mapping. The advantage of the satellite data is that it is much cheaper, the images can easily be obtained, and it gives an objective interpretation of the plant cover.

Because the biological and archaeological knowledge of the National Park in Northeast Greenland was very limited, a privately sponsored 3 year mapping project was carried out in 1988-90. Three NOAA satellite-based vegetation maps were used for planning and selection of a representative study area. These give information on distribution of important biological areas, such as vegetated areas housing large populations of terrestrial herbivores. In addition, ground truthing of a SPOT satellite-based vegetation classification was carried out. The vegetation index distinguished seven categories, but because the vegetation was very patchy and mosaic-like, the interpretation was difficult.

A SPOT-based vegetation map at Zackenberg, Greenland distinguished 16 classes of vegetation, which is too many classes for a true interpretation. Another SPOT based vegetation map of this area is under preparation. Image sources for Greenland vegetation mapping are shown in figure 1.

North Greenland

False color aerial photos magnified to 1:20,500 scale were interpreted as part of an environmental reconnaissance in North Greenland. Five classes were recognized, of which three were vegetated. Based on these aerial photos, the vegetation was mapped in two small (50 km²) areas as part of the studies of foraging dynamics of herbivores.

West Greenland

Three areas in central West Greenland have been mapped based either on aerial photos or SPOT data. These were done as part of a management plan for a local communities or as part of projects concerning the distribution of reindeer and muskoxen habitats.

South Greenland

The vegetation of the protected Qingua Valley in subarctic Greenland has been mapped based on both aerial photos and Landsat MSS data, and a comparison of the methods has been evaluated. Aerial photos and satellite technique have been used in small areas in South Greenland in connection with monitoring the effect of sheep farming.

Plans for the future

A vegetation mapping project covering most of low arctic West Greenland is under preparation in connection with monitoring habitats of reindeer and muskoxen. Initially, it will be based on NOAA, AVHRR data, and for local important habitats a detailed vegetation mapping based on SPOT satellite data will be conducted.

False color aerial photos from most of Northeast and North Greenland at 1:86,000 scale are available for future mapping projects in addition to classified satellite-based maps covering areas in West and East Greenland.

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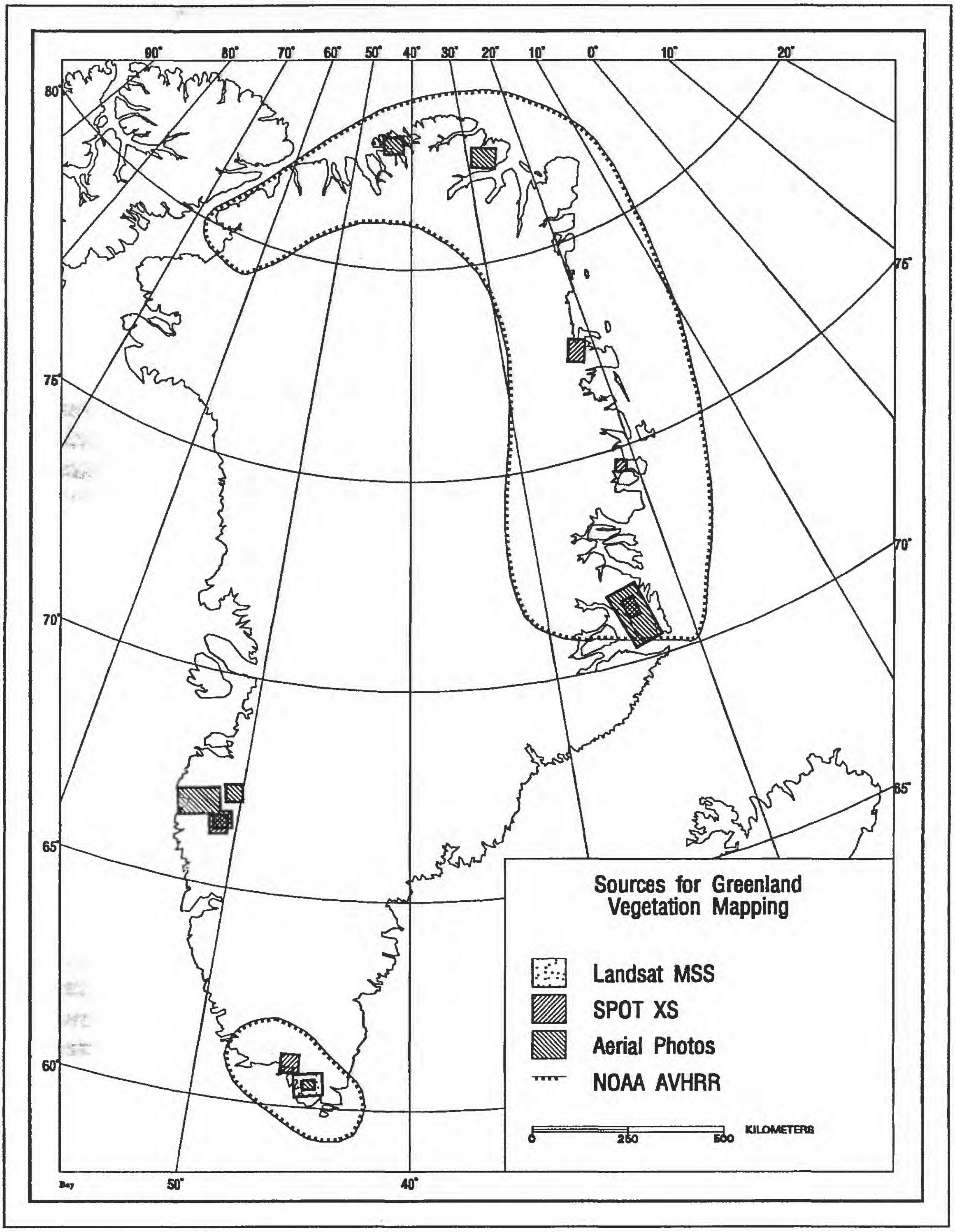

Figure 1. Remotely sensed data sources used for mapping vegetation in Greenland.

VEGETATION MAPPING IN ICELAND

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Vegetation mapping in Iceland started relatively late. In 1955, the Department of Agriculture of the University Research Institute, now the Agricultural Research Institute, started field work for a map of the actual vegetation of the grazing land Gnúpverjaafréttur in South Iceland, mostly at an altitude above 300 meters. The purpose 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 as a whole. The field work was carried out with the aid of aerial photographs and the map was made at a 1:40,000 scale by B. Jóhannesson and I. Thorsteinsson in 1957. The vegetation types used on the map were defined and described by S. Steindórsson, an advisor to the mapping team, based on his study of the vegetation of Iceland for decades. The vegetation is classified as two complexes: Dryland vegetation and Wetland vegetation, and each complex divided into several sociations. These units are based on growth forms and dominant species in the upper layers of the vegetation thus excluding, for the most part, mosses and lichens. During the following 4 years some mapping field work was carried out in the neighboring area but no map was published.

The vegetation mapping continued in 1961 with the intent to extend it to parts of the country with the same principal objectives as before, that is, to determine the carrying capacity of the vegetation of the grazing areas and to provide a basis for their management. The same scale was to be used as on the first maps (1:40,000) and the proposed number of maps covering the whole of Iceland was 289. This was an ambitious plan, and for the next 20 years this work was one of the major programs of the Agricultural Research Institute, under the direction of Dr. Ingvi Thorsteinsson and the botanical guidance of Dr. Steindór Steindórsson, who was, as earlier, the authority behind the legend of the maps. At the beginning, the main emphasis was placed primarily on the central highlands, which have for centuries been used for sheep grazing, but too often overgrazed, resulting in serious and extensive vegetation damage and soil erosion. From 1968 the vegetation mapping also was carried out in the lowlands as well, for the same purpose as earlier and for providing a basis for comparison of the highlands and their vegetation with the lowlands. It was necessary to revise and extend the legend of the maps to cover the lowlands, but the same basic principles were followed as on the first maps.

Six main vegetation complexes are used: dryland vegetation, halfbogs, bogs, fens, aquatic vegetation, and land without vegetation. In addition, land with a mosaic of various communities is not classified but simply called complex vegetation. The main vegetation complexes are then divided into 15 orders which again are divided into 91 sociations, the smallest units used. The six main complexes are rather difficult to compare. For example, the dryland vegetation embraces a broad spectrum from birch-woods in the lowlands to snowbeds in the mountains, whereas the wetland vegetation is considerably more uniform but, nevertheless, split into three complexes. The main criticism of the legend is that the term "land without vegetation" covers all kinds of land with less than 33 percent vegetation cover.

For example, the class includes scattered alpine climax vegetation, recent lava flows with sparse vegetation and lowland soil erosion areas with various secondary successional stages of vegetation, without mentioning orders, sociations, or other units.

The mapping work went on relatively well, in spite of sparse funding at times, and around 1980 most of the uninhabited central highlands and some parts of the inhabited lowlands had been mapped. In the 1980's, the work was continued in the lowlands but due to lack of funds, it was gradually reduced and during the last few years no money has been available for field work. The depression of Icelandic agriculture has reduced the need for the maps from that of 30 years ago.

The Icelandic Survey Department participated in the final work and drawing of the maps from the beginning and also published some maps, but most of the maps were published by the Cultural Fund. The publication of the maps has not, however, kept up with the field work and currently only 64 maps, mainly of the central highlands at 1:40,000 scale have been published. In addition, 28 maps at 1:25,000 scale have been made and published, mainly of lowland areas where there is a need for larger scale maps for planning or other land use and management work. Similarly, eight maps at 1:20,000 scale and even a few at 1:10,000 scale have been published. Some of these larger scale maps have been ordered and paid for by urban or rural communities, other institutions, and large scale construction projects like hydroelectrical power plants. However, most of the mapping work has been funded by official means, either directly or through institutions and funds. Furthermore, 32 maps at 1:40,000 scale are nearly completed but funds for the publication are lacking. The last maps published were made with the help of a computer and all unpublished material is stored in a data bank. Vegetation maps completed, and most of those published, cover about 60 percent of the total area of Iceland.

From 1991 to 1993, a few groups of specialists worked to set up a geographic information system (GIS) in Iceland. One of the groups worked on vegetation mapping, and I had the pleasure of being a member of that group. The group revised and simplified the legend of the earlier maps and is now having two experimental vegetation maps of a part of South Iceland made at 1:25,000 scale. Furthermore, it recommended to the government that vegetation mapping of Iceland be continued and completed within the next 10 years by the Icelandic Museum of Natural History.

So far no vegetation map of Iceland as a whole has been made although it is much needed. The Icelandic Museum of Natural History has decided to make one in the near future, probably at 1:500,000 scale. It will show the potential natural vegetation of the country, rather than actual vegetation, and will be based on all botanical data already collected and available, and on other data that will be collected as needed. In this work, a recently published satellite image of Iceland at the scale of 1:600,000 may be a great help.

Iceland is found on the 1:3,000,000 scale Vegetation Map of the Council of Europe Member States, published in 1979 and revised in 1987, and on the Nordic Council of Ministers Map of Physical Geographic Regions, based mainly on natural vegetation and printed in 1983. The present author participated in the preparation of these maps both of which show vegetation regions or zones.

VEGETATION ZONE MAPPING OF NORTHERN FENNOSCANDIA AND SVALBARD

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Introduction

In the program my presentation is titled "Vegetation Mapping on Svalbard", but during the preparations it was revised so that the title is as above. But, why this distinction between "Vegetation Mapping" and "Vegetation Zone Mapping"? Here are some proposed definitions.
Vegetation Mapping: An attempt to map the spatial distribution of vegetation types, when we want to show "where the mire and the forest are." This is what most often is attempted by botanists using satellite data, with a tendency towards identifying large vegetation stands and a problem arises with different types of "noise."
Vegetation Zone Mapping: An attempt to map a region where there is a characteristic set of vegetation types. However, mapping the spatial distribution of vegetation types, that is, "where the mire and the forest are," is not attempted.
Climatical-phytogeographical Zone Mapping: An attempt to map climatically homogeneous regions based on the distribution of climatic indicator species and indicator vegetation types. In such mapping it is possible to make use of small species, even small hepatics.

What type of coarse-scaled maps exist in Northern Fennoscandia and Svalbard?

Vegetation Maps

There are a number of vegetation maps of northern Fennoscandia, and the entire Swedish mountain chain has been mapped at the 1:100,000 scale. Traditional vegetation maps of Svalbard cover four rather small areas at scales of 1:10,000, 1:12,100, and 1:50,000. There are no coarse-scaled vegetation maps other than satellite based maps of both Svalbard and Northern Norway, and probably also Finland and Sweden. This is because it is almost impossible for the human mind to do all the integrations that would be necessary, at least in areas with varied topography. [Computers do, they do not possess a bad conscience.] For our purpose, maps with this kind of resolution are of no interest except as background data.

Vegetation Zone Maps and Climatic-Phytogeographical Zone Maps

Fennoscandia has a rich tradition in vegetation zone mapping. As I will demonstrate, most classification systems are a mixture of vegetation zone maps and climatic phytogeographical maps of zones or regions. The already classic study is Ahti and others (1968), covering Northern, Middle, and Southern Boreal Zones with a transitory Hemiboreal zone to the mainly Central European Temperate Zone (also called Nemoral). This system was enlarged to cover the whole circumpolar region by Tuhkanen (1984), who also mapped a transitory Hemiarctic Zone in the north between the Boreal Zones and the Arctic. However, Iceland is not included in the Arctic.

The system of Ahti and others (1968) was partly modified and integrated with other abiotic information in a Fennoscandian cooperation to produce the "Natural Geographical Regions" of the Nordic countries (Abrahamsen and others, 1977). This approach may be somewhat similar to "ecoregions." However, I do not think this is used much by botanists because the entities are too heterogeneous and too weakly defined. For example, region 44a includes Tromsø and is defined as "The submaritime birch and pine forest of Tromsø." Birch and pine forests are common in neighboring regions and the mapped area has a wide variety of habitats, including high mountains.

The present classification used in Norway is the "Vegetation Region Map of Norway" made by botanists from four universities in Norway and published at 1:1,500,000 scale (fig. 1; Dahl and others, 1986). A simplified version was published by Moen (1987) at approximately 1:6,000,000 scale. Although it is called a vegetation region map, it is more of a climatic phytogeographic map as I have defined above. Many areas have been defined on the basis of species occurrences; the units are supposed to reflect climate. However, some very important physiognomic or biomorphic vegetation properties are not reflected in the map. For instance, the limit between the *Picea* and *Betula* forests are physiognomically or biomorphically very distinct, but (at least) in Norway this is not primarily a climatological boundary, but a historical one, as *Picea* was a late and slow colonizer and the rest of the vegetation, except the tree species, do not change. There also are boreal enclaves in the northern most part and only north of these enclaves does arctic vegetation develop near sea level. Figure 2 indicates the rim of arctic vegetation in northernmost Norway and the presence of adjacent zones.

The division and distribution of the Northern, Middle and Southern Boreal Zones are generally in accordance with Tuhkanen (1984), who made a circumboreal classification of boreal areas. The lower alpine belt on this map probably corresponds to a southern arctic zone, while the middle and high alpine zones are more distinct.

The next step in this process is the mapping of sectors, and this is now in progress. Brattbakk (1986) produced a map of Svalbard at 1:1,000,000 scale and included two major zones, each with two subzones (called "regions" and "zones", respectively):

- High Arctic:
  - *Papaver dahlianum* Zone
  - *Salix polaris* Zone
- Mid Arctic:
  - *Dryas octopetala* Zone
  - *Cassiope tetragona* Zone

The zones are based on vegetation types, but where vegetation criteria are too difficult to use, the occurrence of single species has been used as a criterion.

Elvebakk (1985) subdivided Greenland, Svalbard, and adjacent parts of Russia in a geobotanical subdivision based on phytosociological criteria. A review of the higher phytosociological syntaxa of Svalbard was later presented by Elvebakk (1994). The nomenclature describes the accepted major divisions of the Arctic as a Polar Desert Zone and an Arctic Tundra Zone as used by Aleksandrova (1980), and included a subdivision of the latter in three parts like the treatment of the boreal zone in Fennoscandia. The concepts of zonal vegetation types (placor[1]) was also used. The map was at a very coarse scale and, of course, for Greenland the pattern is much more a mosaic pattern than the straight lines.

Later Elvebakk (1989) produced another more detailed subdivision of Svalbard based on species distribution patterns and involves all vascular species and concentrates on their value as climate indicators. This climatic-phytogeographic map is not essentially different from that of Brattbakk (1986), although the nomenclature is different and there are some important local changes. The map includes a subdivision of the Middle Arctic Tundra Zone. A new version of this map, including altitudinal gradients and adjusted to a 1:7,500,000 scale is now made (Elvebakk, 1995 in press; fig. 3). The map has three zones, a maritime subzone in the south, and it is available at this workshop together with a corresponding map of mainland Norway produced by Moen (1987) at the same scale.

Conclusions

(1) It is not possible to produce traditional vegetation maps of the Norwegian Arctic at 1:7,500,000 scale. However, a map of vegetation zones or climatic-phytogeographic zones would be very complimentary to a satellite-based vegetation map, especially if it reflects climate zones.

(2) Climatic-phytogeographic maps of mainland Norway and Svalbard are presented based on similar criteria and a homogenous nomenclature system. This system and nomenclature will be used in the standard Norwegian Flora (Lid and Lid, 1994) and in the forthcoming Flora Nordica.

(3) It might be possible to subdivide the Arctic Polar Desert Zone and the southernmost zone of the Arctic, preferably based on experience from countries where these zones are better represented than in Norway.

(4) It is difficult to produce pure vegetation zone maps because our knowledge of vegetation is much less than our knowledge of the flora. The terminology climatic/ phytogeographic map as used by Tuhkanen (1984) is more accurate than vegetation zone maps.

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[1]Placor: that portion of the landscape having well drained moderate surfaces, the vegetation of which is typical of the regional climate.

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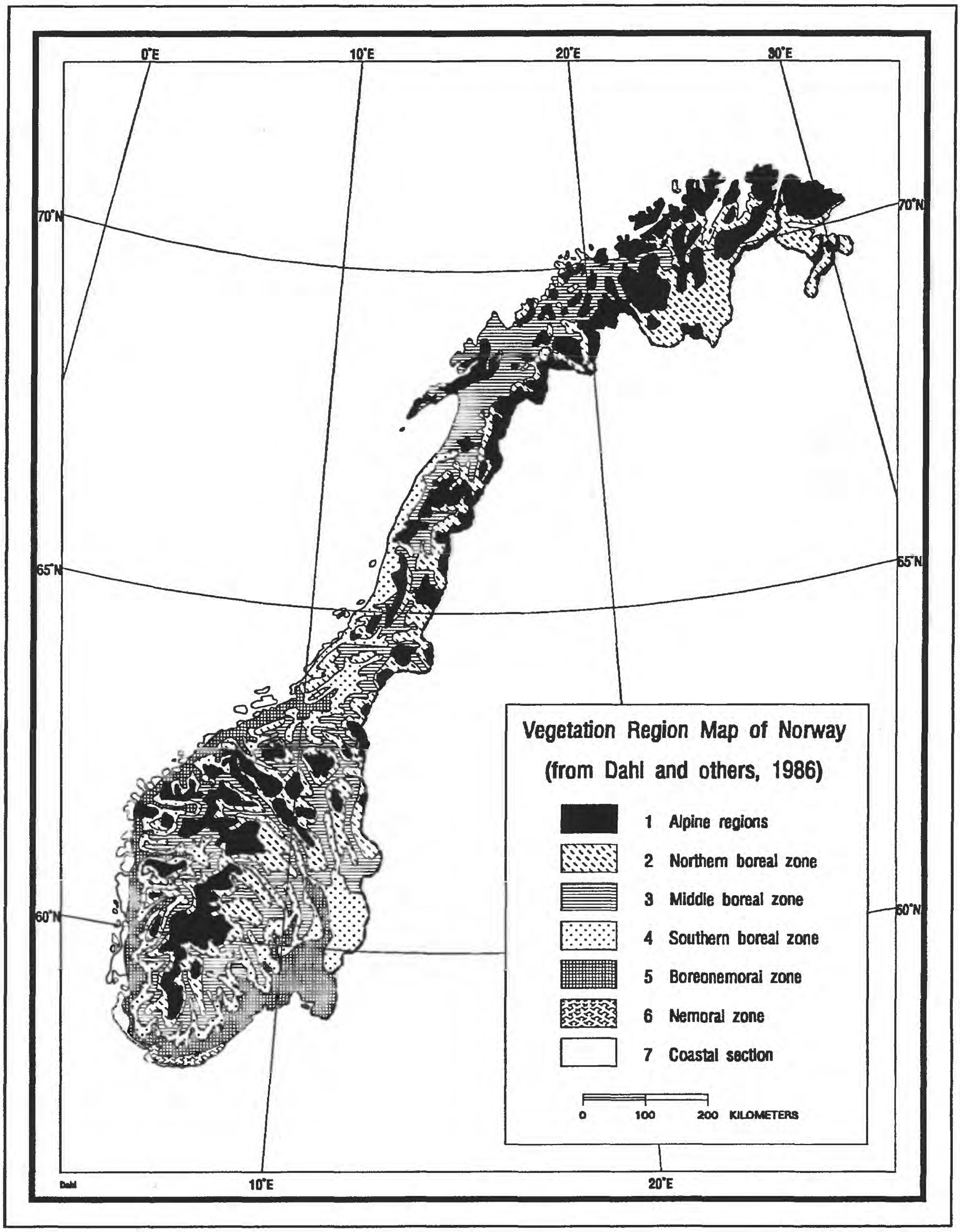

Figure 1. Vegetation zone map of mainland Norway according to Dahl and others (1986).

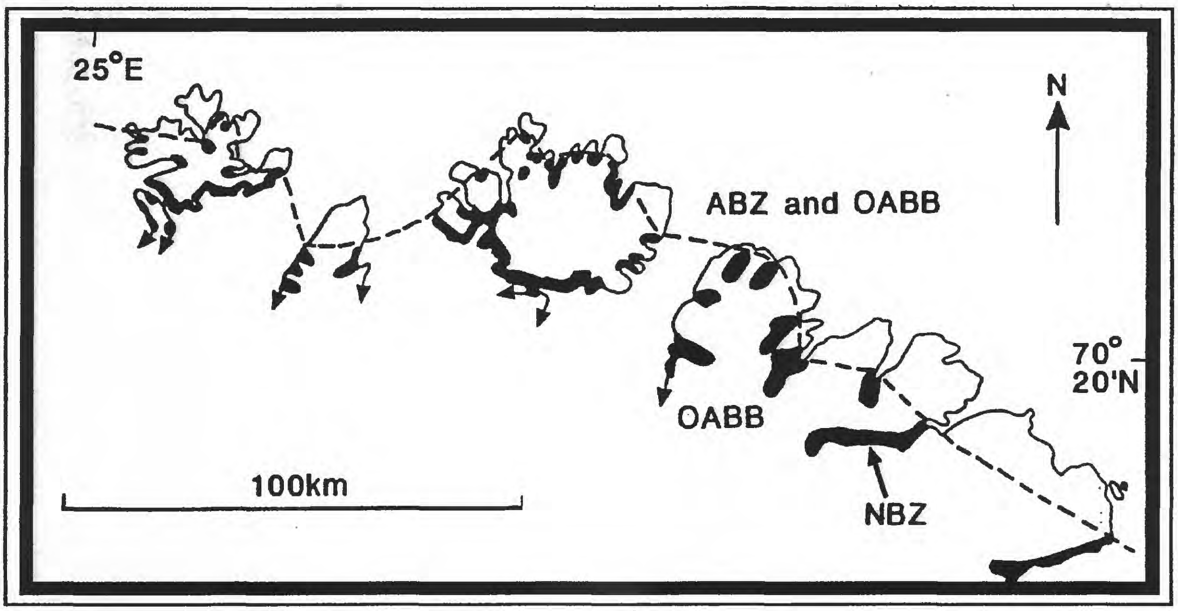

Figure 2. The position of enclaves of the northern boreal zone (NBZ) in northeastern most mainland Norway following Dahl and others (1986). Bordering this zone is alpine vegetation of the oro-arcto-boreal belt (OABB), and north of the boreal line this same vegetation zone is called the arcto-boreal zone (ABZ) when it occurs near sea level. This line coincides very well with the 10°C July isotherm. Most of the lowlands north of the line consist of steep coastal cliffs.

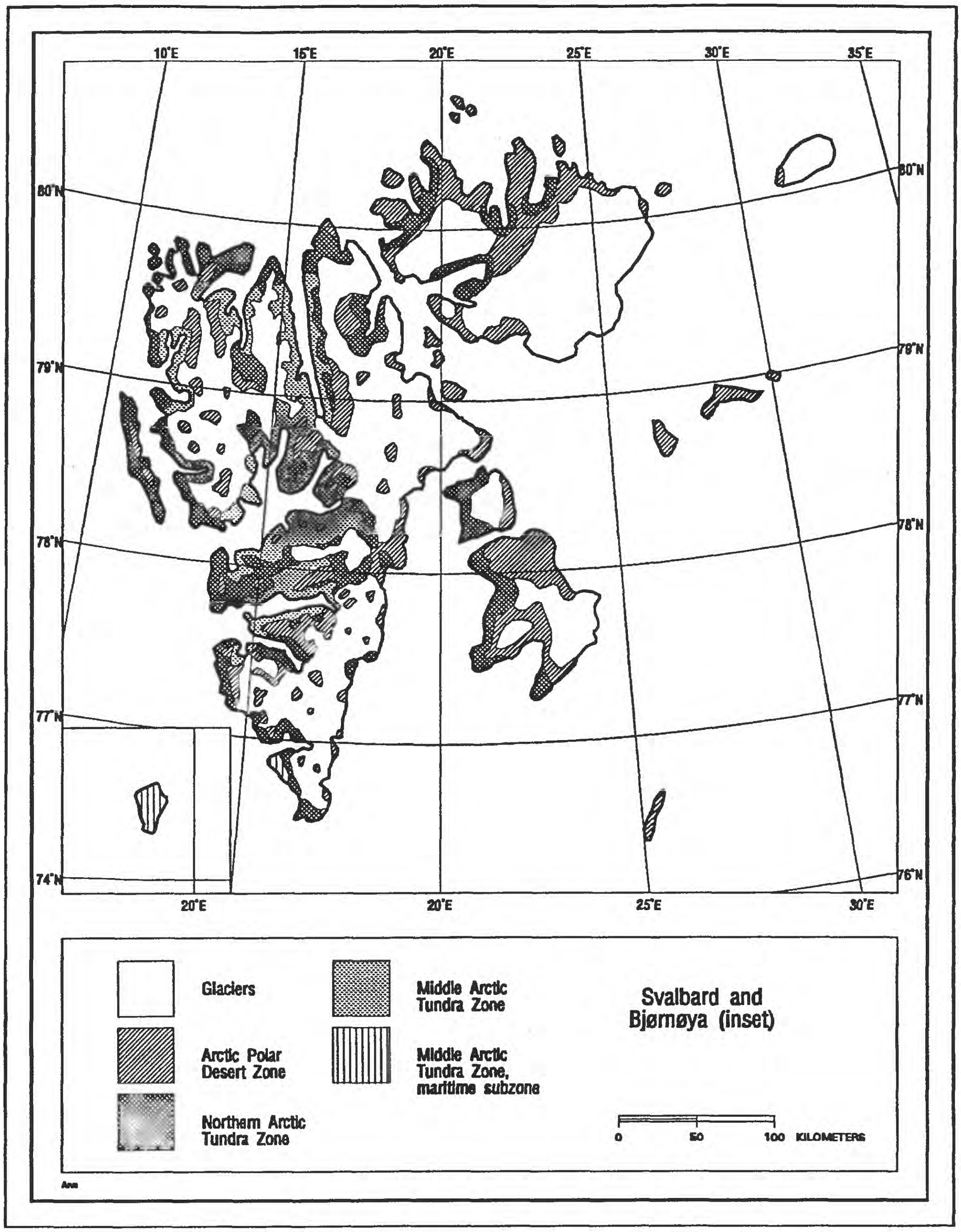

Figure 3. Coarse-scale distribution on Svalbard of the Arctic Polar Desert Zone (APDZ), the Northern Arctic Tundra Zone (NATZ), and the Middle Arctic Tundra Zone (MATZ), after Elvebakk (1995, in press).

VEGETATION MAPPING IN FINNMARK, NORTHERN NORWAY, USING LANDSAT TM DATA

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Introduction

As mentioned by Dr. Elvebakk there are a number of vegetation maps produced from northern Fennoscandia. Most of the maps are based on traditional methods and normally cover small areas.

The production of a coarse-scaled vegetation map is difficult for northern Fennoscandia because of varied topography. Three important ecological gradients should be considered during coarse-scaled map production: (1) the north-south gradient; (2) the oceanic-continental gradient; and (3) the vertical gradient from the lowland to the mountain areas.

Grazing by reindeer (*Rangifer tarandus*) is an important factor influencing the conditions of the lichen cover of the heaths and woodlands in the continental areas of northern Fennoscandia. Reindeer husbandry is practiced intensively throughout most of the Finnmark, county, which also is true in northern Finland. Consumption and trampling by reindeer can drastically change the composition of the lichen stands on heathlands and in extreme cases the recognition of the heath types becomes difficult. Even a moderate degree of grazing can be sufficient to level out the fairly small differences between adjacent heath types, particularly if they are based on the ground layer vegetation. The main objective of this study was to map the vegetation types to detect overgrazed areas. During the mapping process both traditional field registrations and Landsat thematic mapper (TM) satellite data from 1987 to 1990 were used.

The study area - Finnmark county, Northern Norway

Presently, a vegetation change process is taking place on Finnmarksvidda. The changes can be correlated to the dramatic increase in reindeer population during 1976-88. In 1976, the reindeer population was estimated to be 90,000. In 1988 the population was 210,000, old estimates of the optimum population were about 150,000. The present population, which is well above this level, is now damaging parts of the winter grazing areas.

The vegetation mapping project in Finnmark and northern parts of Troms County was initiated in 1988. The predominant bedrock in the inner parts of the area are gneiss and granite. The coastal areas have a more mixed geology belonging stratigraphically to the Caledonian nappe consisting mostly of Cambro-Silurian rocks. The climate in the inner parts of the area is continental with cool winters, fairly warm summers, and a small amount of precipitation. The coastal areas have a more oceanic climate with cool summers, fairly mild winters, and large amounts of precipitation, much of it as winter snow.

Methods

Landsat TM satellite data used in this study are summarized in table 1. The image selection was based on the following criteria: (1) availability of high-quality satellite imagery with minimal cloud coverage; (2) coincidence with the peak vegetation growth of the area; and (3) the possibility to produce a map covering the whole area by pasting the images together.

All image processing was performed using International Information System (IIS), image processing software-System 600. The geographic information analysis was performed in ARC/INFO - a geographical information system. Based on an evaluation of spectral characteristics of the main vegetation types in the area, a three-band combination of Landsat channels TM-4, TM-5, and TM-1 were selected for further classification. An unsupervised clustering algorithm based on the minimum-distance-to-mean classifier was used to separate the data into different spectral classes. Two main statistics for the dataset were worked out in the classification process, one for the vegetation types in the continental parts of the study area, and one for the vegetation types in the coastal areas. During field study an assessment of the separated classes was conducted to verify the resulting satellite-based vegetation map. Homogeneous patches of the different classes were sought out and described with regard to floristic composition and contents. Based on these investigations a preliminary legend of each of the classes was constructed. After the field registration period and further data analyses, an overall vegetation map was developed using the two map products. The result was a "base map" containing 37 vegetation classes. This map was further registered to a topographic map giving the satellite data product a correct UTM projection.

After the interpretation and geometric correction a median filter was applied to the final image. The selected class colors reflect the different vegetation complex types in the area.

The vegetation "base map" was one of the main products from the mapping process. Based on this map, an overview map and other different types of thematic maps were produced, and the data were summarized into coverage statistics. These types of statistics are important when the data are to be compared to other types of geographical information from the study area.

Results

The final vegetation map contained 37 classes that were aggregated into 13 broader defined vegetation classes (table 2). The map covers an area of about 65,000 km^2. Statistics and thematic maps from the investigation are not being presented in this article.

Most of the heathland vegetation in Finnmark is phyto-sociologically classified to the alliance *Arctostaphylo-Cetrarion nivalis* due to the large areas of acidic bedrock. This alliance can be further divided into the associations *Cetrarietum nivalis* and *Cladonietum alpinum,* which are separated by the characterizing lichen species. *Cetrarietum nivalis* occurs in the middle and western parts of Finnmarksvidda. The *Cladonietum alpinum* dominates the inner parts of this area, located on stable moraine substrates. A third lichen heath type dominated by *Stereocaulon paschale* covers large areas on unstable silt and sand substrate, and in areas affected by moderate to heavy grazing pressure.

Heavy grazing pressure over a long period removes the lichen cover. This situation is presently true in the heathlands and woodlands in the middle and western parts of Finnmarksvidda. The same is true on the Finnish side of the border. Reindeer husbandry is currently intensively practiced throughout most of the Finnmark country. The winter and summer ranges of reindeer are separated into two distinct areas in Finnmark. The winter ranges are situated in the interior of Finnmark, located mainly in the municipalities of Kautokeino, Karasjok, and Sør-Varanger. The summer pastures are situated mainly on the islands and peninsulas of northern and western Finnmark, and western Troms. This range rotation has until now preserved the lichen ground of the interior but it is changing. Today, both the middle and western parts of Finnmarksvidda are used during snow-free periods. Summertime grazing is especially disastrous to lichen dominated vegetation types because of lichens' high sensitivity to trampling when dry. Avoiding uncontrolled pasturing is therefore very important during the snow-free period. Today, areas of lichen heath damage located in the middle and western parts of Finnmarksvidda probably are due to a combination of high grazing pressure and trampling, especially during the spring and autumn.

We can recognize the effects of the summer grazing in lichen-dominated vegetation types in northern Finland. Here the winter and summer ranges are located within the same areas. This results in extreme degradation of lichen cover in the lichen heathlands and woodlands of Northern Finland. The result of the overgrazing is well demonstrated on the vegetation map. The white colored, lichen dominated areas are not recognized on the Finnish side.

The vegetation formation in an overgrazed lichen heath can be compared to the vegetation on exposed ridges. The exposed ridges are without continuous snow cover in winter and the communities are exposed to low temperature and strong wind. These ridges are characterized by a very sparse vegetation cover, and the ridge tops are without any vegetation cover. The open heath vegetation bordering the naked ridges are characterized by the species *Loiseleuria procumbens*, *Arctostaphylos alpina, Diapensia lapponica, Juncus trifidus* and the mosses *Polytrichum juniperinum, Dicranum scoparium,* and *Ptilidium ciliare*. The open heath vegetation types are classified to the association *Loiseleurio-Diapensietum*. These vegetation types are represented in the high mountain areas near the coastal zone. Other vegetation types that are rarely represented include moderate snowbeds characterized by *Vaccinium myrtillus, Deschampsia flexuosa, Nardus stricta, and Anthoxantum alpinum*; the more extreme snowbeds are characterized by *Salix herbacea,* and mires, dominated by *Carex* species.

The oligotrophent birch forest vegetation is the most common forest type in the area. *Betula pubescens* totally dominates the tree layers. *Empetrum hermaphroditum, Vaccinium vitis-idaea, Vaccinium uliginosum*, and the dwarf shrub, *Betula nana*, dominate the field layer. To the south these forest types divide into the lichen birch forest and the heather birch forest. Lichen birch forest is characterized by the species *Cladonia arbuscula, C. alpestris, C.mitis,* and *C. rangiferina*. The lichen cover varies from 30 to almost 100 percent. The heather birch forest is characterized by heather (*Calluna vulgaris*) and the mosses *Pleurozium schreberi, Hylocomium splendens, Dicranum fusescens, D. scoparium* and different *Polytrichum* species in the ground layer. The lichen birch forests are located in continental areas. The moss-dominated birch forest types are most common in maritime and submaritime coastal areas. In small parts of the area we find pine forests. Also, we find the same differentiation in lichen pine forests in the interior of the county in Karasjok and in Anarjohka valleys. The heather pine forest types are located in Alta, Lakselv, and Stabbursdalen.

The meso- and eutrophent forest types are found mainly on mica schists, other subsoils rich in calcium, and on marine sediments in the coastal areas. The rich forest types are located mainly in the lowland areas. These forest types are characterized by low herbs, tall herbs and large ferns. The rich forest types are confined mostly to the "fjord-zone" of the county.

Vegetation types given little attention in our vegetation registrations are the bogs, fens, mud-bottom fen, barren gravel, and rock vegetation. The bog vegetation types in the study area are characterized by dwarf shrubs, heather vegetation, and moist sedge tussocks. The fens and mud-bottom fen vegetation types are found in moist or wet areas, partly covered with ponds and open waters. Grasses and sedges are the most common species. River gravel, sand, and silt banks are found along the Anarjohka, Karasjok, and Tana Rivers. The alpine barrens are located in the Gaissa areas, and the high mountain areas near the coast.

Conclusion

Based on Landsat TM data it is possible to produce both fine and coarse-scaled vegetation maps. In Finnmark county and northern parts of Troms, Northern Norway, 3 versions of vegetation maps are produced, containing 13, 21, and 37 vegetation classes.

From the "base map" product it is easy to derive different types of thematic maps. The maps show the main vegetation types within the study area. Based on the map it is possible to detect geographical distribution of different vegetation types, and to compute aerial statistics of selected areas.

Satellite imagery has been used for a variety of environmental studies such as determining above-ground plant biomass, estimating leaf area, vegetation mapping, and reindeer range studies. The combination of using image processing systems and geographic information systems is a very powerful tool in the map production process.

Table 1.--Landsat satellite images used in the mapping of Finnmark, northern Norway.

Path/Row	Quad	Date
195/11	Q 1-4	July 16, 1988
193/11	Q 1,3	July 18, 1987
193/12	Q 1	July 18, 1987
194/12	Q 1	August 26, 1987
197/10-11	Q 1-4	August 26, 1991
196/11	Q 1	August 03, 1991
196/10	Q 1-4	September 1, 1990
194/10-11	Q 1-4/fl	August 08, 1990

Table 2.--Interpretation key to the vegetation map of Finnmark, northern Norway.

Classes	Color	Interpretation
0	Black	Unclassified areas
1	Light blue	Water
2	Green	Birch forest vegetation (oligotrophent/eutrophent)
3	Blue-green	Pine forests, including mixed forests (pine/birch)
4	Blue	Mires, bogs and wetlands
5	Orange/red	Snowbeds and wet heather vegetation types
6	Light green	Mountain birch forest
7	Dark blue	Bare rocks in the mountain areas
8	Orange	Empetrum heather vegetation
9	Pale green	Lichen birch forest
10	Light pink	Exposed heather vegetation, including overgrazed heather vegetation
11	Pink	Sparsely vegetated areas in the mountain region
12	White	Lichen heath vegetation
13	Yellow	Different types of meadow vegetation

PHYTOCOENOTIC MAPPING OF WESTERN SIBERIAN ARCTIC

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A botanical-geographical study of the Western Siberian Arctic on a region-topological basis was conducted by the author from 1969-75. Data revealing phytocoenotic composition, structure, dynamic features, and peculiarities of spatial distribution of plant communities and their combinations were obtained. These results served as a basis for a legend and a 1:1,000,000-scale map of tundra vegetation (fig. 1). This map, in its generalized form, is a part of the vegetation map of the entire Western Siberian Plain (Main Directorate for Geodesy and Mapping, 1976).

The geobotanical map legend (table 1) was composed according to the principles of regional-topological classification (Sochava, 1964, 1979). In addition, classification of the basic mapping units was defined in consideration of the peculiarities of horizontal structure (Meltzer, 1977a, 1977b, 1980, 1982).

For homogeneous plant cover and patchy vegetation, a phytocoenotic classification (associations, groups of associations, and others) was accepted, (Sukachev, 1935). These included communities of shrubs on slopes, homogeneous fens, tussock tundras of the arctic zone, and others, according to internal phytocoenotic heterogeneity.

For vegetation with heterogeneous horizontal structure, the main classification object was the territorial unit of the plant cover, microphytocoenochor, as suggested by V.B. Sochava (1968, 1978). Such heterogeneity is stipulated by the abiotic phytocoenotic processes (cryogenic, deflation, and others). Several forms of vegetation with heterogeneous composition were distinguished. First, the proper tundra groups: shrubby moss hummock and spotty hummock tundras, lichen polygonal tundras, hilly-hollow and polygonal bog tundras, and thinned groups of plants on deflation bare spots. Polygonal and flat and frost mound bogs are widely spread. For river valleys with a developed flood-plain, several communities of valley plant cover were distinguished. Hydroseries were also distinguished for the vegetation of lacustrine depressions and on the drained lakes and sea-shore growing salt meadows.

Using the classification of microphytocoenochor, we can distinguish types, groups of types and classes of types. In West Siberian tundras, there are two classes of microphytocoenochor types dominating plant communities with similar water supply: automorphic and hydromorphic. The automorphic class includes groups of types that are mainly characterized by atmospheric nutrition. We established the following groups of automorphic types: plain, sand plant, and deflation deposits.

The hydromorphic class of microphytocoenochor types combines groups of types that have outside sources of soil moistening. It consists of two classes, flowing and stagnant moistening; and two types of microphytocoenochor, valley (flood-plain series), and hollow (microbelt series). The following types occur in habitats with stagnant moistening (groups of microphytocoenochor types of plain, weakly-drained watersheds): shrubby moss, hilly and spotted tundras, hilly-hollow, and polygonal, flat and frost-mound bogs.

The main mapping units at 1:1,000,000 scale are groups of microphytocoenochor types for vegetation with heterogeneous horizontal structure, and groups of associations for homogeneous plant cover, sometimes according to scale units larger than taxons of classifications. These are combinations of plant groups (mesophytocoenochor), which as a rule represent an ecological series from bogs or boggy tundras to moss (plain) or lichen (psamophyte) tundras.

The entire legend of the vegetation map of Yamal-Gydan tundras is as follows. The large subdivisions of the classification and legend correspond to taxonomical units suggested by V.B. Sochava. For our territory, the taxonomical units are tundra vegetation and two phratria plant formations: arctic and amphiatlantic suppressed to it (Sochava, 1964; Ruks, 1973).

According to Sochava (1964), the type vegetation is characterized by a definite set of biomorphs with certain living forms. Phratria formations reflect the regional peculiarities of the plant cover. Thus, arctic phratria tundra formations are characterized by a very low edaphic role of some plants. At the same time, several species, among them representatives of the arctic and arcto-alpine flora (*Dryas punctata, Cassiope tetragona, Carex rupestris, Salix polaris, Andromeda arctica*), are very common in arctic tundras. Their genetic homogeneity and isolation are, to a large extent, the result of the history of the development of arctic flora (Tolmachev and Yurtsev, 1970). Amphi-Atlantic phratria of the tundra formation include tundra communities with hypoarctic and boreal species (*Betula nana, Salix glauca, S. lanata*, and others) belonging to the amphi-Atlantic part of the Arctic (Budanzev, 1970).

We distinguish two zonal groups of formations, arctic and subarctic. Within the subarctic tundra formation, two subzonal types are identified, typical and shrubby tundras. The typical tundra subzone is further subdivided into northern and southern subzonal strips. Zones, subzones, and subzonal strips reflect provincial peculiarities of tundra plant cover. This was taken into consideration in mapping the plain communities. The comprised geobotanical maps served as a basis for fractional botanical-geographical division into districts.

The most important phytocoenotic, floristic and botanical-geographical boundary on the investigated surface is the boundary between the arctic and subarctic. This boundary is delineated by all researchers of the North but explained differently. Analysis of zonal subdivision is given in the book by Alexandrova (1977). We share V.B. Sochava's view that this boundary separates the dry "arctic" zone from the "humid" or "temperate" zone. The arctic zone includes arctic tundras and polar deserts; the humid zone includes subarctic tundras and northern and middle taiga. In 1948, V.B. Sochava had some doubts about V.B. Gorodkov's assertion that the boundary separating the true arctic lies between the polar deserts and arctic tundras. Such boundaries, according to Sochava, should be farther south and coincides with the region of stable influence of arctic air. This boundary coincides approximately with July 6°C isotherm. In such conditions the circulation of atmospheric radiation balance changes considerably and influences the main regime of physical-geographical phenomena. This boundary is in harmony with the history of plant cover development. During the postglacial period, arboreal plants did not inhabit the Arctic, so a lack of forest in arctic tundras is a primary characteristic (Giterman and others, 1968). To the south of this boundary "tundra phytocoenosis are to a large extent secondary of boreal forest and bog formations" (Sochava, 1948, p. 8). These facts were corroborated in the physical-geographical subdivision into districts of Northern Asia (Sochava and Timofeev, 1968) and the demarcation of the northern boundary of the subarctic (Sochava and others, 1972). This boundary is very significant to floristic researchers (Yurtsev, 1966; Tolmachev and Yurtsev, 1970).

The analysis of previous research and our own research suggests that we should mark the boundary between the arctic and subarctic in the rank as a zone. As mentioned before, this boundary is substantiated by botanical-geographical and florogenetic criteria which influences the classification of vegetation (Meltzer, 1977a; 1977b). In average scale mapping of tundra vegetation (Meltzer, 1980) two phratria formations, arctic and amphi-atlantic, correspond to these zones. They reflect the genetic nature of their plant cover subdivisions.

The zone of subarctic tundras vegetation is divided into two subzones, typical and shrubby tundras. The subzones of typical tundra includes two subzonal strips: northern and southern. Within zones, subzones and subzonal strips, geobotanical districts and subdistricts that reflect the regional peculiarities of the plant cover are identified.

In 1980, due to intensive industrial development of northwestern Siberia, it became necessary to research and develop environmental maps of the developed territories. We developed methods and produced a series of large scale (1:125,000) phytoecological maps of the gas territory situated in different zones and subzones of far northwestern Siberia.

We adhere to the notion "ecological map" as a map in which "biocentric trend" reflects the connection of biota (vegetation or animal kingdom) with environment parameters (Sochava, 1979).

The matrix legend of the phytoecological map contains data on the phytocoenotic and floristic compositions and structure of horizontal and vertical components of plant cover. Characteristics of habitat parameters for each mapping unit are given. These characteristics determine the formation of plant communities for this region: soil (depth of peat horizon), state of seasonal-thaw layer, variability of mesorelief, and water nutrient regime. The main mapping units at 1:125,000 scale are associations and groups of associations for homogeneous plant cover and types and groups of types of microphytocoenochor for vegetation with heterogeneous horizontal compositions. In some cases, combinations of plants are shown. All legend numbers are united into two divisions: erosional-marine terrace vegetation and flood-plain vegetation. Table 2 presents a fragment of a phytoecological map legend showing a standard subzone of typical Yamal tundra.

Phytoecological maps serve as a basis for showing areas of phytocoenosis stability to mechanical disturbances. The estimation of phytocoenosis stability is based on the regularities of successions and plant cover technogenic dynamics and the character and intensity of industrial impacts.

Phytoecological maps represent qualitative surface characteristics and serve as a basis for quantitative values. They are very convenient for estimation of ecological-economical resources in the territory.

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Table 1. Excerpt from the Legend of the Phytoecological Map, West-Siberian Formations of Sub-Arctic Tundras, Northern Belt of Typical Tundras of Yamal (Vegetation of erosional-marine terraces).

Mapping units[1]	Dominants of plant cover	Shrub layer	Herb-dwarf shrub layer % Cover / Height, cm	Moss lichens layer % Cover / Height, cm	Depth of peat layer, cm	Location on mesorelief	Type of water regime	Thickness of active layer, m
Dwarf shrub-lichen-moss hillocky tundras of well-drained uplands and slopes								
1. Sedge-dwarf shrub-lichen-green moss/dwarf birch with willow low shrub-herb-moss hummocky tundras	*Vaccinium minus, Arctous alpina, Aulacomnium turgidum, Cladina rangiferina, /Betula nana, Carex arctisibirica, Aulacomnium turgidum, Polytrichum affine*	Prostrate in microdepressions. Projective cover unclosed	20-50[2] / 3-7 20-100[3] / 5-7	50-70[2] / 2-3 20-100[3] / 5-7	2-5	Well-drained parts of uplands	Atmospheric	0.5-0.7[2] 0.4-0.5[3]
2. Graminoid-dwarf shrub-green moss and lichen-green moss with dwarf birch and willow low-hillocky tundras combined with a dwarf birch-herb-moss tundras	*Salix polaris, S. nummularia, Rubus arcticus, Festuca rubra, Arctagrostis latifolia, Luzula confusa, Dicranum angustum, Aulacomnium turgidum*	Feebly marked	30-70 / 5-20	25-60 / 2-5	2-5	Slopes of uplands	Atmospheric, lateral drainage	0.7-1.0
3. Combination of dwarf shrub-lichen-moss hillocky, graminoid-dwarf shrub-green moss and shrub-herb-green moss tundras	*Vaccinium minus, Salix polaris, Carex arctisibirica, Poa pratensis, Betula nana, Salix glauca, Dicranum angustum, Cetraria nivalis, Cladonia amaurocraea*	On slope depressions, height 0.3-0.4 m., projective cover 20 - 40%	20-50 / 5-20	10-60 / 2-5	from 2-3 to 7-8	Eroded slopes	Same	0.7-0.8
4. Dwarf birch and willow-dwarf birch-dwarf shrub-graminoid-green moss low hillocky tundras	*Betula nana, Salix glauca, Arctous alpina, Festuca ovina, Equisetum arvense, Pyrola grandiflora, Rumex arcticus, Hylocomium splendens var alaskanum, Stereocaulon paschale.*	Height from 0.15 to 0.4 m. Projective cover 20 - 40 %	50-60 / 10-20	70-90 / 3-5	3-7	Slightly sloping drained uplands	Same	0.5-0.7

[1]Units of vegetation with heterogeneous composition (microphytocoenochora) which grow in different conditions of microrelief are divided by an inclined line (/). Vegetation on heightened forms of microrelief (hummocks, high centered polygons) is given before the line, vegetation on lower microsites after the line.

[2] Raised microsites

[3] Lower microsites

Table 2. Co-Subordinate Units of the Botanical-Geographic Regionalization of Western Siberia Tundra

Zones	Provinces	Subprovinces	Subzones	Subzonal belts	Circuits	Subcircuit
A. Arctic Western Siberian Tundra	Karsk	Karsk	Arctic tundra	Shrubless	1.Yamal Arctic	Tambeisk
					2.Gydan Arctic	a-Yaruyakh
						b-Mongo-Cheyakh
B. Subarctic Western Siberian Tundra	Yamal-Gydan	I-Yamal Subarctic	Typical tundra	Rare and Low volume shrub	3.Northern Yamal	Seyakkhin
				Low volume shrub	4.Middle Yamal	Peuntok
			Shrub tundra	Shrub	5.Southern Yamal	Khadyta-yakh
		II-Tazov-Gydan Subarctic	Typical tundra	Rare and Low volume shrub	6.North Gydan	a-Yuribei
						b-Gydinsk
				Low volume shrub		
				Low volume shrub	7.Middle Tazov-Gydan	a-Sydyyakh
						b-Tanam
						c-Poelovo-yakh
			Shrub tundra	Shrub	8.Southern Tazov-Gydan	a-Kkhadut-teyakh
						b-Messoyakh

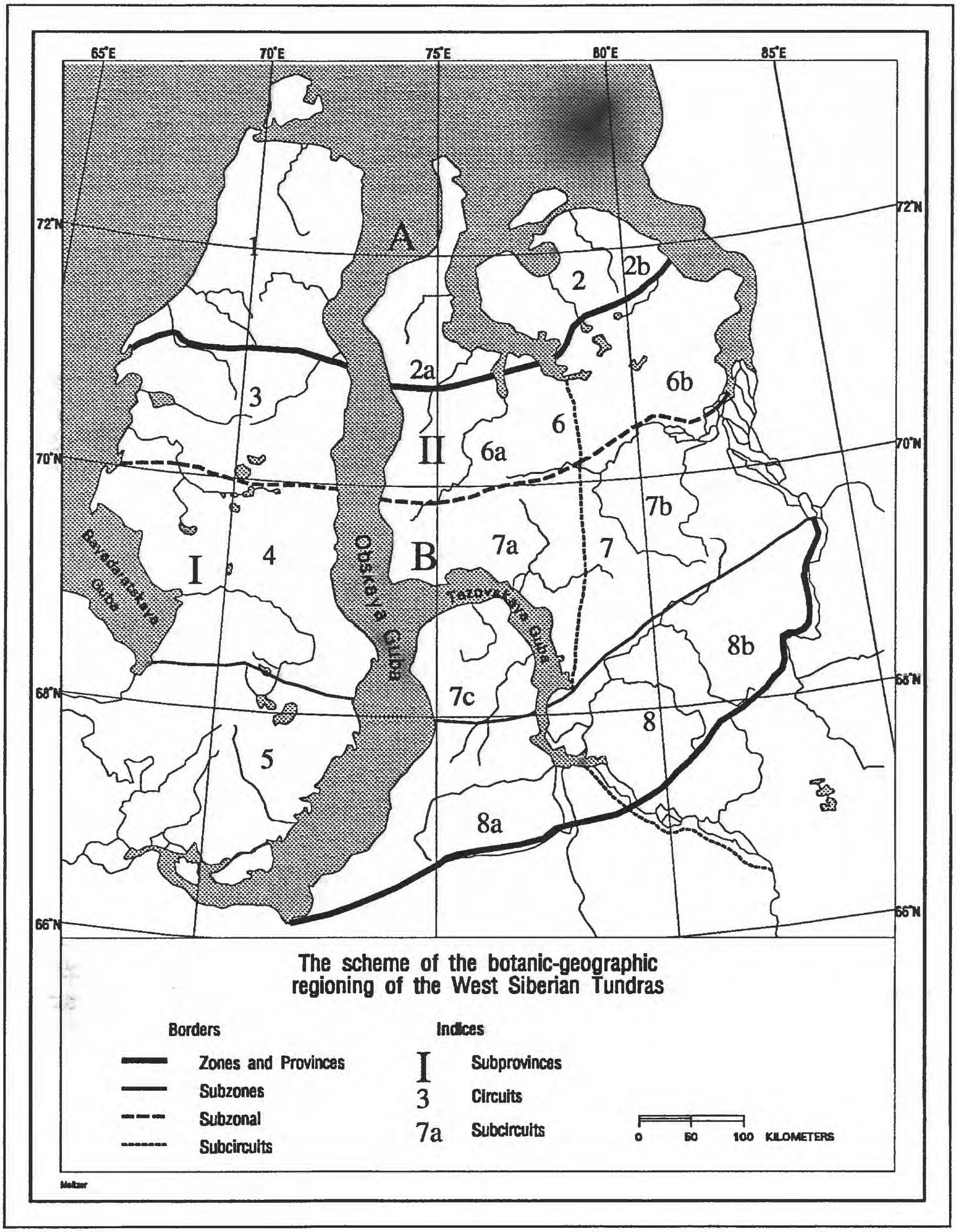

Figure 1. Map of botanical-geographic regionalization of West Siberian tundra.

AN ATTEMPT AT SMALL-SCALE GEOBOTANICAL AND LANDSCAPE MAPPING IN NORTHWESTERN SIBERIA

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The landscape map of northwestern Siberia (1:1,000,000 scale) was prepared and printed on the basis of data from long-term expeditionary research at the Institute VSEGINGEO and from decoding satellite images (1:200,000 scale). The map gives information about the distribution of basic vegetation types and their correlations with geologic, geomorphologic, and geocryological conditions. The basic unit on the map is locality, which is singled out in the landscape by satellite images and represented by shading. For all localities, the typical vegetation types contain a combination of major geocryological characteristics: distribution of permafrost, its composition and thickness, ice content, presence of massive ground ice, peculiarities of temperature regime, and certain complex exogenous geologic processes.

The map is accompanied by a series of small zonal 1:10,000,000-scale sketch maps, which include landscape zoning, lake distribution, ground ice occurrence, stability of permafrost to technogenic disturbances, restoration of vegetation cover after disturbances, recommended types of recultivation, and diagrams of landscape regions that reflect their morphological structure.

The 1:200,000-scale geobotanical map was prepared for the central, intensively developed part of the region. It was composed by decoding satellite images, and by using landscape maps (1:100,000 scale), aerial observations, land survey, and detailed geobotanical descriptions.

For small-scale mapping of vegetation cover on the basis of satellite images, except for direct decoding results, the indirect maps have important significance. The correlations between relief and vegetation help determine more accurately phytocoenoses arranged for certain relief forms. Therefore, a middle-scale landscape map, revealing the correlations between vegetation, relief, and other components, were used for compiling the geobotanical map of Nadym-Pur watershed.

The most distinguished plant communities on the map often belong to association groups, instead of belonging to classes that correspond with the urotshistshe (one of the lowest level landscape units, defining a specific morphological portion of the landscape that separates it from neighboring parts) of the landscape map. Microcombinations and mesocombinations have significant distribution. Microcombinations characteristically are peatlands, on which plant community complexes are developed. The complicated contours on the map represent, in most cases, meso-combinations of plant communities that correspond with urotshistshe combinations .

The data analysis of land investigations, the basis on which the geobotanical map was compiled, shows that the water and temperature regime of soil and soil generating rocks are the leading ecological factors determining the development of plant communities. The presence or absence of permafrost greatly affects the soil temperatures. Therefore, geocryologic conditions are very significant for vegetation cover distribution and viceversa; vegetation development can exert considerable influence on permafrost.

THE PRINCIPLES OF THE CREATION OF THE VEGETATION MAP OF EAST EUROPEAN AND WEST SIBERIAN TUNDRAS AT 1:7,500,000 SCALE

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Astract -- The tundras of East Europe and West Siberia occupy a large region in the Russian North. This region is delimited as a separate province within the subzones of arctic and subarctic tundras. Characteristics that define the region's integrity include vast plains that dominate the modern topography and the general humidity of the climate. The species composition and vegetation structure of these tundras have much in common. Hence, it is possible to develop a uniform approach to the problem of their spatial plant cover differentiation.

The creation of a new small-scale (1:7,500,000) survey map of the East European and West Siberian tundras as part of the Circumpolar Arctic Vegetation Map is a separate task. It is complicated and labor-consuming because of the need for analysis and generalization of all the available facts at a principally new level of knowledge.

We consider the climatic zonation, regional history, and landscape geomorphology to be the basis of spatial differentiation of tundra plant cover for this level of mapping. This scale allows us to reflect, in sufficient detail, the zonal characters of the vegetation within the community composition for each legend syntaxon.

Regional genesis features of tundra plant cover are well reflected by its floristic peculiarities and also by its correspondence to the specific complexes of regional genesis, the so called phratrias of plant formations. The two such phratrias of tundra formations are distinguished for the West Siberian plain, namely the arctic and amphiatlantic phratrias. It is necessary for this project to put these two approaches into correspondence with each other.

The outlines of the mapping units, their dimensions, and pattern, are defined by the macrorelief. Relief is the most significant factor at the proposed scale. The correspondence of the mapped vegetation units to the topography should be illustrated by the inclusion of tabulated area statistics or remote sensing images, or both, within the legend.

Our methodology should include the following types of data:

1. Map schemes of the zonal and subzonal plant cover subdivision.
2. Schemes of regional differentiation.
3. Typological geobotanical maps at 1:1,500,000 to 1:4,000,000 scale.
4. Geomorphologic or landscape maps at 1:4,000,000 scale or less.
5. Hypsometric maps of the same scale range.
6. Large scale phytocenotic mapping data and the aerospace images of the key regions and samples.

THE VEGETATION MAP OF TAIMYR PENINSULA BASED ON LAND MANAGEMENT DATA

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The map of 'Vegetation and Fodder Supply of Taimyr' (Vegetation and Forages of the Taimyr National Circuit, 1:500,000 scale, 1975) was developed according to ground-truth sampling and air-visual phytocoenological studies for land management purposes. Associations and complexes of associations were taken as main units for this map. Communities shown were characterized by their fodder phytomass content and supply. Thus, the combination of plant biological groups that reflect environmental changes and various phytomass supply were taken into account. At the midscale, groups of associations and formations were used as mapping units.

Zonal principles (that is, tundra vegetation, boreal vegetation) were used in the map legend for combining of phytocenoses into higher ranks and regional features of vegetation interrelations with characteristics of the landscape were drawn (that is, mountain vegetation, plain vegetation). The legend contains 167 items. The specialized map has both botanical and applied significance. Phytocenologic division into districts also was produced, which allowed verification of plant cover structure, community peculiarities and distribution and zonal, altitudinal and longitudinal alignment of areas covered by different communities.

Several zones such as the arctic desert zone and the tundra zone, which can be divided into subzones of arctic, northern-, mid-, and southern-subarctic tundras, can be traced onto the Taimyr Peninsula from north to south. The taiga zone occurs in the very south of Taimyr. It consists of the high northern, sparse larch woods (woodlands), and northern taiga subzone. Nival and subnival belts (mountain tundras), mountain woods, and timberline are identified in mountains. Two provinces, the Gydan-Yennisey and the Pyasino-Khatang, separated by the Yennissey-Pyasino interfluve, can be distinguished meridianally because of the increasing continentality of the climate. The limit between these provinces is a floristic boundary as well. For instance, ***Larix sibirica***, and ***Betula nana*** are found westward, whereas ***Larix gmelinii***, and ***Betula exilis*** grow eastward.

The eastern part of the Gydan-Yennissey province is recognized as a western Taimyr subprovince, whereas the Pyasino-Khatang province is subdivided into central and eastern Taimyr subprovinces with a border along Taimyr lake. Thirty-nine phytocoenological districts are distinguished in the study area.

The technique used for vegetational fodder supply accounting is based on the correlation between the plant's height, cover, and phytomass. For the Taimyr (which occupies 860,000 km^2), fodder phytomass was calculated for fruticose lichens (reindeer mosses), shrubs (willows and dwarf birches), and grasses for subzones and belts. Plant cover (percent), economic supply (100 kg/10,000 m^2), and reindeer feeding ability (reindeers per day) are shown for lichens and for "green plants" on the inserts of the map.

The *Phytocoenological Map of Yakutia USSR* (area of 2,300,000 km^2) of the same scale was developed by our team in 1965, using techniques developed by Prof. Andreev. Parts of the map are shown in *Phytocoenological Map of Lower Kolima Region and Abiy Region.* Later, the 1:2,500,000-scale geobotanical map was produced for *Yakutia* tundras and all accumulated material were used to develop the *Phytocoenological Map of Taimyr and Yakutia Tundra Zone* (1:10,000,000 scale), which shows vegetation cover of zones, subzones, and altitudinal belts.

Legend for *Phytocoenological Map of Taimyr and Yakutia Tundra Zone*

(1) Arctic desert zone. The arctic desert zone occupies the Cheluskin Cape. Arctic deserts also occur in Byrrangaa mountains as a belt. Vegetation here is discontinuous (cover about 10 percent).

(2) Arctic tundra subzone. Most of the territory occupied by this subzone is covered by sedge-dryad-moss frost-boil tundras. The northern limit of willow tundra distribution is considered to be the southern border of the subzone.

(3) Northern (high) subarctic tundra subzone. The rare presence of *Betula nana* and *Betula exilis* serves as a diagnostic feature of the subzone. Hypoarctic dwarf shrubs such as *Vaccinium uliginosum* and *Ledum decumbens* together with *Dryas punctata* are very common. Sedge-dryad moss tundras dominate (25 percent). They alternate with the shrub-moss frost boil subarctic tundras. The northern limit of dwarf-birch shrub tundra distribution is considered to be the southern border of the subzone.

(4) Mid-subarctic tundra subzone. *Ledum decumbens* and *Vaccinium uliginosum* are the dominate species. *Alnus fruticosa* also appears here. One third of the subzone area is occupied by willow and dwarf-birch tundras. The southern limit is drawn along the northern limit of shrub thickets (such as willows, dwarf-birch, alder) distribution.

(5) Southern (low) subarctic tundras subzone. *Salix lanata, S. glauca, Betula nana, B. exilis,* and *Alnus fruticosa* shrubs dominate. Willow and birch shrubs are very common in interfluve areas. Woodland tundras together with larch woodlands appear along the southern edge of the subzone.

(6) High northern *Larix* woodland subzone. Alternation of woodland and tundra vegetation, presence of trees, that on the other hand are losing their edificatory role, are typical for this subzone. The southern edge of the woodland tundra distribution is thought to be the southern limit of the subzone. Mountain vegetation have distinguishable altitudinal belts.

(7) Mountain tundra belt (nival and subnival). Thinned out fellfield vegetation is most common. The belt's lower limit runs at 500-700 meters above sea level.

(8) Mountain wood and woodland belt. This appears as a narrow band along the gorges of Putorana Plateau. *Larix gmelinii* dominates here. Also *Larix*-shrub-moss woodlands are common. The belt upper limit runs at 200-500 meters above sea level.

(9) Northern (high) taiga, sparse larch woods subzone. Phytocenological border between this subzone and one adjacent to the north is unclear. Both of these subzones are considered to be subzonal variants of a single boreal type of vegetation. The woody layer is composed of *Larix, Picea*, and *Betula.* Tundra communities are absent on the placors (level, moderate sites). There are fewer open areas than those covered with woods.

References

Map of Vegetation and Forages of the Taimyr national Circuit, 1975, Saratov, Roszemproyect, 1:500,000 scale.

VEGETATION MAPPING IN ARCTIC YAKUTIA

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Some materials for the compilation of the Circumpolar Arctic Vegetation Map include the following:

(1) Geobotanical map of the USSR (Lavrenko and Sochava 1954) at 1:4,000,000 scale.
(2) Ecological-phytocoenotic Map of Asiatic Russia (Sochava and Bajborodin, 1977) at 1:7,500,000 scale.
(3) Map of Vegetation of the Northern regions of Yakutia (Shchelkunova, 1964-65) at 1:500,000 scale.
(4) Vegetation map in the Agricultural Atlas of Yakutia (Andreev, 1989) at 1:5,000,000 scale.

The Geobotanical Map of the USSR designates two large groups of formations for the tundra zone of Yakutia--arctic deserts and tundra, with meadows and grassy swamps represented as well. The first group contains 9 legend units while the second is represented by two. Basic drawbacks in these maps are underestimation of mountain and arctic tundras, underestimation of areas of scree sparce vegetation and cliffs, and no reflection of tussock-*Mochezhina* or medallion (frost-scar) ridge complexes. The second map has had many minute trifles removed but expresses necessary legend corrections. The third map, namely a map of northern regions, reflects plant cover according to relief forms with sufficient detail, but zonation is weakly expressed. The fourth map, published in the Agricultural Atlas of Yakutia, was based on aerovisual observations (fig. 1) and its legend has 30 units expressing the zonal-typological approach. This may be most similar to the desired product of the Circumpolar Arctic Vegetation Mapping Workshop.

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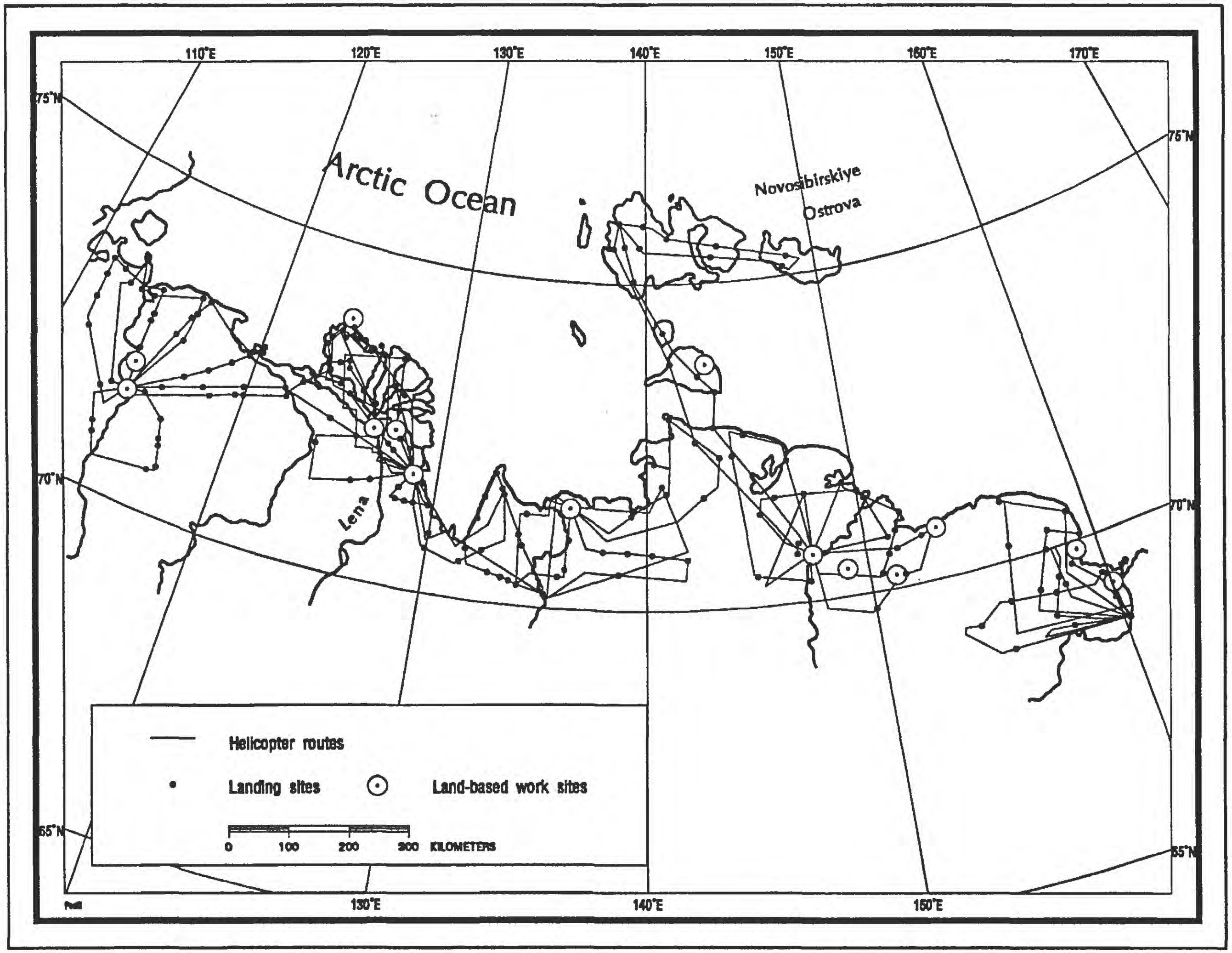

Figure 1. The degree to which the flora and soil vegetation cover of the tundra zone of Yakutia have been studied.

JOINT YAKUTAI-JAPAN RESEARCH PROJECT: DECODING THE REMOTELY SENSED IMAGES OF VEGETATION IN THE LOWER REACHES OF THE LENA RIVER

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A joint research effort between scientists from the Sakha-Yakutia Republic and Japan began in 1992. This research was aimed primarily at studying global warming. The team consisted of both biologists from the Yakutian Biology Institute, Hokkaido University, the Forest and Forest Products Research Institute, and the Japanese National Institute for Environmental Studies, together with permafrost specialists from Moscow University, the Yakutian Permafrost Institute, and the Japanese Institute of Low Temperatures. The biological program includes floristic, phytocoenologic, physiologic, growth form, dendrochronologic, and insect ecologic research, mainly in the comparative aspect for all the subzones within Yakutia.

In 1993, field work was conducted on the left bank of the Lena River in its lower reaches near the northern timberline. This is the territory of the Chekanovsky Range and its outcrops from 70.5° to 72°N latitude and from 125° to 127.5°E longitude.

Our main objectives were to map vegetation cover of the area by ground truthing satellite images, and also tracing the character and dynamic tendencies of both the northern and the altitudinal timberlines. The work was based on a July 23, 1973 Landsat MSS colour image at 1:500,000 scale. The image was very high quality with high resolution and practically no clouds. The image was processed by computer into a rectangular mosaic with different sized pixels to simulate ground area differences. The different pixel colors distinguished the different vegetation units. Such a format made it easy to find key areas throughout one preliminary analysis period.

The reconnaissance flight was completed on board the An-2 biplane. The flight altitude was about 1 km above sea level. The orientation was based on a pilot map at 1:1,000,000 scale. The spatial coordinates were taken with a 100 m precision at any flight moment with the help of a GPS-antenna, which received United States of America satellite signals. The terrain character was permanently documented by a videocamera.

Three key areas were chosen, primarily in tundra areas bordering large open woodlands composed of *Larix gmelinii*, the typical vegetation for the region. One plot of 10 by 80 to 100 meters was chosen within each key area. Such a plot was chosen to include both the open woodland and the bordering tundra community. A standardized relevé and measurements of canopy characters were then produced, including measurement of tree growth dynamics. The resulting 1:500,000-scale geobotanical map includes 9 legend classes: larch, open larch woodland, grass vegetation, lichens, sparce tundra vegetation, boulderfield, burnt areas, water, and uncertain areas (mainly due to clouds). Good correspondence was found between the decoded data results and the geobotanical map of the existing Atlas of the Yakutian Republic Agriculture of 1989. The scales are 10 times different in this case, but nevertheless the legend in the atlas still contains more information because it represents the combinations of some vegetation communities and lists all the dominant plant species. We should try to decode the space images more concretely and mask out more differences in the future.

THE EXPERIENCE OF VEGETATION MAPPING OF CHUKOTKA

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Abstract -- The vegetation map of Chukotka was prepared in the laboratory of reindeer range ecology at the Magadan Agricultural Research Institute. We used the results of field research and literature on the flora and vegetation of different districts of Chukotka. Additionally we used economic-geobotanical maps from State farms raising reindeer. These maps were made by special State service on reindeer ranges developed by Prof. V.N. Andreev. We worked on key plots in different climatic zones of Chukotka. The data of the land management State service have been useful for diagnosing the distribution of the main vegetation types. We prepared the vegetation map at a scale of 1:200,000. We completed a general map using shared macrocombinations characterized by a predominance of one or two vegetation associations with the presence of other associations. There were 2,300 polygons from this map which were transferred to the topographic maps at 1:250,000 scale. The legend includes the main types of vegetation and their combinations and complexes for a total of 58 units.

The cold desert and tundra vegetation is divided into: the high elevation montane tundras (2 units), mountainous and arctic tundras (10 units), and subarctic tundras (13 units). The forest type is divided into *Pinus pumila* thickets (9 units), the larch (*Larix gmelinii*) dense and open forests (1 unit), *Populus suaveolens* - *Chosenia arbutifolia* forests (1 unit), and the shrub thickets on river floodplains include 3 units. The sparse vegetation of gravel or sandy sea shore and river banks is distinguished as a separate unit.

III. CONSIDERATIONS FOR A CIRCUMPOLAR VEGETATION MAP LEGEND

LATITUDINAL (ZONAL) AND LONGITUDINAL (SECTORAL) PHYTOGEOGRAPHIC DIVISION OF THE CIRCUMPOLAR ARCTIC IN RELATION TO THE STRUCTURE OF THE VEGETATION MAP LEGEND

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The 1:7,500,000-scale map to be created may reveal the principal regularities of arctic vegetation with latitudinal (zonal) differentiation determining the legend structure. This paper primarily concerns a system of phytogeographic subzones of the tundra zone in its broader interpretation (the northern polar, cold, treeless region) and the development of the traditions of Russian tundrology. The scheme was published first in 1978 (Yurtsev and others, 1978, 1985) and now is modified according to new data (Edlund, 1990; Yurtsev, 1992, 1993). The tundra zone (fig. 1) is divided into 6 subzones (I - VI). The two southernmost (V-VI) occur in all but the oceanic sectors and often are considered as oceanic boreal rather than subarctic treeless territories. The six subzones are naturally united into two groups: the Hypoarctic (corresponding to the Low Arctic of western authors: III - VI) and Arctic (the High Arctic of western authors: I-II).

The features of the Hypoarctic are as follows: the prevalence of continuous vegetation, the forming of acid organic beds over mineral soil horizons, the increased activeness (very often coenotical dominance on placors) of the hypoarctic oligotrophic complex of minute arboreal plants (low to middle shrubs, dwarf shrubs), mosses, and fruticose lichens (Yurtsev, 1966), and eutrophic herbs are forced to intrazonal habitats (except for carbonate landscapes). The Southern Hypoarctic Tundra Subzone (IV) is characterized by an increased role of shrub tundras in the landscape: in the sectors with milder, snow-rich winters, shrub tundras also occupy placors (that is, plainy, drained, silty interfluves); in the more continental subzones (on silt), they are forced into various depressions and slopes; but on interfluvs they are replaced by sedge-cottongrass tussock tundras. The Subzone III ("northern tundras", "northern subarctic (hypoarctic) tundras", "typical tundras" of various authors) is now often divided into two separate subzones: the Middle Hypoarctic ("middle subarctic") (Aleksandrova, 1977, 1980), and Northern Hypoarctic ("northern subarctic") tundras. However, more data are needed to demarcate the above subunits circumpolarly. In the middle hypoarctic tundras, the positions of low shrubs weaken and leave interfluves, represented by willow thickets. The dwarf birches pass from the layer of low shrubs into the dwarf shrub layer and the shrub alders disappear. In the placor dwarf shrub-sedge-moss tundras, the diversity of arctic-alpine herbs and dwarf shrubs increases. The northern hypoarctic tundra subzone is an ecotone to the arctic tundra subzone. Willow low shrub thickets almost disappear even in floodplains, and the role of hypoarctic dwarf shrubs in vegetation weakens.

In the arctic group of subzones (I-II), the hypoarctic minute arboreal plants (including dwarf birch) drop out from the flora or, at least, from the set of active (thriving) species. Low shrubs are absent and the tundra sod becomes thin and regularly perforated (as in frost boil and dry polygonal tundras) with the humus horizon being organic-mineral and almost base-saturated, even on acid rocks. The diversity of arctic-alpine eutrophic herbs in placor tundras often increases due to the extending habitat range of organophobic species; however, the habitat diversity decreases. In the Arctic Tundra subzone (II), the dwarf shrub tundras, dominated or co-dominated by arctic-alpine prostrate summer-green species of *Dryas* and/or *Salix*, are still widespread. In the southern variants of the subzones (IIs) a heath formation, dominated by *Cassiope tetragona* (an evergreen hemi-prostrate dwarf shrub), occurs and is locally common. The contrast between the floodplain and interfluve vegetation almost disappears. Mires (most often mineral) still sustain species of *Cyperaceae*, usually mixed with grasses. In the northern variant (IIn), the coverage of vegetation decreases. Among prostrate dwarf shrubs, *Salix* ssp. are most important and many herbaceous species acquire a pulvinate habit. The high-arctic tundra subzone (I), as interpreted here, corresponds to the polar desert zone (Aleksandrova, 1977, 1980; Chernov and Matveya, 1979). Some mature plant communities of the subzone have a significant ground cover (polygonal, frost-boil, hummock high arctic tundras; semideserts [Bliss, 1981]) This is typical of the northern most Ellesmere Island with fine-grained soils, rich in moisture. The desert-like habit of the bedrock terrain is, to a significant extent, edaphically controlled (Gold and Bliss, 1992). Dwarf shrubs are practically absent as are *Cyperaceae*. Cryptogams (lichens, bryophytes, and cyanobacteria) play a greater part and are more diverse than flowering plants.

Within each subzonal unit of the legend, a number of regional (longitudinal-sectoral) subdivisions can be distinguished that differ from one another primarily by the set of active, dominant or characteristic of both species. For their identification, our floristic subdivision scheme of the Arctic may be used based on the detailed lists of differential and co-differential species for each unit (altogether 6 provinces and 20 subprovinces; fig. 2).

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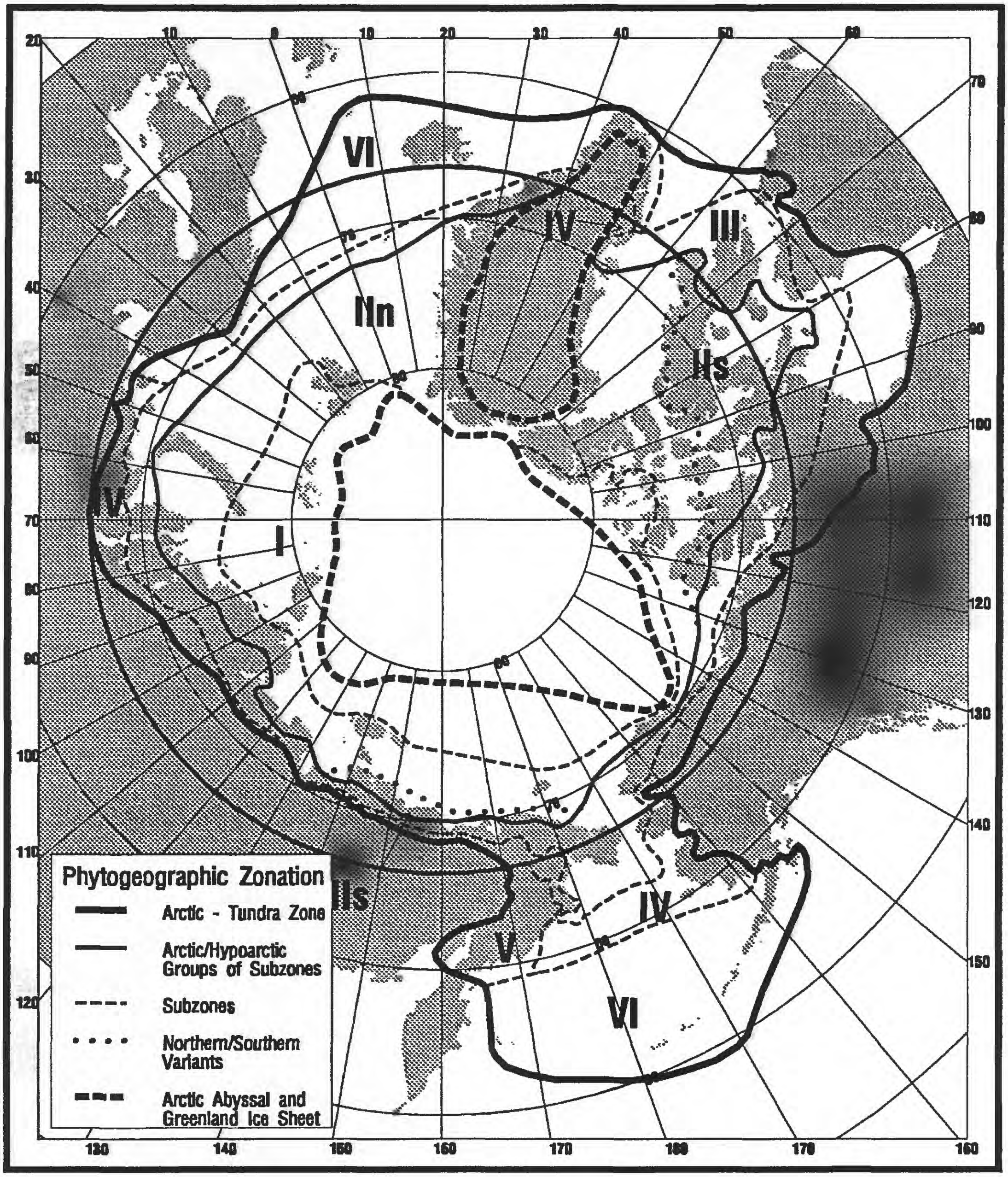

Figure 1. Phytogeographic zonation of the circumpolar arctic region.

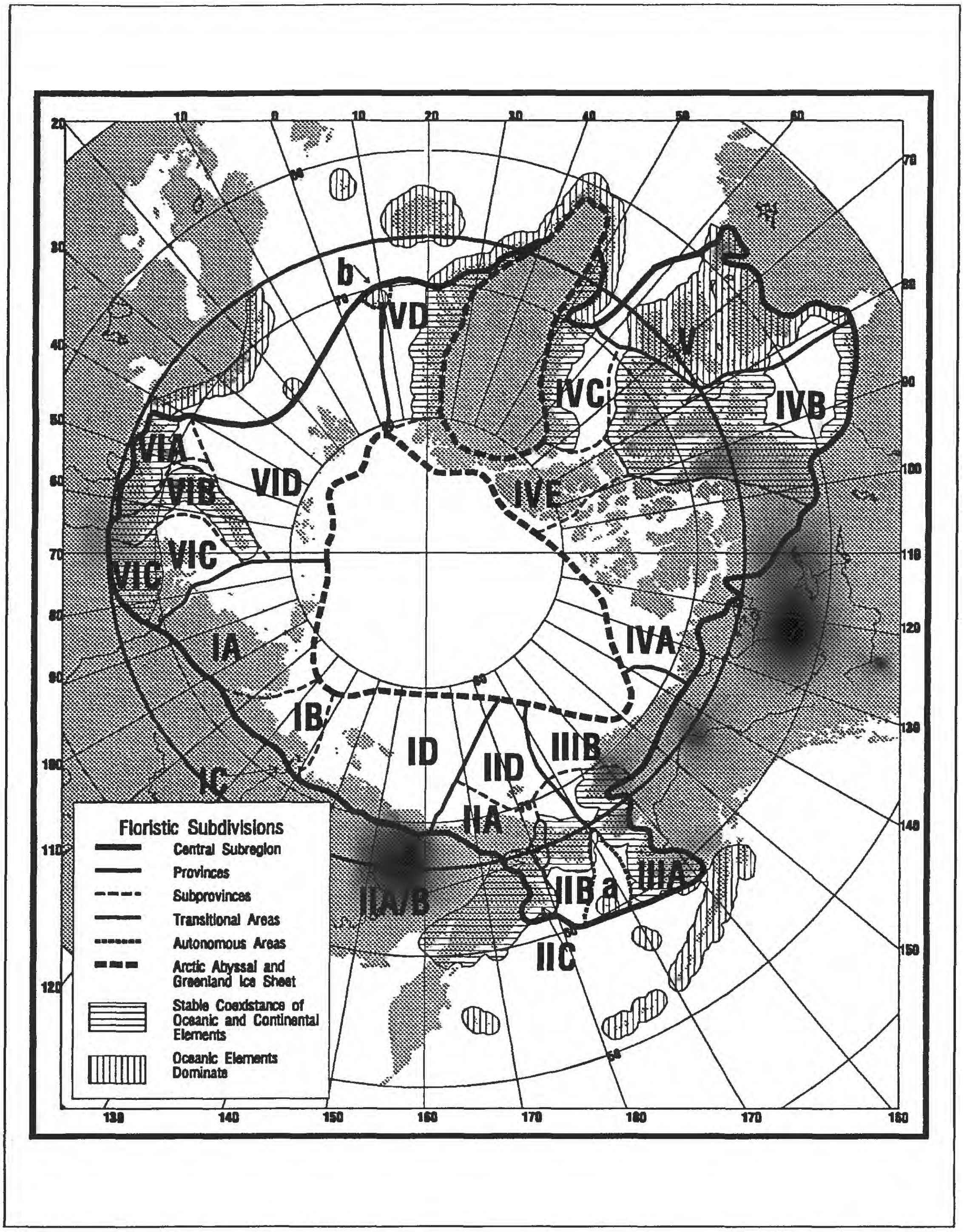

Figure 2. Floristic subdivisions of the circumpolar arctic region (see Note 2 for detailed description.)

Note 1. For Yurtsev's phytogeographic zonation of the Arctic (modified from Yurtsev, 1994).

Arctic group of subzones (Subzones I and II, corresponds to the High Arctic of western authors): Characterized by an absence or scarcity of hypoarctic minute arboreal plants (including dwarf birch) and an absence of low shrubs; the tundra sod is thin and the vegetation canopy is open with numerous frost boils and dry ice-wedge polygons; the soil humus horizons are organic-mineral and almost base-saturated even on acidic rocks. The diversity of Arctic-alpine eutrophic herbs on moderate sites is often high due to the extension of habitat range of nonpeatland species, however, the habitat diversity is less than that in the hypoarctic zone.

Subzone I, High-Arctic tundra [Corresponds to the polar desert zone of some Russian authors, for example, Aleksandrova (1977, 1980); Chernov and Matveyeva (1979)]: Some mature plant communities of the subzone have significant ground cover, for example, polygonal, frost-boil, hummock, high-Arctic tundras and semideserts of Bliss (1979). The desert-like character of the bedrock terrain is to a significant extent edaphically controlled. Cryptogams (lichens, bryophytes, and cyanobacteria) play a greater part and are more diverse than flowering plants. Prostrate arboreal plants are normally lacking as are Cyperaceae in mires.

Subzone II, Arctic tundra: This subzone has an abundance of dwarf-shrub tundras, dominated or co-dominated by Arctic-alpine species. Prostrate summergreen species of *Dryas* and/or *Salix*, are widespread. In the northern variant (IIn) , the coverage of vegetation is less; among prostrate dwarf shrubs, *Salix* spp. are most important; and many herbaceous species acquire a pulvinate habit. In the southern variant (IIs) a heath formation, dominated by *Cassiope tetragona* is locally common. There is little contrast between the floodplain and interfluve vegetation. Mires (most often mineral) sustain species of Cyperaceae, usually mixed with grasses.

Hypoarctic group of subzones (Subzones III - VI, corresponds to the Low Arctic of western authors): There is a prevalence of continuous vegetation, forming acidic organic beds over mineral soil horizons. There is increased abundance and often dominance on mesic interfluves of hypoarctic oligotrophic complex of low and dwarf shrubs, mosses and lichens. Arctic-alpine eutrophic herbs are forced out to intrazonal habitats (except on carbonate landscapes).

Northern hypoarctic tundra: [Subzone III, corresponds to the 'northern tundras', 'northern subarctic tundras' of various authors. It is often divided into two separate subzones: the middle hypoarctic (= middle subarctic of Alexandrova (1977, 1980) and northern hypoarctic (= northern subarctic) tundras.] The latter is an ecotone between the southern hypoarctic and the Arctic tundra subzones. Low shrubs and willow thickets are not abundant even in floodplains, and dwarf shrubs are relatively unimportant compared to more southerly areas. In the middle hypoarctic tundras, low willow shrublands are restricted mainly to riparian areas; the stature of dwarf birches is generally that of dwarf shrubs (less than 20 cm), and shrub alders are not present. There is high diversity of Arctic-alpine species on mesic sites with dwarf shrub-sedge-moss tundras.

Southern hypoarctic tundra (Subzone IV): Shrubs are abundant, particularly in riparian areas. In sectors with milder, snow-rich winters shrub tundras occupy mesic upland surfaces; in the more continental sectors, the shrubs occur mainly in depressions and some slopes, but on mesic interfluves they are replaced by sedge-cottongrass tundras. The two southernmost subzones (V and VI) are considered as oceanic boreal rather than subarctic treeless territories. Subzone V consists of the large stlaniks (***Pinus pumila***) in the far northeast of Asia. Subzone VI has a predominance of oceanic mesic meadows and heaths.

Note 2. For Yurtsev's floristic subdivisions (provinces and subprovinces) of the Arctic (modified from Yurtsev, 1994).

The longitudinal boundaries delineate regional provinces and subprovinces based on sets of dominant or characteristic, or both, plant species. For a description of the floristic characterization of each unit, consult Yurtsev (1994).

I. East Siberian Province
- IA, Taimyr
- IB, Anabar-Olenek
- IC, Kharaulakh
- ID, Yana-Kolyma

II. Chukotka Province
- IIA, Continental Chukotka
- IIB, Beringian Chukotka
- IIC, South Chukotka
- IID, Wrangel Island

III. Alaskan Province
- IIIA, Beringian Alaska
- IIIB, Northern Alaska

IV. Canada-Greenland Province
- IVA, Central Canadian
- IVB, West Hudsonian
- IVC, West Greenland
- IVD, East Greenland
- IVE, Ellesmere-North Greenland

V. Baffin-Labrador Province

VI. European-West Siberian Province
- VIA, Kanin-Pechora
- VIB, Ural-Novaya Zemlya
- VIC, Yamal-Gydan
- VID, Svalbard

FLORISTIC STUDIES IN RELATION TO VEGETATIONAL CHANGES

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One of the main reasons to map vegetation is to provide baseline data for studies of vegetation change over time. In thinly inhabited areas, most vegetation changes will be caused by climatic changes. In the Arctic, the climatic parameter most closely associated with vegetation change is summer temperature. This can be expressed in several ways, such as mean July temperature, degree days per summer season above a certain temperature, or even average length of frost-free season. Changes in vegetation theoretically provide some of the most powerful proxy data from terrestrial environments for models of climatic change.

There are several problems associated with this approach. Most important is the slow rate of change of natural vegetation. Coupled with the short time since documented studies of vegetational change began, our work tells us little about the rate at which changes occur and even less about the processes involved in these changes. Even studies in change in timberline location and its relation to climatic change are, as yet, relatively inconclusive.

There are indications that in the late glacial and early Holocene, vegetation in some far northern areas changed rapidly and perhaps nearly simultaneously over broad areas. An example is the rapid establishment of the "Birch zone" in Beringia some 13,000 to 12,000 years before present. Such examples suggest that vegetation change in the north is not necessarily a shifting of vegetation belts poleward or southward. Rather, it may often be a shift in emphasis between local vegetation types. In the example above, dwarf birch may have expanded from many small, local "pockets". Birch scrub could have rapidly achieved dominance over a previously existing steppe-like vegetation. The steppe, in turn, could be confined to rare pockets of appropriate habitat, ready to rapidly recapture the area if there were a return to its preferred environmental conditions.

If the process outlined above is common, it leads to several important implications. First, vegetation change can be quite rapid if it is based on a change in importance of certain species or communities, or both. Second, the establishment, or re-establishment, of similar vegetation types in two different areas could take place at radically different rates, depending on whether the process of change was based on expansion of existing patches of previously rare vegetation types or by migration from a distant source area. Third, one should be able to predict which process of vegetation change is likely to occur, based on the presence or absence of certain rare species or communities, or both, that might have the potential to expand rapidly as conditions changed. Fourth, studies of floristic zonation, which consider rare species as well as common ones, may provide both a suggestion as to which of the two processes is likely to be most significant in a given location, and also may suggest something of the potential nature of the newly emerging vegetation type. Finally, this scenario of two different processes suggests that two quite different end products might result from the effects of climatic change on two vegetation types that were initially quite similar in aspect, but differed in terms of the rarer floristic elements they supported. Some of these end products might be different from any currently recognized vegetation types.

From this line of thinking, my suggestion is that students of vegetation and vegetation mapping maintain an awareness of the potential importance of species and communities that are of rare and local occurrence within a study area. I suggest that these rarities may often be the "seeds" for widespread vegetational changes. Careful study of the taxonomy, genetics, ecological tolerances, requirements, and associations may give us important hints of the nature of vegetational and climatic change.

CONSIDERATIONS REGARDING A LEGEND FOR A CIRCUMPOLAR ARCTIC VEGETATION MAP (1:7,500,000 scale) BASED ON GREENLAND EXPERIENCE

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Abstract -- A vegetation map (1:7,500,000 scale) of Greenland is presented. The mapping units are based on similarities and dissimilarities in the inventory of syntaxa. This inductive mapping approach is discussed. Syntaxonomy is considered as an important tool in vegetation mapping.

Introduction

The legend of a circumpolar arctic vegetation map (1:7,500,000 scale) preferably should include Braun-Blanquet syntaxa. Such vegetation units are considered to relate more completely to past and present environmental conditions. The association, which is characterized by uniform floristics and structure, provides the most detailed information. This paper presents a first, simple vegetation map of Greenland based on syntaxonomy, and includes a procedure for distinction of the mapping units. Its primary aim is to demonstrate the possibility of grouping areas by diagnostic combinations of syntaxa, analogous to the distinction of associations by means of diagnostic species combinations, including character, differential, and constant companion species in the Braun-Blanquet approach. Such an inductive method allows in the future a classification of the arctic territory into hierarchical units, which might be considered at least supplementary to the (few) existing geobotanical schemes based on either floristics or structure (for example, Aleksandrova, 1980; Bliss, 1975; Yurtsev, 1994). The possibility of characterizing phytogeographical zones by means of syntaxa was already shown by Elvebakk (1985) for the European Arctic and adjacent regions.

Methods

The construction of this vegetation map is based on my own local inventory field studies on Ellesmere Island, Canada (in 1992) and several localities in Greenland (in 1966, 1963, 1969, 1981, 1992 and 1993). These studies resulted in a rather global quantitative assessment of vegetation type occurrences (syntaxa) in ice free lowland localities (<500 m) as follows: '-' not observed (absent?), r-rare, o-occasional and c-common. Vegetation types include syntaxa of aquatic, amphibious, bog, mire, spring, tall herb and shrub, snowbed, dwarf shrub, grass and lichen, debris, rock, salt marsh and beach vegetation (see table 1).

The 10 localities (table 1) are grouped according to similarities in their syntaxonomical inventory. The vegetation includes wet meadows (*Scheuchzerio-Caricetea*), xerophytic grass and dwarf shrub vegetation on richer (basic-calcareous) soil (*Carici-Kobresietea, Dryas integrifolia-Cassiope tetragona* community), tall herb and shrub (mostly willow) vegetation

(*Mulgedio-Aconitetea, Festuco-Salicetum*), bogs (*Oxycocco-Sphagnetea*), acidic dwarf shrub heaths (*Loiseleurio-Vaccinietea, Empetreto-Betuletum nanae, Sphaerophoro-Vaccinietum, Cassiopetum tetragonae, Empetrum-Vaccinium* community and *Phyllodoco-Salicetum*), snowbed vegetation (*Salicetea herbaceae*) and acidic grass heaths (*Caricetea curvulae*). Areas of Greenland not visited by me are syntaxonomically evaluated from the literature (survey in Daniëls, 1994). The results are not included in table 1.

All vegetation types are rather well defined syntaxonomically and refer to natural vegetation. They have a dense cover and might be recognizable from air photographs (other vegetation types might be less useful in this respect). They are related to substrate (wet-dry, calcareous - not calcareous), duration of snow cover (absent, short, long), climate (subarctic, arctic, low and high arctic, suboceanic-subcontinental, and geographical distribution (Eurosiberian, circumpolar North American, and others). Thus, areas with a similar set of syntaxa are supposed to be ecologically uniform.

Vegetation map and legend (see table 1, fig. 1)

Provisionally, this results in the construction of a vegetation map of Greenland with 7 regions and 7 legend units (fig. 1). They will be shortly described below.

Region 1. Northwest, north and northeast Greenland; locality #1 in table 1. Wet meadow vegetation (*Scheuchzerio-Caricetea*) and *Dryas integrifolia- Cassiope tetragonae* community are common; willow scrubs (*Festuco-Salicetum*) and the dwarf shrub *Betula nana* are absent. This zone belongs to the Polar Desert of the High Arctic (Bliss, 1975).

Region 2. The inland of east and northeast Greenland. The dwarf shrub community *Cassiopetum tetragonae* is present; *Empetrum-Vaccinium* community and *Mulgedio-Aconitetea* communities are absent. This region corresponds to the Polar Semi-Desert of the High Arctic, sensu Bliss (1975).

Region 3. Coastal east and east-northeast Greenland. Wet meadow vegetation (*Scheuchzerio-Caricetea*) and *Dryas integrifolia-Cassiope tetragona* community are common; *Betula nana* is present; *Festuco-Salicetum* is absent. This region might be part of region 1. According to Bliss (1975) it belongs to the Polar Semi-Desert of the High Arctic.

Region 4. The inland of west-northwest Greenland; locality nos. 2 and 3. Wet meadow communities (*Scheuchzerio-Caricetea*) and *Dryas integrifolia-Cassiope tetragona* community are common; willow scrub (*Festuco-Salicetum*) occurs. This region belongs to the Low Arctic Tundra, sensu Bliss (1975).

Region 5. The inland of west and southwest Greenland; locality nos. 4, 5, and 6. Bog vegetation and *Empetro-Betuletum nanae* are common; snowbed communities (*Salicetea herbaceae*) are rare. This region belongs to the Low Arctic Tundra, sensu Bliss (1975).

Region 6. West and northwest Greenland and the inland of southeast Greenland; locality nos. 7, 8, and 9. Dwarf shrub heath vegetation, including *Cassiopetum tetragonae* (*Loiseleurio-*

Vaccinietea), snowbed communities (*Salicetea herbaceae*) and willow scrub and tall herb vegetation (*Mulgedio-Aconitetea*) commonly occur. This region belongs to the Low Arctic Tundra, sensu Bliss (1975).

Region 7. Coastal southeast and southwest Greenland, and south Greenland, locality no. 10. Dwarf shrub heaths, including *Sphaerophoro-Vaccinietum* and *Phyllodoco-Salicetum* (*Loiseleurio-Vaccinietea*) and snowbed communities (*Salicetea herbaceae*) are common; however *Cassiopetum tetragonae* (*Loiseleurio-Vaccinietea*) is absent. This region belongs to the Low Arctic Tundra, sensu Bliss (1975). South Greenland with open, low *Betula pubescens tortuosa* woodland might be considered as a separate region.

More phytosociological research, particularly in North and East Greenland, is necessary for adjustment and obtaining more detail. Moreover the sampling procedure within the localities must be defined in detail.

Conclusion

A comparison between the vegetation map presented and the geobotanical division of Greenland by Aleksandrova (1980), Bliss (1975) and Yurtsev (1994; map 1) might allow some remarks. Along the east coast of Greenland the borderline between the subregion of the arctic and subarctic tundras sensu Aleksandrova (1980) is drawn at about 70°N. latitude (map 1). The arctic tundras are syntaxonomically characterised by wet meadows, *Dryas-Cassiope* community (*Carici-Kobresietea*) or *Cassiopetum*; all other *Loiseleurio-Vaccinietea* communities and *Festuco-Salicetum* (*Mulgedio-Aconitetea*) are absent. Application of this concept for the west coast of Greenland moves the borderline between the arctic and subarctic tundras here from about lat. 70°N. to about lat. 75°N. The distinction between High Arctic and Low Arctic in Greenland by Bliss (1975) is strongly supported by syntaxonomical evidence. The Low Arctic is differentiated against the High Arctic by the tall herb and shrub vegetation of the *Mulgedio-Aconitetea* class and the *Phyllodoco-Salicetum callicarpaeae* of the class *Loiseleurio-Vaccinietea*. In the concept of Yurtsev (1994) most of Greenland belongs to the Tundra Zone, which is subdivided into Arctic and Hypoarctic Tundra Subzones. Greenland north of about lat. 70°N. belongs to the northern variant of the arctic tundra subzone. Coastal Southeast Greenland between lat. 70°N. and 64°N. and West Greenland from southern Disko, lat. 70°N, to 67°N. belongs to the north hypoarctic tundra subzone. The inland parts of west Greenland belong to the southern hypoarctic tundra subzone, while the remaining of southern Greenland is not considered as belonging to the tundra zone (fig. 1). This division matches rather well our syntaxonomical scheme. The southern hypoarctic tundra subzone, for example, might be characterised by bog vegetation and *Empetro-Betuletum*. However, the borderline between the northern hypoarctic tundra subzone and the southern variant of the arctic tundra subzone at the west coast of Greenland is not supported by syntaxonomical evidence; it should be moved more to the north. Finally a remark on Elvebakk's (1985) preliminary scheme. The hemiarctic zone (HAZ) is distinguished from the southern arctic tundra zone (SATZ) in Greenland by the *Phyllodoco-Vaccinion* (*Loiseleurio-Vaccinietea*) and *Lactucion* (=*Mulgedio-Aconitetea*), which should not be important or absent in SATZ. However, in the SATZ both vegetation types are common; thus this concept should be reviewed.

The use of syntaxonomy in the division of the Arctic was already shown for Svalbard by Elvebakk (1985); also Böcher (1954). However the Arctic is still poorly studied according to the Braun-Blanquet approach. Thus for the moment the application of syntaxonomy in the construction of a legend for the circumpolar arctic vegetation map seems still rather illusory. However, it must be realized, that arctic vegetation is rather uniform and not very diverse. Many vegetation types are widely distributed and uniform, some (mainly higher) syntaxa being certainly circumpolar in distribution. Moreover detailed vegetation descriptions based on quadrat-analysis exist from all over the Arctic (Aleksandrova, 1980; Walker and others, 1994). International cooperation among arctic scientists using uniform or equivalent methods and investigation of joint phytosociological efforts both in the field, laboratories, and libraries, will undoubtedly contribute to the achievement of the prospected circumpolar arctic vegetation map in the near future.

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Table 1.--Syntaxonomical inventory of 10 localities in Canada and Greenland. [SVP-Sverdrup Pass; MAM-Mamorilik; NUG-Nugssuak near Qaersut; SSF-Söndre Strömfjord; LAF-Lakse Fjord; UUM-surroundings of Uummaannaq; TAI-Angmagssalik inland; UPE-Upernavik Island; DIS-southern Disko; TAC-Angmagssalik coast; CAN-Canada; WC-west, SWG-Southwest, NWG-Northwest and SEG-Southeast Greenland; i-inland, c- coast; dol-dolomite, mar-marble, cla-clay, gn-gneiss, bas-basalt; c- continental, sc-subcontinental, osc-oceanic-subcontinental, o- oceanic (Böcher, 1954). Nomenclature of syntaxa according to Daniëls (1982, 1994). *Sphaero-Vaccinietum* is *Sphaerophoro-Vaccinietum*]

Locality nr.	1	2	3	4	5	6	7	8	9	10
Name	SVP	MAI	NUG	SSF	LAF	UUM	TAI	UPE	DIS	TAC
Region	CAN	WG	WG	SWG	NWG	WG	SEG	NWG	WG	SEG
Coast/inland	i	i	c	i	i	(c)	(i)	c	c	c
Geology	dol	mar	cla	gn	gn	gn	gn	gn	gas	gn
Climate	c	c	sc	c	sc	sc	osc	o	osc	o
N. Lat (Degrees)	80	80	70	67	72	70	66	73	69	66
Scheuchzerio-Caricetea	c	c	c	c	c	c	c	c	c	c
Carici-Kobresietea	c	c	c	c	r	c	c	o	c	o
Dryas-Cassiope comm.	c	c	c	-	-	-	-	-	-	-
Mulgedio-Aconitetea	-	o	o	c	c	o	c	o	c	c
Festuco-Salicetum	-	o	o	c	c	o	c	o	c	c
Oxycocco-Sphagnetea	-	-	-	c	c	o	o	r	o	o
Loiseleurio-Vaccinietea	-	-	r	c	c	c	c	c	c	c
Cassiopetum tetragonae	-	-	-	r	o	o	o	o	c	c
Phyllodoco-Salicetum	-	-	r	o	r	c	c	o	c	c
Empetrum-Vaccinium comm.	-	-	-	-	-	o	c	c	c	c
Empetro-Betuletum	-	-	-	c	c	c	c	r	o	o
Sphaero-Vaccinietum	-	-	-	-	-	-	-	c	c	c
Salicetea herbaceae	o	r	r	r	o	o	c	c	c	c
Caricetea curvulae	-	-	-	-	-	-	-	-	-	c
Verrucarietea	c	c	-	-	-	-	-	-	-	-
Rhizocarpetea	o	r	c	c	c	c	c	c	c	c
Asplernietea	-	o	r	c	o	-	o	-	o	o
Thlaspietea	o	r	c	c	c	c	c	c	c	c
Honkenyo-Elymetea	-	-	r	c	r	r	r	r	o	r
Asteretea	-	-	o	r	c	r	o	o	o	c
Montio-Cardaminetea	o	c	o	c	c	o	c	c	c	c
Littorelletea	-	-	-	o	-	-	-	-	r	o
Potametea	r	r	r	c	o	o	-	o	o	o

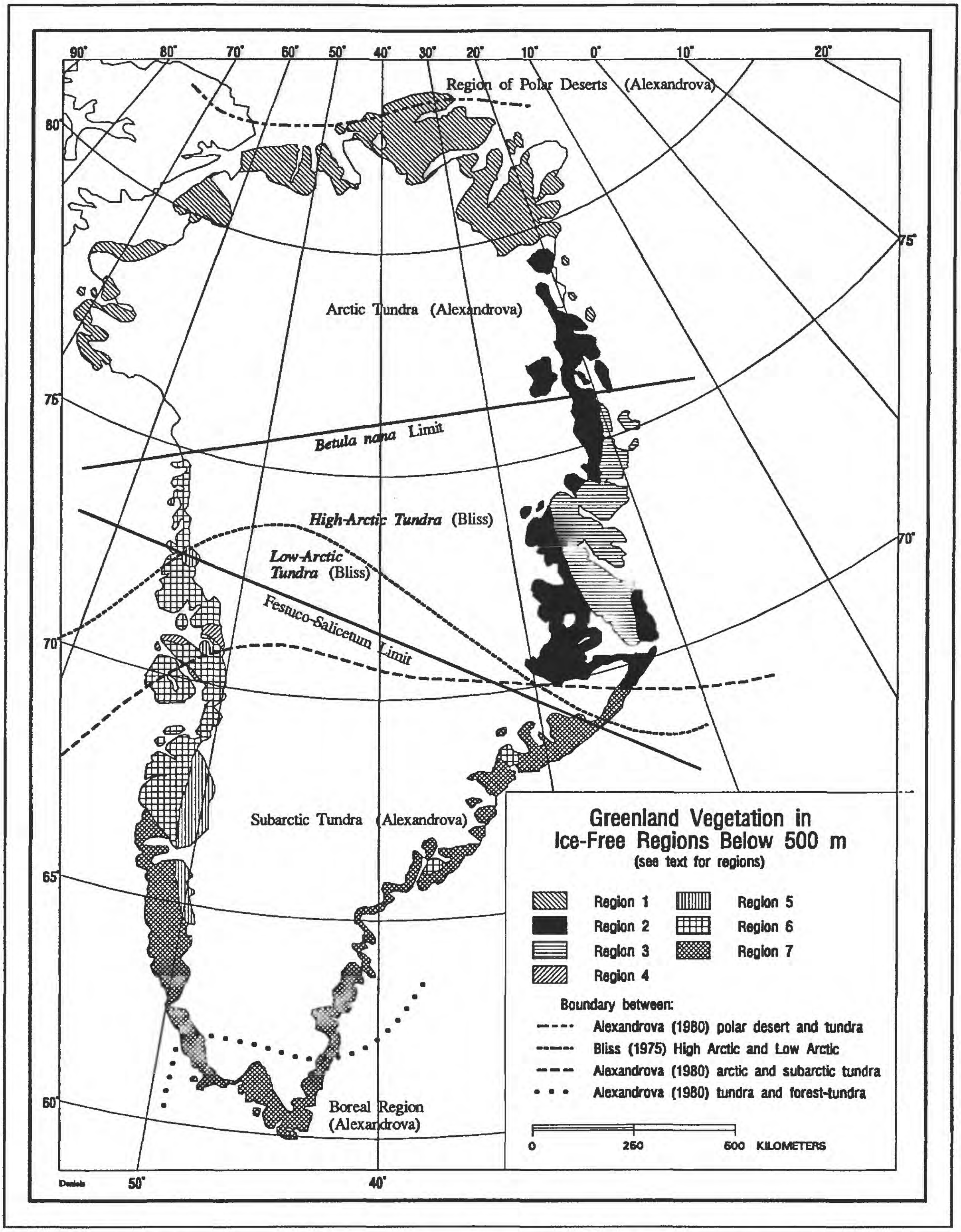

Figure 1. Provisional vegetation map of Greenland (see text for description of each region.)

PRINCIPLES OF THE RUSSIAN SCHOOL OF GEOBOTANICAL CARTOGRAPHY AND ITS APPLICATION TO THE CREATION OF A CIRCUMPOLAR ARCTIC VEGETATION MAP

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Abstract -- A legend for a vegetation map of the circumpolar Arctic at 1:7,500,000 scale could be designed as a hierarchic staircase system where typological categories (types of vegetation, classes, groups of formations, and formations) and geographical (regional) variants serve as stages. A scheme of zonal and subzonal partition from tundra and whole northern treeless region, for example, northern, middle (typical) and southern tundras, is of substantial importance for separation of legend subdivisions. Mountain vegetation is reflected with registration of all altitudinal zonation diversity. Separation of dynamic categories (that is, potential vegetation) is planned for areas with prolonged anthropogenic disturbances such as 100 years of reindeer pasturing. For nonplacor types of communities, especially for mountain territories, for patches of sand deposits and outcrops of calcareous rocks, basic ecological characteristics are incorporated into the legend in a diagnosis of units mapped.

DOMINANT-BIOMORPH APPROACH TO THE CLASSIFICATION OF VEGETATION AND ITS REFLECTION IN THE STRUCTURE OF THE LEGEND OF THE VEGETATION MAP OF CHUKCHI PENINSULA

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The vegetation of Chukchi Peninsula has been of late depicted on two small-scale maps, namely the *Geobotanical Map of the USSR* of 1956 and the vegetation map in the *Atlas of the Arctic* of 1986. On the 1:4,000,000-scale *Geobotanical Map of the USSR,* five legend items are represented for the vegetation of the peninsula, and on the 1:10,000,000-scale vegetation map of the *Atlas of the Arctic*, there are three. Zonal and regional characters of the vegetation are shown on both maps but the vegetation of the Chukchi Peninsula is depicted in less detail than is allowed by the scale in each case.

The dominant-biomorphic classification of the vegetation allows us to determine the preliminary correspondence of plant cover units with its syntaxons on a remote sensing basis. The legend items of the map at 1:7,500,000 scale clearly correspond to the territorial units within the peninsula area, that is, to the combination of several syntaxons that are typical to the corresponding map area; so several syntaxons are used for the composition of each legend item. Such syntaxons belong to the top levels in the classification hierarchy, but these levels can often be different.

The legend of the Chukchi peninsula vegetation map (fig. 1) is of a regional character as is the classification on which it is based. Both orographic and zonal principles are followed within the legend composition. Its main four subdivisions are: A: plains vegetation; B: mountain vegetation; C: coastal vegetation; and D: extra-zonal vegetation. The subzonal variants exist within the plains and mountain topics. The extra-zonal vegetation as well as some coastal vegetation variants are mapped by means of out-of-scale symbols. The whole legend comprises 18 items. In the variant of the legend (below) two essential elements of the characteristics of the vegetation are absent: biomorph types of plant communities and the names of the dominant species. These elements occur in the original version.

The framework of the map legend

A. The plains vegetation

I. The Northern hypoarctic tundras

1. The northern variant of the northern hypoarctic tundras (n.h.t.).
2. The southern variant of the n.h.t.
3. The coastal variant of the n.h.t.

II. The Southern hypoarctic tundras (s.h.t.).

4. The willow-scrub variant of the s.h.t.

B. The mountain vegetation

I. The system of mountain altitudinal vegetation belts (a.v.b).

5. The northern tundras variant of a.v.b. in the noncarbonate middle height mountains.
6. The southern tundra variant a.v.b. in the noncarbonate middle height mountains (with alder thickets in the bottom belt).
7. The northern tundra variant of a.v.b. in the noncarbonate low mountains.
8. The northern tundra variant of a.v.b. in the carbonate low mountains.
9. The southern tundra variant of a.v.b. in the noncarbonate low mountains:
    a. with alder thickets in the bottom belts.
    b. with willow thickets in the bottom belts.
10. The southern tundra variant of a.v.b. in the carbonate low mountains (with alder thickets in the bottom belts).

II. The vegetation of extended strongly dissected uplands.

11. The northern tundra vegetation of noncarbonate uplands.
12. The southern tundra vegetation of noncarbonate uplands.
13. The southern tundra vegetation of carbonate uplands.

C. The coastal vegetation

14. The halophytic vegetation of the low sea coasts.
15. The vegetation of the coastal bedrock and bird cliffs (⊏⊐⊏⊐⊏⊐).
16. The vegetation of the thermo-eroded loose deposit coasts (xxxx).

D. The extrazonal vegetation

17. The vegetation in the vicinity of mineral hot springs (★).
18. The cryo-xerophytic vegetation patches (▲).

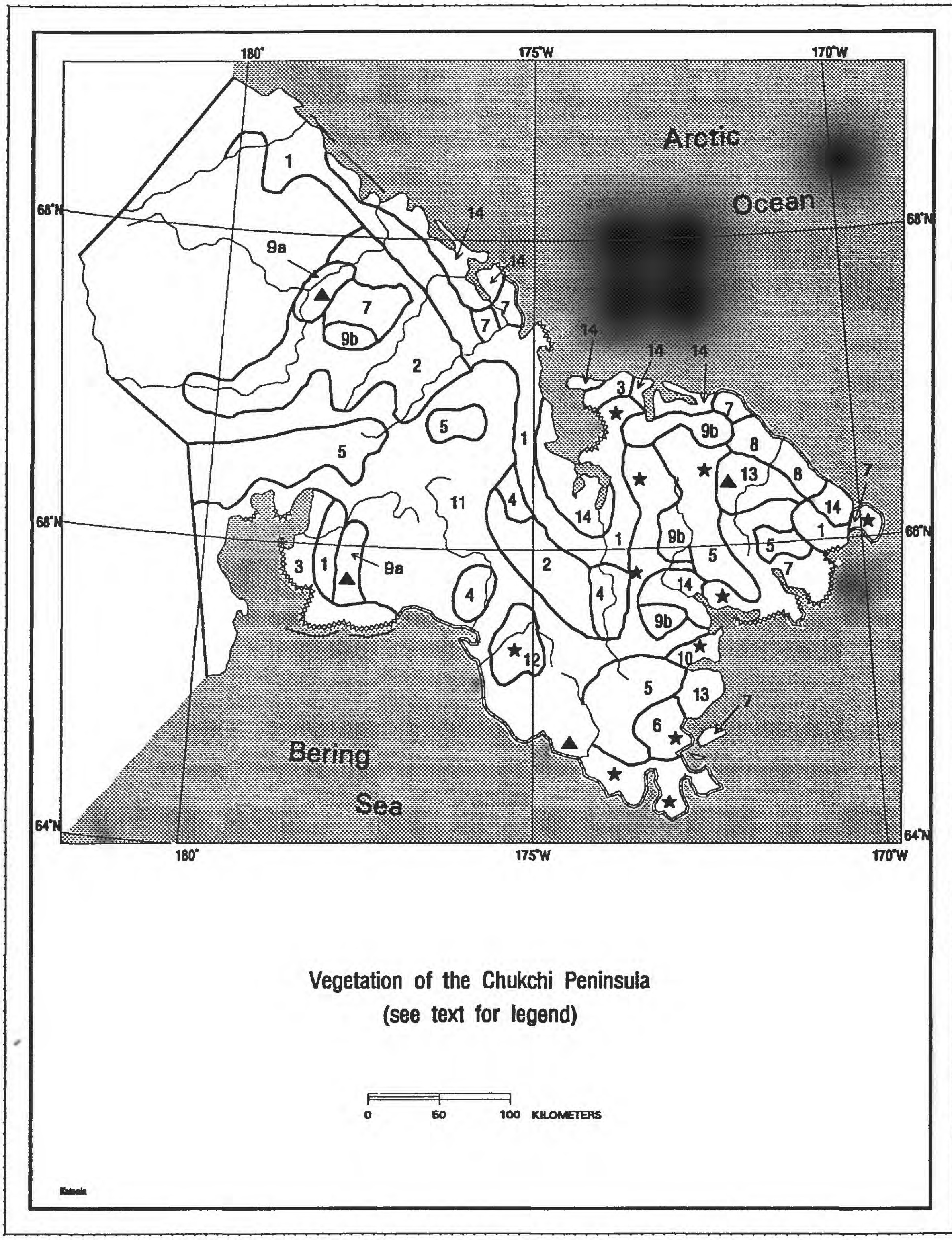

Figure 1. Dominant-biomorph vegetation map of the Chukchi Peninsula (see text for description of each type).

IV. GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING

NORTH SLOPE BOROUGH GIS: THE CREATION OF A MULTIDISCIPLINARY INFORMATION SYSTEM THAT REFLECTS THE NEEDS OF THE INUPIAT PEOPLE AND THE NORTH SLOPE BOROUGH

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The North Slope Borough (NSB) was incorporated following the 1972 Alaska Native Claims Settlement Act. The NSB comprises over 91,000 square miles in Northern Alaska (USA). There are 8 villages with 6,000 residents, of which 80 percent are Inupiat Eskimo. Barrow is the largest village with 3,000 residents and is the NSB's center of government. The goal of North Slope Borough was self determination. The residents wanted to benefit from the resources that were being taken from the Slope, primarily energy related, and improve the standard of living of its people. At the same time they wanted to preserve their cultural identity and subsistence lifestyle.

The NSB Geographic Information System (GIS) was started in 1981 to help the Inupiat people address these issues. Working in cooperation with State and Federal agencies the NSB GIS pioneered data collection techniques and GIS technology. Over the past 13 years a substantial amount of information has been assimilated in the form of digital databases. In 1991, the facility moved to Barrow from Southern Alaska (Anchorage) to allow resident access and better decision making support. This information ranges from biological data, such as caribou habitat and vegetation mapping, to a traditional land use inventory that reflects the use and perceptions of the land by the Inupiat.

The circumpolar people are known as the Inuit. They inhabit the northern most regions in Russia, Greenland, Canada, and the North Slope of Alaska. Due to changes in the political arena and efforts by the Inupiat, they have once again united as a people with shared cultural identity and similar concerns.

Because of the importance of a healthy environment to the Inupiat people, and the effect of outside influences on their traditional culture, access and an understanding of ecological information throughout the circumpolar region is essential.

Our goals at the NSB GIS are to provide the tools and information needed to make responsible, ecological decisions. These includes:

(1) Producing educational and planning tools for the residents of the NSB.
(2) Integrating traditional knowledge and empirical knowledge into a cohesive database .
(3) Working with the Inuit Circumpolar Conference (ICC) and other native groups throughout the region in establishing research and project priorities.
(4) Acting as a central repository for data relevant to the NSB and circumpolar region.
(5) Aiding researchers in defining Inuit needs and priorities in scientific investigation and assist on project work.

There is a wealth of knowledge found in the Inuit culture as well as support for ecological research in the Arctic. The Inuit people and lifestyle should be considered when discussing all facets of the arctic environment as they are the residents of this bountiful land and ice.

INFORMATION ON THE RUSSIAN ARCTIC ECOLOGICAL ATLAS

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The deterioration of the ecological situation in Russia has become more serious during the last 10 years. Such a dramatic situation causes an increase of attention paid to the arctic region, the ecological reserve of Russia. A State scientific-technical project named "The Ecological Safety of Russia" was developed in 1993. Our work editing the *Ecological Atlas of Russian Arctic* is being done as a part of this project. More than 60 scientists from about 20 scientific institutions are taking part in this joint effort. More than 400 maps are proposed to be included in the atlas. These maps will describe various natural components of the arctic region, including the changes from anthropogenic pressure and possible predictions for future development. The average map scale will be 1:10,000,000. In addition, there will be many insert maps of smaller and larger scales.

The aim of the Russian *Arctic Ecological Atlas* is to:

(1) Reflect the current status of arctic and subarctic ecosystems;
(2) Show possible changes in ecosystems that may occur from various alterations in climate and anthropogenic disturbances;
(3) Show anthropogenic activity in the arctic;
(4) Study the possible ways disturbed ecosystems can recover;
(5) Organize the most rational land management to preserve flora and fauna biodiversity.

The atlas structure will consist of three parts:

Part A: Introduction
Part B: Natural-ecological potential and current condition of natural ecosystems
Part C: Anthropogenic activity and rational land management.

Terrestial natural systems will be described component by component. The map sets for each component will contain all the necessary information for work with vegetation. For instance, climatic features, distribution and characteristics of permafrost, information on ecologically significant soil features such as its acidity, characteristics of the root-zone of the soil layer, types of the soil cover structure, zonal, and regional peculiarities, and others.

The vegetation map set will consist of about 15 maps. An ecological-phytocenological map and an insert map of the subzonal subdivision of the tundra zone will show the topographical, zonal, and sectoral differentiation of arctic vegetation. This is intended to demonstrate the relationship between vegetation and physical geographical conditions by means of thermal latitudinal zonation (based on availability of summer warmth) and by showing the substrate lithology, permafrost, topography, soil types, and snow conditions. Coupled with pure vegetation, other features of each unit such as sensitivity to certain anthropogenic pressures, natural revegetation ability, and the utility of plant cover in its habitat (such as permafrost stabilization, or root prevention of soil erosion) will be reflected.

Several maps will show species cover of arctic vascular plants, and either the floristic subdivisions of the region or the northern limits of various life form distribution will be drawn (for instance, limits of open woodlands, single trees and shrubs, and others). Several maps on vegetation productivity (annual phytomass) or its geographical pecularities are also intended to be included in the atlas. A few maps will be dedicated to vegetation changes caused by anthropogenic disturbances.

A HIERARCHIC GEOGRAPHIC INFORMATION SYSTEM FOR NORTHERN ALASKA: INSIGHTS TOWARD A CIRCUMPOLAR ARCTIC VEGETATION MAP

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Introduction

We are in the process of building a hierarchic geographic information system for northern Alaska as part of the Arctic System Science Program (Walker and Walker, 1991). The hierarchy consists of three principal spatial domains: (1) plot level, 1-10^4 m^2 (maps at 1:10 scale), (2) landscape level, 10^4 to 10^8 m^2 (maps at 1:500 to 1:5,000 scale), and (3) regional level, 10^8 to 10^{10} m^2 (maps at 1:25,000 to 1:250,000 scale). At the plot-level, we are using permanent plots to (1) map and monitor species composition and vegetation structure to examine long-term changes in vegetation, (2) examine trends in species composition, soils, and site factors along environmental gradients, and (3) classify the vegetation according to the Braun-Blanquet approach. At the landscape level, we are making vegetation maps based primarily on photointerpreted information supplemented with detailed ground observations. At the regional level, we are using a combination of photointerpretation and classification of satellite-derived digital data. This paper summarizes what we have learned regarding the controlling environmental factors at the plot, landscape, and regional levels, with insights toward the development of a circumpolar vegetation map.

Controlling environmental factors for vegetation patterns

Plot scale

At the microscale, Cantlon (1961) defined the principal controls on vegetation patterns as those associated with the soil moisture and microsite gradients as influenced by microtopography, cryoturbation, winter snow depth, and small-scale disturbances. Although this scale is relatively unimportant to a circumpolar vegetation map, the species and their distribution patterns are very important to plot-based process-level studies that are being used to address global-scale issues and for landscape and regional analyses of biodiversity. It is, therefore, important that the classification developed for the circumpolar Arctic be hierarchically linked to vegetation units based on floristic criteria. The advantages of using an internationally accepted method of vegetation classification such as the Braun-Blanquet approach were outlined at the 1991 International Circumpolar Vegetation Classification Workshop (Walker and others, 1994b).

Landscape Scale

At the landscape level, vegetation patterns are largely controlled by soils and site factors that vary over distances of hundreds of meters. At this scale, vegetation patterns are defined by (1) longer topographic gradients associated with hillslopes, moraines, and mountains, (2) hydrologic features associated with small watersheds and water tracks, and (3) parent material associated with glacial, glaciofluvial, eolian, and marine events. Maps at 1:500 and 1:5,000 scales clearly show the patterns related to hydrological features and different age glacial surfaces. Large-scale disturbance features also have major effects on the overall productivity of landscapes. For example, at Toolik Lake, Alaska, the normalized difference vegetation index (NDVI) on different age glacial surfaces is strongly correlated with time since deglaciation (Walker and others, 1994a; fig. 1). The NDVI has been shown to be strongly correlated with biomass in moist tundra ecosystems (Shippert and others, 1994). Similar patterns are associated with loess deposits and river floodplains.

Regional Scale

The regional level is the most important with respect to development of a circumpolar map. At this level, regional temperature, floristic consideration, and large-scale substrate patterns are important.

Temperature

The latitudinal temperature gradient is compressed on the North Slope due to the presence of the cold Beaufort Sea and the Brooks Range, which blocks the flow of warm air from interior Alaska (Conover, 1960). Within 100 km of the coast, the mean July temperature increases from about 4°C at the coast to about 10°C at the northern edge of the Arctic Foothills and approaches 12°C in some valleys of the foothills. Along the coast, north of the 7°C mean July isotherm, the vegetation is dominated by wet sedge-grass meadows composed of *Eriophorum angustifolium*, *Carex aquatilis*, and *Dupontia fisheri*. At some extreme sites along the coast and on the off-shore islands, the vegetation has a High Arctic character with no low shrubs, open vegetation cover, and less than 100 vascular plant species. The region north of 7°C isotherm is within the arctic tundra subzone of Yurtsev (1994; subzone II of fig. 1, page 81). A few kilometers inland and south of the 7°C July isotherm, the dominant vegetation on upland sites consists of shrub-poor tussock tundra. Tussock tundra is better developed in the Arctic Foothills, where it dominates most landscapes. This region corresponds to the northern hypoarctic subzone of Yurtsev (1994; subzone III of fig. 1, page 80) and subarctic zone of Sochava (1962). Shrub tundra corresponding to Yurtsev's southern hypoarctic tundra is dominant in western Alaska and on favorable sites in the warmer sections of the Arctic Foothills, and in areas receiving higher amounts of precipitation (Yurtsev 1994; subzone IV of figure 1, page 80). Birch (*Betula nana*) and alders (*Alnus crispa)* are major components of many vegetation types in these areas.

Floristic considerations

The floristic influences, described thoroughly by Murray (1978), Young (1971), and Yurtsev (1994) define the regional floras that are shaped by climatic and environmental factors. Along a north-south gradient, the zones of Yurtsev (1994) and Young (1971) provide a good framework for the increase in floristic diversity with temperature. Along an east-west gradient, the influences of Asian and Beringian floras are quite strong, particularly in western Alaska, and decrease toward the east. Yurtsev (1994) has divided the Alaskan province of the Beringian Sector into two subprovinces. The Northern Alaska subprovince includes the more continental (central and eastern) parts of the Brooks Range, the northern foothills, and the arctic coastal region. The Beringian subprovince has a much richer flora and includes the Yukon River delta, the Seward Peninsula, and Lisburne Peninsula.

Substrate

Soil pH controls many large-scale patterns of vegetation related to a variety of disturbance factors, including loess areas, glaciated regions, and floodplains of the larger rivers (fig. 2; Walker and Walker, 1991; Walker and Everett, 1991; Walker and others, 1994). There is little overlap of dominant vascular plants, mosses or lichens in acidic and nonacidic tundra areas (table 1). Moist acidic tundra has high cover of deciduous shrubs, primarily *Betula nana* and *Salix planifolia ssp. pulchra*, and relatively low cover of barren frost scars (frost medallions). Areas dominated by deciduous shrubs have relatively high NDVI. In contrast, moist nonacidic tundra has relatively low cover of deciduous shrubs, more open plant canopies due to the presence of more frost scars, and relatively low NDVI. The distinctions between acidic and nonacidic tundra are so fundamental that they are the primary criteria for separating vegetation units at the second level of a vegetation classification hierarchy developed for the foothills region (table 2).

Satellite-derived classifications

It is generally not possible to use satellite data to interpret floristically-derived community types across very broad regions because different vegetation communities do not have distinguishing spectral characteristics. However, classifications of Alaskan tundra derived from Landsat MSS data suggest that most tundra landcover units can be derived from a combination of only a few spectrally distinct materials that do occur across broad regions, including open water, green deciduous vegetation (particularly deciduous shrubs), evergreen vegetation, light colored standing dead vegetation (particularly standing-dead graminoid leaves), and bare soil (fig. 3); (Walker and others, 1982; Walker and Acevedo, 1987). Spectral mixture analysis is a promising recently-developed technique for remote sensing, whereby the percentage of major components of the landcover can be determined for each pixel by considering each pixel's spectrum to be a linear combination of spectra of these components (Adams and others, 1986).

Integration of NDVI values derived from multiple advanced very high resolution radiometer (AVHRR) observations through the growing season portray seasonal biomass production (Goward and others, 1985). Integrated NDVI maps of Alaska display a clear trend of higher NDVI, indicating higher biomass, inland from the northern coast (Binnian and Ohlen, 1993). This is due to a combination of higher temperatures and the influences of other factors such as high cover of lakes on the coastal plain. Relatively low NDVI is seen in loess affected areas in the Prudhoe Bay area and the northern front of the Arctic Foothills and is thought to be caused by high relative cover of bare soil due to frost scars, high amounts of standing dead vegetation, and relatively low cover of deciduous shrubs. In northwestern and western Alaska, higher productivity of shrub-tundra vegetation is associated with a wetter and warmer summer climate.

Because biomass is such an important variable for numerous biogeographic and global change questions, it may be desirable to produce two maps at the same scale: one that displays patterns of NDVI derived from AVHRR data, and one that displays dominant plant communities as derived from photointerpretation and synthesis of existing maps.

Conclusions: toward a circumpolar vegetation map

(1) The tundra portion of Alaska forms a very small part of the total circumpolar arctic vegetation. However, climate gradients are strongly compressed here and the vegetation includes broad representations of most of Yurtsev's (1994) zones, except for Zone I (Polar Desert).

(2) At the regional level, important influences on vegetation patterns are
   (a) the major physiographic regions,
   (b) north-south latitudinal variation in primary production and floristic diversity (that is, Yurtsev's zones),
   (c) east-west variation in floristic composition (that is, Yurtsev's sectors), and
   (d) large-scale variation in substrate.

(3) The latitudinal gradient seems to follow the criteria established for Yurtsev's zones. However, the high biomass in wetter portions of northwestern Alaska suggests that temperature and precipitation need to be considered to establish a predictive relationship with biomass. Composite NDVI images derived from AVHRR data appear to accurately portray broad trends in seasonal biomass production across northern Alaska. This needs to be confirmed with more detailed ground observations.

(4) Yurtsev's sectors provide a good framework for separating the relatively depauperate flora of Northern Alaska, from the rich Beringian flora of western Alaska.

(5) Within these broad zones and sectors, regions of dominant vegetation can be delineated based on physiographic features, large landforms, and disturbance features. It may be possible to define a circumpolar set of terrain types that could be used to stratify the satellite-derived data. Boundaries separating the coastal strip, thaw-lake plain, foothills, and mountains are relatively easy to draw.

(6) We should consider making two circumpolar vegetation maps: one derived from AVHRR data portraying seasonal biomass production, and another derived from photo-interpretation and synthesis of existing maps that portrays dominant vegetation types.

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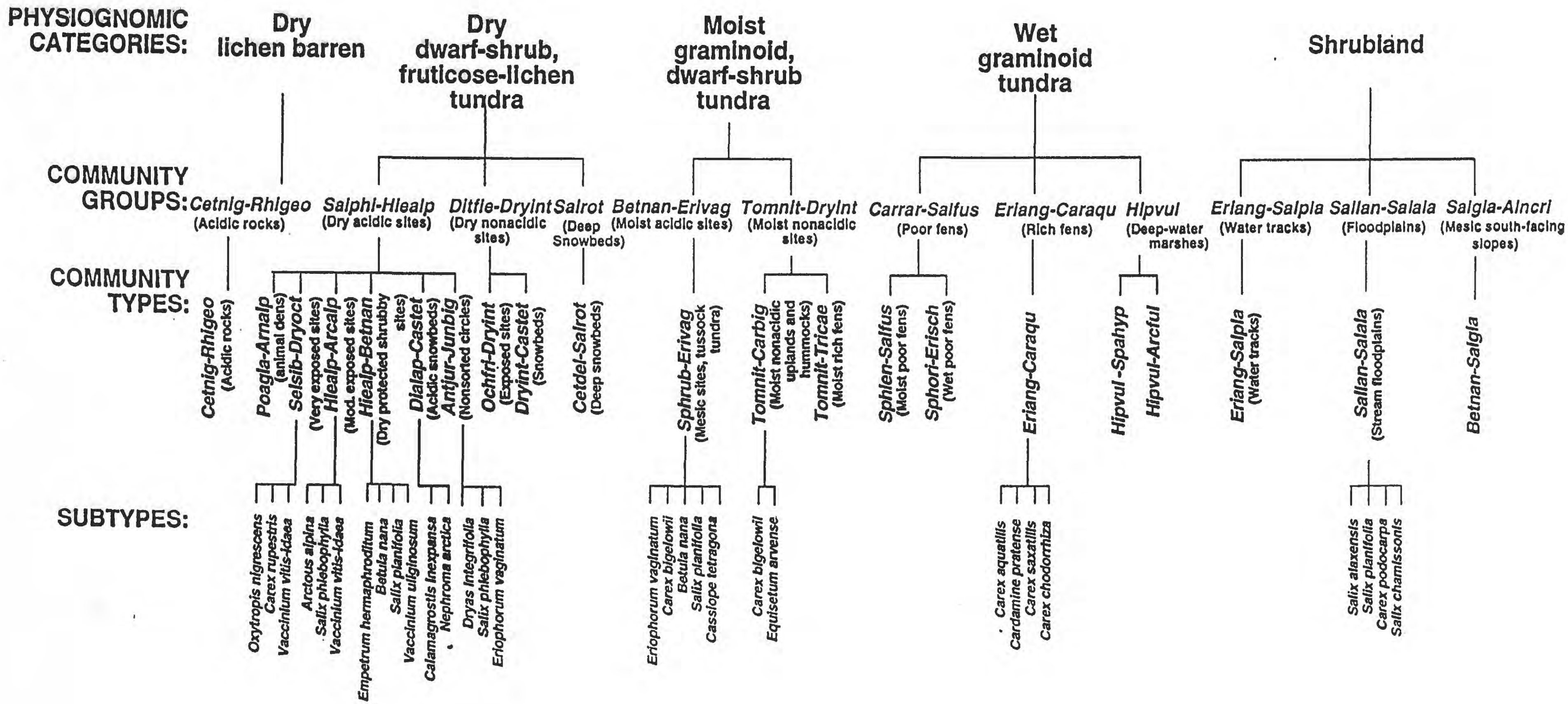
Table 1. Comparison of moist acidic and non-acidic tundras (Walker and Acevedo, 1987)

	Unit				
	IIIa Moist non-tussock-sedge, dwarf-shrub tundra	*IIIb* Moist tussock-sedge, dwarf-shrub tundra	*IVa* Moist tussock-sedge, mixed-shrub tundra	*IVb* Moist non-tussock-sedge, mixed-shrub tundra	*Vb* Moist low-shrub tundra
Character					
Soil pH	Neutral to alkaline	Slightly alkaline to slightly acidic	Acidic	Acidic	Acidic
Cryoturbation	Generally high	Moderate	Moderate to low	Low to moderate	Low
Soil flow (solifluction)	Low to moderate	Low	Low	Moderate	Low to moderate
Occurrence near coast (north of 7 °C July mean isotherm)	Common on mesic sites	Occasional on stable sites	Rare	Absent	Absent
Occurrence inland	Mesic stream banks and frost-active slopes	Moderately frost-active slopes	Abundant on all mesic acidic substrates and stable sites	Slopes with moderate solifluction	South-facing slopes and stable warm upland sites
Composition (partial list of important species):					
Low shrubs (0.2–1.5 m):					
Alnus crispa	0*	0	0	0	0–4
Betula nana spp. *exilis*	0	0	3	3	3–4
Ledum palustre spp. *decumbens*	0	0–2	3	3	3
Salix glauca	0	0–2	1	1	3
S. lanata ssp. *richardsonii*	0–2	0–2	1	1	2
S. pulchra†	0	0	3	3	3–4
Vaccinium uliginosum	0	0–2	3	3	3
Dwarf shrubs (< 0.2 m):					
Dryas integrifolia	3	3	1	1	2
Rubus chamaemorus	0	0	2–3	2–3	2–3
Salix arctica	3	3	1	1	2
S. pulchra†	0–3	2	3	3	3
S. reticulata	3	3	1	1	3
Vaccinium vitis-idaea	0	1	3	3	3
Graminoids:					
Arctagrostis latifolia	2	2	1	1	1
Carex aquatilis	0–3	1	0	0	0
C. bigelowii	3	3	3	3–4	2
Eriophorum angustifolium	3–4	3	0–3	0–2	2
E. vaginatum	1	3–4	3–4	0–2	2
Bryophytes:					
Aulacomnium palustre	2–3	2–3	3	3	3
Dicranum spp.	0–3	0–2	3	3	0–3
Ditrichum flexicaule	0–3	0–2	1	1	1
Hylocomium splendens	0–3	3–4	3–4	3–4	3–4
Polytrichum juniperinum	0–3	0–2	3	0–3	3
Ptilidium ciliare	0–2	0–3	0–3	0–3	0–3
Sphagnum spp.	1	1	2–4	2–4	2–4
Tomenthypnum nitens	2–4	2–4	2	0–3	1
Lichens:					
Cetraria cucullata	3	3	3	3	2–3
C. islandica	3	3	3	3	2–3
Cladina arbuscula	0	0–2	2–3	2–3	2–3
C. rangiferina	0	0–2	2–3	2–3	2–3
Dactylina arctica	3	3	3	3	2–3
Peltigera aphthosa	2	2	2–3	2–3	3
Thamnolia subuliformis	3	2–3	0–2	0–2	0–2

* 0 = absent; 1 = rare; 2 = occasional; 3 = frequent to abundant; 4 = dominant within the respective canopy layer.
† *S. pulchra* is listed as a dwarf shrub and a low shrub; near the coast it is prostrate; inland it grows up to 2 m tall.

Table 2. Hierarchic vegetation classification for the Toolik Lake and Imnavait Creek region. The community names are composed of two six letter taxa abbreviations, each of which includes the first three letters of the genus name and the first three letters of the species names (Walker and Walker, 1994).



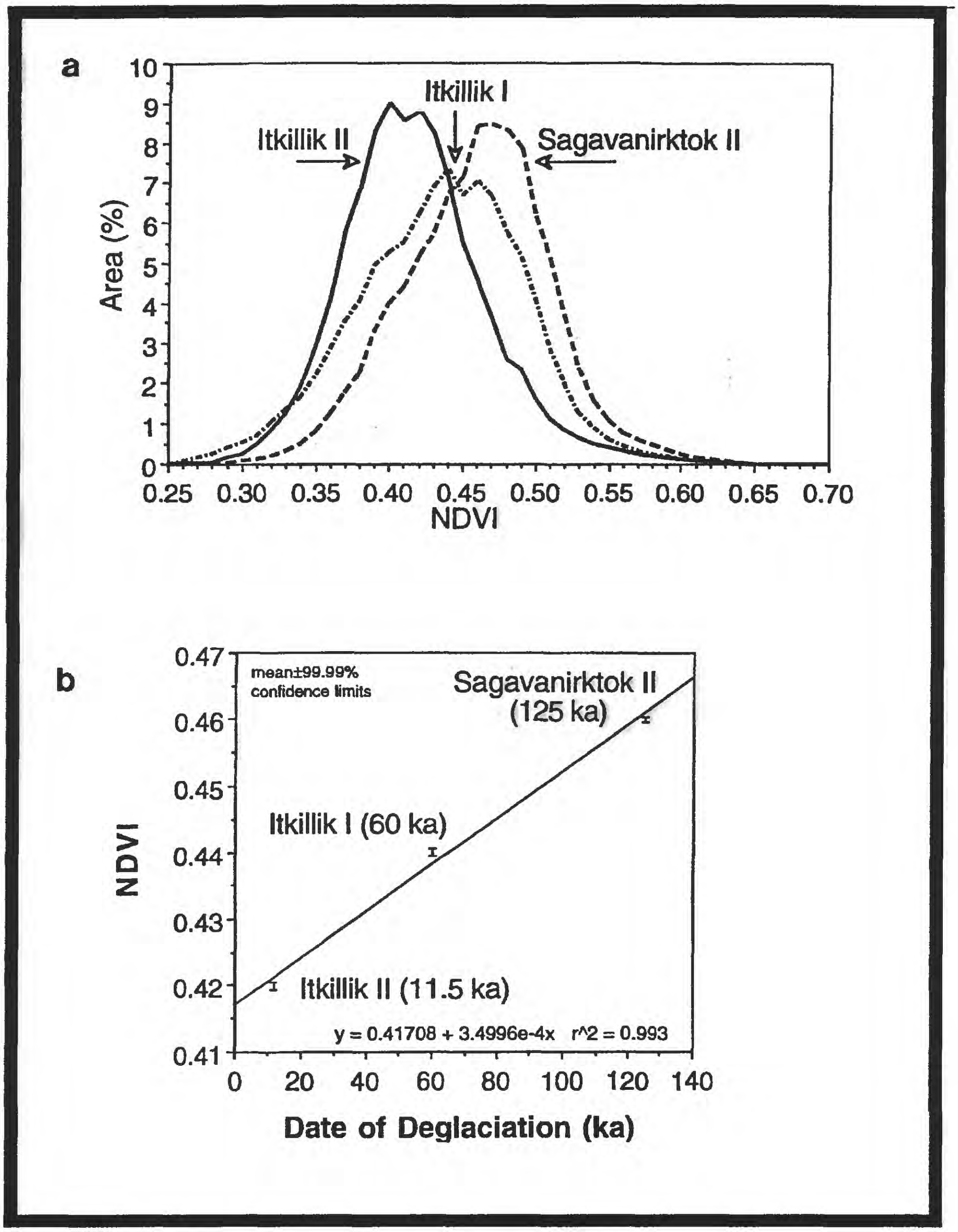


Figure 1. Distribution of NDVI on three different age glacial surfaces (a) in northern Alaska (approximate de-glaciation dates: Itkillik II, 11.5 ka; Itkillik I, 60 ka; Sagavanirktok, 125 ka.). NDVI vs. time since deglaciation (b). The reasons for this biomass-age correlation are complex and are thought to be due in part to the evolution of drainage networks (extensive willow shrublands in the stream channels and water tracks on older surfaces) and the development of moss carpets on upland sites that increase the water-holding capacity of the soils and the occurrence of deciduous shrubs. This same approach could be used to examine the relationship between NDVI and other natural disturbances such as age of floodplain terraces and effects of loess (Walker and others, in prep.).

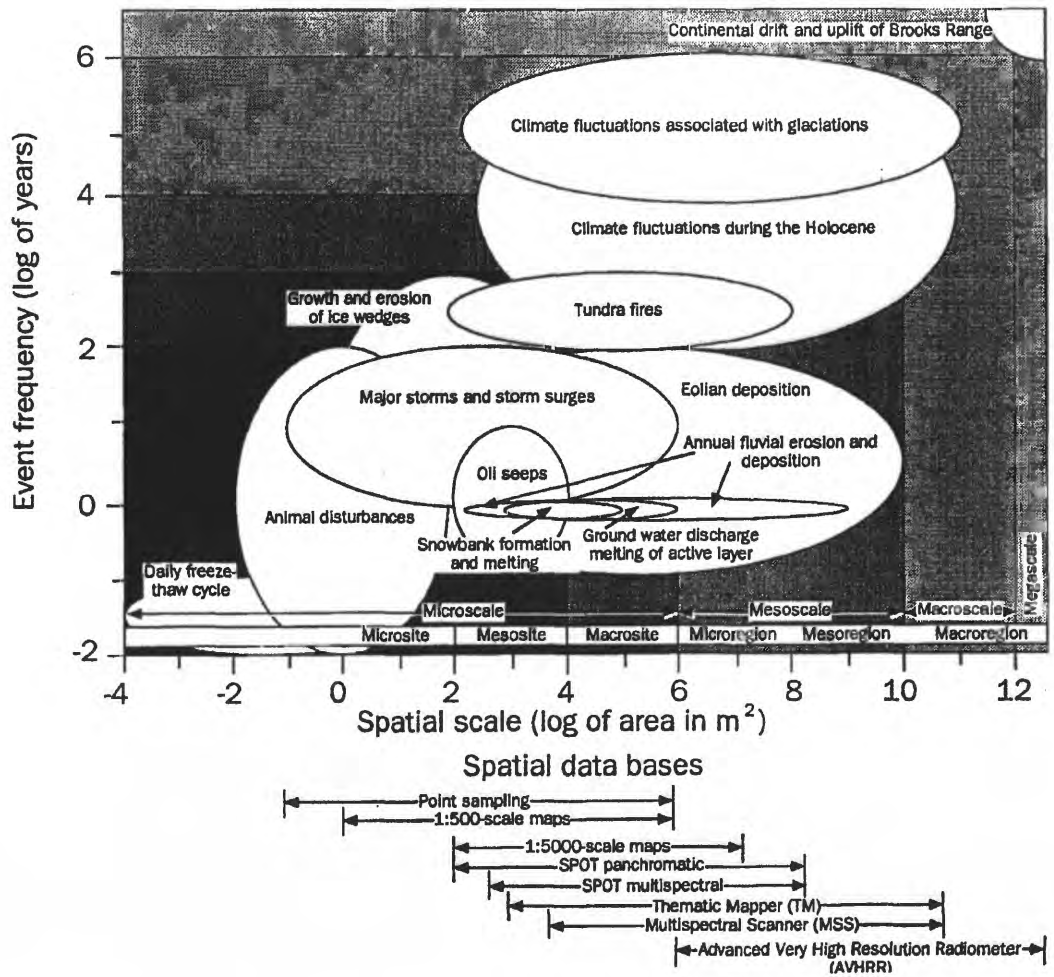


Figure 2. Spatial and temporal scales of natural disturbances in northern Alaska. Scales of various data collection methods are shown along the x-axis. The lower scales (left arrows) are the minimal sample area, or pixel size, of each sensor. The upper limit (right hand arrows) are the size of a standard image. Disturbances relevant for a circumpolar vegetation map at 1:5,000,000 are those of meso-region to macro-region size: climate fluctuations associated with glaciations, Holocene glaciations, eolian deposition, and fluvial erosion of the larger floodplains (Walker and Walker, 1991).

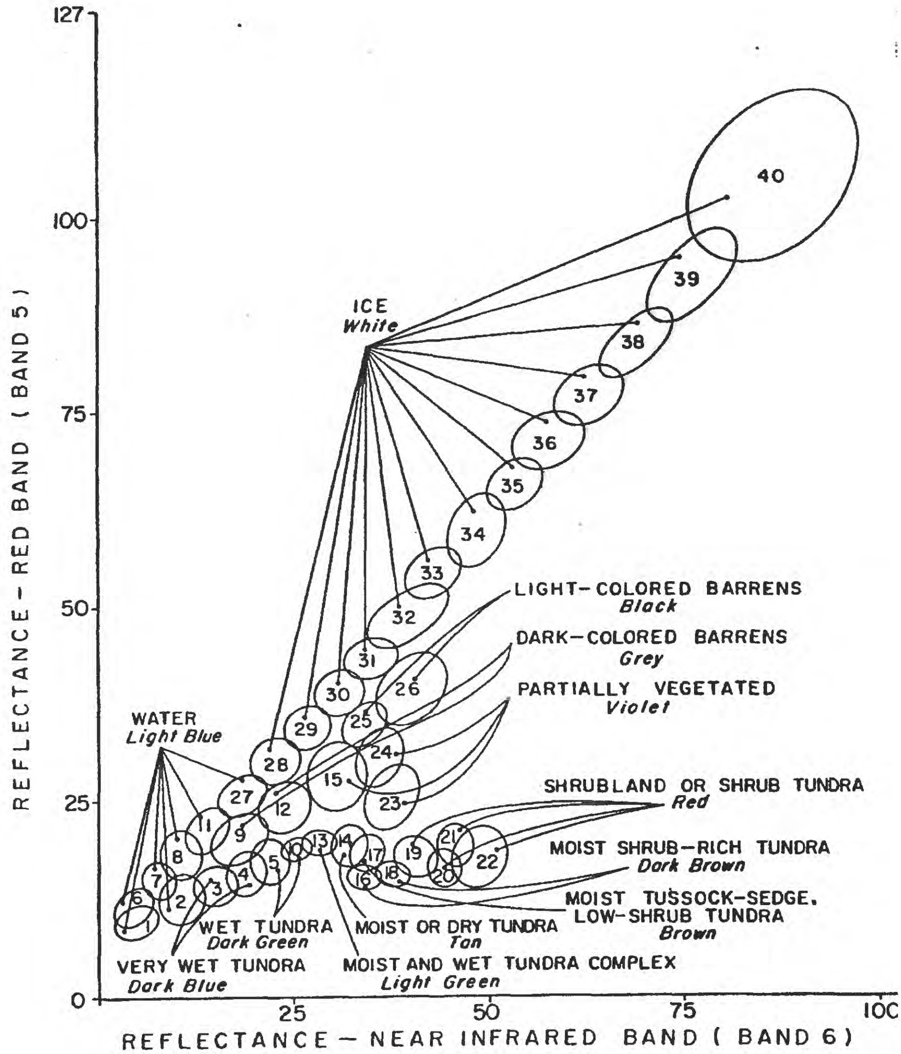


Figure 3. Cluster diagram for classification of the Beechey Point Quadrangle, Alaska. Each cluster represents a group of pixels with a range of reflectance values in the red and infrared bands. The pixels assigned to each cluster can be displayed independent of the other pixels. The dominant vegetation in each cluster was determined either from aerial photographs or from ground observations. A vegetation type was then assigned to each cluster. Similar patterns of clusters occur for all the tundra regions examined. Most of the vegetation types fall along an arc of clusters, whereby the left-hand portion of the arc consists of vegetation types that have increasing amounts of open water (open water at the extreme left, followed by aquatic vegetation an pond complexes, wet tundra, moist/wet complexes, moist tundra, and dry tundra: clusters 2-5, 10,13, and 14). At about the mid-point of the arc the vegetation types begin having increasing percentages of deciduous shrub vegetation. Deciduous shrubs have high absorption in the red band and high reflectance in the infrared band, such that further to the right along the arc, the vegetation is increasingly dominated by shrubs (tussock tundra, followed by shrub-dominated tussock tundra, and true shrublands on the far right; clusters 17-22; Walker and Acevedo, 1987).

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS: THEIR APPLICATION TO MAPPING CIRCUMPOLAR ARCTIC VEGETATION

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The circumpolar arctic is a large, relatively undeveloped region generally extending from the boreal forest boundary north to the pole. The boundary of the arctic has been subject to many different definitions. Problems associated with production of a Circumpolar Arctic Vegetation Map include acquisition of vegetation data in a cold climate, a short growing season, poor accessibility to the study area, and political and language barriers. Additionally, arctic vegetation scientists produce local and regional vegetation maps in their own language with project-specific legends, class descriptions and scales, all in locally preferred map projections. Difficulties in vegetation boundary delineation and data transfer from large scale to small scale also are of concern when combining this information into a standardized single map at an entirely new scale and projection. Remotely sensed data and geographic information systems (GIS) can be used to help minimize these problems and help produce a single, concise circumpolar vegetation map.

Plant associations tend to repeat themselves at various hierarchies across the landscape. Associations that are similar reflect similar spectral information that can be recorded by remote sensing instruments. The recorded spectral data can be used to provide information on vegetation physiognomy, structure, location, seasonal profile, and boundary delineation. These data may be obtained via aircraft and satellite systems and used in analog or digital format at a variety of scales. Aircraft derived data are normally useful for site specific mapping at large (1:25,000 and larger) and medium (1:25,000 to 1:100,000) scales. Color-infrared photography is most commonly used for vegetation mapping, although black-and-white photography is used if no other data are available or other objectives are involved. Scales may range from 1:6,000 to 1:100,000; optimum time of year for data acquisition is during peak greenness.

Satellite derived data are useful for regional and circumpolar mapping at medium, small (1:250,000 to 1:1,000,000), and very small (1:1,000,000 to 1:7,000,000) scales. Three satellite systems most commonly used for vegetation analysis are: Landsat, Satellite Pour l'Observation de la Terre (SPOT), and advanced very high resolution radiometer (AVHRR). Data acquired from satellite systems provide a means to inventory and document environmental conditions over large areas in a relatively short period of time (1 to 3 years) and with repeatable acquisition capabilities (table 1). They offer synoptic views of the landscape and can be analyzed manually or using automated image processing techniques. They can also be merged with other digital datasets or used in a geographic information system.

The GIS is designed to accept, organize, analyze, and display different types of information. Data may be accepted as spatial (points, lines, polygons, grid cells) or attribute (descriptive, qualitative, quantitative). Data may be put into a GIS at different scales and projects and analyzed at common map projections and scales. Data layers may be analyzed singularly or in multiples for an entire geographic area or a portion of an area. General capabilities of a GIS include:

(1) accepts data in one or more formats
(2) stores and maintains data in different or common geographic relationships
(3) searches, retrieves, and performs statistical analysis on one or more data layers
(4) performs modeling using different data layers
(5) produce new information on spatial associations not previously understood
(6) output analysis results in a variety of formats (tabular file, digital file, maps).

The use of a GIS in support of a circumpolar vegetation mapping project could prove to be very beneficial. Each respective country could begin converting their vegetation data into a common map legend using the map scales and projects they are familiar with. These different maps could then be recorded into a GIS and converted to a common map scale and projection for editing and edge matching. Upon completion of the draft maps, the information could then be plotted out at a final desired scale.

GIS databases may be developed on a local, regional, circumpolar, or global scale. An example of a regional database exists for Alaska. The Alaska Land Characteristics database contains time-series AVHRR data and its derivatives, land cover, topography, soils, permafrost, hydrography, geology, ecoregions, and mean annual precipitation. Two circumpolar databases nearing completion are the Conservation of Arctic Flora and Fauna (CAFF) and the Circumpolar Permafrost Map (CPM). The CAFF database will supply, among other things, information concerning vegetation in protected areas. The CPM database will contain information on location of permafrost, some of which extend beyond the Arctic.

Global GIS databases also may be useful sources in a circumpolar vegetation mapping project. Six common ones include: Digital Chart of the World (Defense Mapping Agency, 1992), Earth Topography -5 minute (NOAA/NGDC, 1992), Matthews Global Vegetation (Matthews, 1993), Major World Ecosystems (Olson, 1989), World Soil Database (Staub and Rosenzweig, 1992), and Global Hydrographic Dataset (Cogley, 1991). The information content and spatial representation of these data (table 2) are at very small scales (1:10,000,000 to 1:30,000,000) but may be useful for some applications.

Data derived via remote sensing and analyzed in a GIS may have many uses towards the development of a circumpolar vegetation map. Remote sensing information can be obtained by aircraft or satellites and used to produce vegetation maps, resolve boundary disputes, and provide biophysical parameters about the landscape. Existing map data or new data derived by remote sensing can be organized and analyzed in a common framework facilitating compilation of information to be presented, as well as final map production.

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Table 1. System parameters for SPOT, Landsat, and AVHRR multispectral satellite data

Satellite	Pixel Size	Ground Area	Repeat cycle
SPOT	20 m	60 x 60 km	26 days
Landsat	30-80 m	185 x 185 km	16-18 days
AVHRR	1.1 km	2500 x 1500 km	2-3 times/day

Table 2. Six common datasets in different global GIS databases.

Database	Resolution or Scale	General Data Content
Earth Topography - 5 Minute	5 min. x 5 min.	Average land and sea floor elevations
Matthews Global Vegetation	$1^\circ \times 1^\circ$	32 vegetation categories
Major World Ecosystems	1:30,000,000	44 ecosystem complexes
World Soil Database	$1^\circ \times 1^\circ$	Soils, texture, and slope
Global Hydrographic Data	$1^\circ \times 1^\circ$	18 different data layers (including type)
Digital Chart of the World	1:1,000,000	17 different data layers (including vegetation)

THE UNEP/GRID PROGRAM

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The global resource information database (GRID) is a system of cooperating centres within the United Nations Environment Programme (UNEP) dedicated to making environmental information more readily accessible to environmental analysts as well as international and national decisionmakers. Its mission is to provide timely and reliable georeferenced environmental information and access to a unique international data service to help address environmental issues at global, regional, and national levels. Environmental data are converted into integrated information usable by both national and international decision-makers and scientists anywhere in the world. Therefore, the GRID programme helps bridge the gap between scientific understanding of Earth processes and sound management of the environment.

GRID is coordinated from a programme activity centre (PAC) at the UNEP headquarters in Nairobi, Kenya, and is supported through the funds of UNEP, bilateral donors, individual national governments, and in-kind support from industry. The two UNEP-funded centres are GRID-Nairobi and GRID-Geneva, with other centres established in cooperating institutions in Brazil, Denmark, Japan, Nepal, Poland, Thailand, the United States, Western Samoa, and Norway. Each centre is responsible for acquisition, management and distribution of data in either a regional or thematic realm, and undertakes decision support activities relevant to its regional or sectorial role.

The long-term objectives of GRID are to: (a) enhance availability and open exchange of global and regional environmental georeferenced datasets, (b) provide UN and intergovernmental bodies with access to improved environmental data management technologies, and (c) enable all countries in the world to make use of GRID-compatible technology for national environmental assessment and management.

GRID-Arendal's strategy for arctic database development

The GRID node in Arendal, Norway was opened in 1989 as the fourth node in the GRID network and has been given responsibility for the polar and nordic regions. Since 1989, a goal of GRID-Arendal has been to establish and populate a digital database concentrating on environmental themes in the arctic. As a strategy to realize this goal, GRID-Arendal follows both long-term and short-term objectives toward digital data development and recovery.

The long-term objectives are to establish GRID-Arendal within the UNEP/GRID system as the main provider of environmental information for policy and decisionmaking on all matters relating to international environmental management of the arctic. Additionally, GRID-Arendal will strive to establish, maintain, and continuously develop an arctic environmental database.

More immediate objectives to be achieved within the next 3 years include: (1) orienting

GRID-Arendal toward expanding the GRID-Arendal arctic environmental database through transfer of datasets from cooperating institutions and projects, (2) contributing to the development of a comprehensive arctic environmental database, and (3) establishing project cooperation with relevant arctic institutions and international program. By adhering to a general strategy through a results-oriented approach, GRID-Arendal will be able to fulfill its primary responsibility of strengthening GRID-Arendal's position as the major GRID node responsible for the polar regions and the maintaining the GRID arctic database.

Major project initiatives at GRID-Arendal

The following descriptions provide a summary of GRID-Arendal's mapping and GIS activities within the arctic region. Each project will contribute to a comprehensive arctic environmental database and data directory. The information and products generated from these projects will be available through GRID-Arendal's information service, which manages distribution of datasets and provides online access for the retrieval of digital information.

International Northern Sea Route Programme (INSROP)

GRID-Arendal is assisting with the design and implementation of an environmental information system to evaluate the effects of increased commercial traffic through the Russian north-east passage. The information system is to serve as a common framework to organize both physical and biological data and as a tool to permit scientists and decision makers to investigate scenarios, such as consequence analysis, risk assessment, and sensitivity modeling.

Arctic environmental database for Europe and Asia

The Ministry of Environment in Norway has provided funds to GRID-Arendal to initiate a pilot study with select Russian institutions in an effort to develop an environmental database for the arctic region of Europe and Asia. The initial project focus will be on establishing a project advisory board, identifying key Russian institutions, and developing a strategy for data recovery. The overall objective of the project will be to build a comprehensive environmental database by targeting valuable Russian spatial datasets, converting data from analog to digital format, and making the data available to a world wide community.

Arctic Monitoring and Assessment Program (AMAP) and Conservation of Arctic Flora and Fauna (CAFF)

In support of the environmental protection strategy agreed upon by members of the arctic nations, GRID-Arendal is assisting the Arctic Monitoring and Assessment Program (AMAP) with the development of a project directory that will provide a comprehensive overview of environmental monitoring and research projects focusing on the arctic. In addition, GRID-Arendal is supporting the Conservation of Arctic Flora and Fauna initiative by developing a digital database for protected areas in the Arctic.

Circumpolar Ecozone Mapping Initiative

GRID-Arendal in concert with the U.S. Environmental Protection Agency, U.S. Geological Survey, and Environment Canada is pursuing the development of an ecoregional database for arctic and subarctic circumpolar areas. The projects objective is to expand the ecoregionalization framework to the circumpolar region through consistent methodologies across international boundaries. The goal of this effort will be to produce a consistent multipurpose ecological area map that identifies significant ecosystem components.

The Digital Chart of the World (DEW) data - arctic region

GRID-arendal has extracted the arctic region (that is, areas above the 50th parallel) from the Digital Chart of the World in the polar stereographic projection. The goal of the project is to provide users access to cut-outs from these data for any desired area in the Arctic. The Digital Chart of the World is based on the U.S. Defense Mapping Agency's operational navigational chart series and contains a variety of basemap information including drainage, road and utility networks, political boundaries, city locations, physiography, and hypsography.

ARCTIC ENVIRONMENTAL DATABASE: PROGRAMME FOR THE RUSSIAN FEDERATION

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Moscow State University (Russia), the World Conservation Monitoring Centre and the Scott Polar Research Institute (Cambridge, United Kingdom) have begun a collaborative environmental project. The project is aimed at the developing a georeferenced Arctic environmental database to describe the biodiversity resources and the threats to their conservation, as well as other environmental phenomena that reflect the links of arctic ecosystems to global and regional ecological processes. The database will be compiled and made available through a geographic information system (GIS) facility established at Moscow State University. Data will be drawn from existing published information, remote sensing, and field work on factors such as biogeography, protected and environmentally sensitive areas, glaciological features, environmental threats, human settlements, and economic activities. Particular attention will be paid to biodiversity resources of the Arctic such as breeding areas for migratory birds, mammals, and freshwater fish distribution.

The pilot phase of database development will assess data needs and develop data collection techniques for the Kola Peninsula. The main implementation phase will extend coverage to the rest of the Russian Arctic. The interpretation of multispectral satellite imagery will be conducted at Scott Polar Research Institute and at Moscow State University. The field work will be carried out in Monchegorsk and Kirovsk areas to calibrate the methods for evaluating the composition and state of arctic vegetation by spectrometric data. The pilot GIS project, focused on the Kola Peninsula, will be implemented to identify the potential users and their requirements, develop relevant database architecture, and define hardware and software configuration.

Upon completing the project, data will be made available to the global user community through the digital Biodiversity Map Library developed at the World Conservation Monitoring Centre. The Russian database is intended to be a precursor to a wider program covering all eight sovereign nations of the Arctic. It is therefore intended to concentrate on criteria, methodology, database structures, communication, and data sources and types. By doing so, a relevant experience will be gained on the usefulness of data and on the issues associated with geographical data handling, such as data access, quality, error, uncertainty, and integration. The database development will be coordinated with other initiatives in the remaining arctic countries.

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THE INTERNATIONAL DATABASE ON THE ARCTIC ENVIRONMENT: PROBLEMS AND PROSPECTS

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Dear colleagues, ladies, and gentlemen:

Russia, among eight arctic countries, signed the declaration for the Arctic Environment Protection Strategy (14 June 1991, Rovaniemi, Finland) and thus, adopted the obligations of the joint plan of activities included into the strategy for protecting the arctic natural environment. In accordance with the results of the Meeting of Ministers in Nuuk (1993), The Ministry of Environmental Protection of Russia is developing a strategy to implement the obligations of the declaration, in particular the Arctic Monitoring and Assessment Program (AMAP) and data exchange issues.

At present, a great body of information is available at different institutions of Russia studying the Arctic and the North. However, the information is nonsystematized and rather inaccessible because most of the data are in different branches of national institutes subordinated to various departmental services. It is in various formats, mainly in analogue form.

To integrate the departmental services available in Russia to observe the national environment state (including the observational network of Rosgidromet, Roscomzem, Roscomnedra, and others) as well as their methodological, metrological, and information contiguity, the Russian government adopted in November 1993 the statement "On Establishing the United Federal System of Ecological Monitoring of Russia." This statement entrusts the Ministry of Environmental Protection of Russia with coordinating the activities of ministries, departments, institutions and organizations that monitor the natural environment; creating a database on the natural environment and resources; and establishing ecological information systems and providing for their operation.

To harmonize measurements of environmental protection and ensure integration into international ecological information systems, in 1991 The Ministry of Environmental Protection appealed to the Government to be included into the United Nations Environmental Program/GRID (Global Resources Information Database) System.

The GRID System makes it possible to :

(1) Make data on the national environment accessible to broadest possible community of national and international users in an easily understandable and accessible form.
(2) Centralize access to data available in a number different environmental monitoring databases.
(3) Regulate geographically referred datasets on the basis of the GRID System allowing for transmission of information to decisionmakers in the areas of environmental protection in the most appropriate format.

The GRID/Arendal Center (Norway) is responsible for collecting, processing, and submitting information about the state of the natural environment in Northern countries, adjoining seas, and the Arctic region. In this connection, the Ministry supported the initiative of the GRID/Arendal Center and its Director General Dr. Svein Tveitdal to organize the joint project "The Database on the Arctic Natural Environment for Europe and Asia."

To implement the first phase of the project, the International Workshop was held (1-3 September 1993, Norway) with 11 circumpolar countries participating. The participants decided to establish an international reference base of Arctic natural environmental data (International Arctic Environmental Data Directory, IAEDD) consisting of interrelated units in Arctic and in other countries engaged in studying the Arctic. The International Steering Committee for IAEDD was also established. From Russia , this Committee is represented by Prof. N.G. Rybalsky, Deputy Minister of Environmental Protection and Mrs. O.A. Novoselova, Head of the Department for Ecology Monitoring.

At the next meeting of IAEDD (December 7-10, 1993, San Francisco) the delegates discussed comparison, assessment and coordination of the available data catalogues (IAEDD, ASTIS, GRID) including standardization of access mechanisms (using the INTERNET network), data exchange formats and quality assessment.

In the framework of implementing the agreements made concerning the database (catalogue) on the Russian Arctic, the Russian Ministry of Environmental Protection is carrying out the following coordination work:

(1) Inventory of the available data sources (including departments, research institutes, research groups, and other data sources). The inventory is being done by means of detailed questionnaires designed to determine data sources, formats, data bank characteristics, possibilities of remote access, and integration into international systems.
(2) Establishment of the National GRID/Moscow Center and its infrastructure including northern sectorial centers to ensure effective communication with national databank organization and integration into international ecological information databases.
(3) Organization of studies within the AMAP Programme taking into account possible international cooperation, creating data banks in standards and formats recommended by IAEDD.

The Federal Programme "The Ecological Security of Russia" administered by Ministry for Environmental Protection of Russia, has collected a considerable amount of data from different organizations on many Arctic basin concerns including ecological monitoring, ecological mapping, developing GRID technologies (including the integration of remote sensing monitoring data). At present, the Federal Strategy Programme on Protection of the Arctic and North Natural Environment is being established as well as a short-term program for protecting the Arctic natural environment. One section of this program is designated for compiling a map of Russian arctic vegetation.

A circumpolar map of Arctic vegetation created by synthesizing the classic methods for botanical mapping with the possibilities of modern computer technologies (including GIS, GRID, and remote sensing methods) would allow balanced collection and exchange of data and increased information access, which in turn would meet the demands for studying and natural environment protection planning on the national and international level.

Suggestions for draft resolution of the Circumpolar Arctic Vegetation Mapping (CAVM) Workshop:

1. To set up an International Executive Committee (IEC) for the development of the CAVM that would include representatives of circumpolar countries.
2. To charge the IEC with the coordination of participating countries using GIS technologies and incorporating remotely sensed data.
3. Taking into consideration the current activities in the creation of the International Environmental Arctic Database, to examine the feasibility for using environmental monitoring data for the CAVM, including the data on human-induced damage to vegetation that can be partly assessed on the basis of remotely sensed data analysis within the GIS framework.

The Ministry of Environmental Protection of Russia is able to provide a list of the institutions involved in creating environmental vegetation maps or researching vegetation monitoring, or both, using remote sensing methods and GIS technologies.

Appendix A

Walker, D.A., 1995, Toward a new circumpolar arctic vegetation map: St. Petersburg workshop: Arctic and Alpine Research, v. 27, p. 103-104. Reprinted with kind permission from the Editor of Arctic and Alpine Research, Boulder, Colo.

Information

TOWARD A NEW ARCTIC VEGETATION MAP: ST. PETERSBURG WORKSHOP

The Arctic is in many ways a single natural unit, with many common ecological and political interactions. A new map and series of derived products is needed for a wide variety of important circumpolar issues, including studies of arctic biota and biodiversity, arctic ecosystems and their interactions with the global climate system, land-use planning by circumpolar native peoples, planning for international protected areas, and education. A new circumpolar vegetation map would provide a common legend and language for the ecosystems of the arctic region. It would also be a key component of circumpolar geographic information system (GIS) databases. As a first step toward a new map, the Circumpolar Arctic Vegetation Mapping Workshop was held in St. Petersburg, Russia, 21–25 March 1994. The 51 participants reviewed the status of vegetation mapping in each of the circumpolar countries, formulated a strategy for making a vegetation map database, and developed a framework for the vegetation map legends.

The idea for a circumpolar arctic vegetation map grew from an earlier International Workshop on Classification of Circumpolar Arctic Vegetation held in Boulder, Colorado, in March 1992, where the attendees recognized that our knowledge of arctic vegetation has increased markedly in recent years and that no single existing classification or map accurately portrays the synthesis of existing knowledge (Walker et al., 1994). Several coarse-scale (greater than 1:10,000,000) vegetation maps exist for the Arctic as part of global vegetation databases. The scales of these maps are, however, too coarse for regional modeling efforts. Similarly, many more detailed vegetation maps portray relatively small areas of the Arctic. The weaknesses of this collection of maps are that they entail many different scales and classification schemes, are derived using different mapping techniques, and are often constrained by political boundaries. For regional or global extrapolations, all the maps must be generalized to the lowest common denominator, so that the power and information contained in the original high-quality data sets are lost.

The participants at the St. Petersburg workshop agreed that a new map should be derived from an electronic map database that contains the latest state of knowledge and could be updated as new information comes available. Currently there is a need for two types of vegetation maps, one that displays the circumpolar distribution of biomass, and a second depicting regions with characteristic sets of vegetation types based on plant physiognomy and floristic composition. The first is important for numerous studies related to global carbon budgets and climate change and can be derived rather quickly using remote-sensing technology. The second requires the synthesis of vegetation information contained in existing maps.

The boundaries on existing coarse-scale maps of the Arctic are very general and of marginal use for global GIS databases. The new vegetation map will be tied to global satellite-derived spatial databases and digital terrain models. One of the products of the project will be a false-color mosaic of cloud-free composited false-color images from the Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA satellites (1.1-km pixel resolution). The image will be a polar projection of the terrain north of 50° latitude, and will be used as a base for the vegetation mapping. The first map products will utilize a Lambert azimuthal equal-area projection of the circumpolar region at a scale of 1:7,500,000. At this scale, the entire circumpolar Arctic north of treeline can be displayed on a single 100 × 100-cm map sheet. The projection is compatible with the US-Canada ecoregion mapping program and the circumpolar permafrost mapping projects.

A map of the normalized difference vegetation index (NDVI) will be prepared from the same data set as the base map for the vegetation-type map. The map will display the maximum NDVI value during the growing season for each pixel. The U.S. Geological Survey Earth Resources Observation System (EROS) Field Office in Anchorage, Alaska, will prepare both remote-sensing products as color hard-copy maps and in digital form on a CD-ROM.

To make the first synthesis map, regional experts will manually interpret regions with similar assemblages of vegetation classes. This will be done from combinations of aerial photographs and satellite images. Map-polygon boundaries will be interpreted from existing vegetation maps and guided by landscape units as they appear on false-color AVHRR images. Because this will be a synthesis, no field effort will be involved. Separate teams of scientists will work on vegetation maps for each of the circumpolar countries. Frequent communication between representatives from each country will be necessary to ensure uniformity of the maps. The separate maps will be assembled and recast into a single map with some simplification where necessary. Remote sensing and GIS technology now make map creation a dynamic process. The raw data can be continually updated and maps modified based on new information.

The legend will employ a combined floristic-physiognomic-ecological approach (Sochava, 1962) used extensively by the Komarov Botanical Institute. It will be a three-level hierarchic legend that will use a derivative of Yurtsev's (1994, in press) north-south floristic zones at the highest level of the hierarchy. The second level of the hierarchy will be derived from Yurtsev's (1994, in press) east-west floristic sectors. The lowest level of the mapping will be based on physiographic, geomorphic, and geologic boundaries that enclose areas with similar vegetation assemblages. The maps will also employ matrices of supplemental information that will characterize each map unit in terms of dominant phytosociological units, dominant and differential plant species, characteristic parent material, and geomorphic situation.

The participants agreed to collaborate on the following products:

1. A compendium of abstracts for the workshop in time for the Circumpolar Arctic Flora and Fauna meeting in Reykjavik, Iceland, September 1994. This is being published as an Open File Report by the U.S. Geological Survey and includes a review of the current status of arctic vegetation mapping in each of the circumpolar countries (Walker and Markon, in press).

2. A bibliography of arctic vegetation maps. This is being further pursued within the context of the Circumpolar Arctic Flora and Fauna (CAFF) project.

3. The first map products showing zonal divisions and sectors according to the scheme of Yurtsev (1994).

4. A map of the normalized difference vegetation index

(NDVI) integrated for an entire summer season for the Arctic region and displayed at 1:9,000,000.

5. A satellite-derived false color image of the circumpolar region in a snow-free state, which will be used as the base map for production of the vegetation map. The image will be produced at 1:7,500,000 scale using a Lambert equal area projection. Items 4 and 5 are being developed by the USGS/EROS Alaska Field Office. Both map products will be published in color and in digital form on CD-ROM.

The following are members of the Circumpolar Arctic Vegetation Mapping (CAVM) executive committee: Christian Bay, Denmark; Fred Daniëls, Germany; Eythor Einarsson, Iceland; Arve Elvebakk, Norway; Andrei Kapitsa, Russia; Sergei Kholod, Russia; David Murray, U.S.A.; Steve Talbot, U.S.A.; Skip Walker, U.S.A.; Boris Yurtsev, Russia; and Stephen Zoltai, Canada. The executive committee agreed to meet again at Arendal, Norway, in 1995 to present the progress on the legends. The workshop was funded by the U.S. Department of State through the National Fish and Wildlife Foundation as part of the Circumpolar Arctic Flora and Fauna (CAFF) project and the U.S. National Science Foundation as part of the Arctic System Science (ARCSS) program. For further information contact Skip Walker at the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado 80309-0450, U.S.A., phone 303-492-7303, email swalker@taimyr.colorado.edu.

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For the Executive Committee of the CAVM Project

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CURRENT RESEARCH AND TEACHING

Toward a new arctic vegetation map: a review of existing maps

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Introduction

A circumpolar arctic vegetation map and series of derived products are needed for a variety of current issues, including resource development, studies of arctic biota and biodiversity, arctic land-atmosphere, ice, ocean and human interactions, land-use planning, and education. A new map would provide a common legend and language for the ecosystems of the arctic region. It would also be a key component of circumpolar geographic information systems (GIS). At the Circumpolar Arctic Vegetation Mapping Workshop held in St. Petersburg, Russia, 21-25 March 1994, 51 participants from all the circumpolar countries reviewed the status of mapping north of the arctic treeline, and developed an approach to formatting a series of new maps. 15 papers by regional experts described the status of arctic vegetation mapping in each of the circumpolar countries (Walker & Markon in press).

Status of vegetation mapping

Alaska (S.S. Talbot)

A comprehensive bibliography concerning maps of arctic Alaska has recently been prepared (Talbot in press). At present, only one map covers all of arctic Alaska (Spetzman 1963; scale 1:2 500 000). There have been numerous variations derived from this map at similar scales (e.g. Küchler 1966; Anon. 1973). Until the late 1970s there were relatively few maps at larger scales. In response to increasing resource development, planning mandates, and wildlife-habitat studies, federal and state agencies sought efficient vegetation mapping methods to inventory regions within the Arctic at higher resolution.

Conventional photo-interpretation was used in western Alaska for 1:60 000-scale range surveys of Hagemeister Island (Swanson & Laplant 1987), Nunivak Island (Swanson et al. 1986) and the Seward Peninsula (Swanson et al. 1985) and habitat analysis in the Hazen Bay, Yukon Delta National Wildlife Refuge (Tande & Jennings 1986) and northwest Alaska (Becia 1987). Concurrently, satellite, multispectral-scanner (MSS) data became available, influencing the direction of research by providing a new tool to inventory large areas of public lands. Vast Arctic landscapes were mapped using satellite images at intermediate scales (mainly 1:250 000). Consequently, maps covering the greatest portions of Arctic Alaska are at 1:250 000 scale.

Visually-interpreted Landsat maps were prepared for several national parks: Kobuk Valley (Racine 1976), Chukchi-Imuruk area (Racine & Anderson 1979), and Katmai Western Extension (Young & Racine 1978). Computer classification of satellite digital data was

Appendix B

Walker, D.A., Bay, C., Daniëls, F.J.A., Einarsson, E., Elvebakk, A., Johansen, B.E., Kapitsa, A., Kholod, S.S., Murray, D.F., Talbot, S.S., Yurtsev, B.A., and Zoltai, S.C., 1995, Toward a new arctic vegetation map: a review of existing maps: Journal of Vegetation Science, v. 6, p. 427-436. Reprinted with kind permission from the Editor of Journal of Vegetation Science, Opulus Press, Uppsala, Sweden.

done in several portions of western Alaska, including the Alaska Peninsula and Bristol Bay area (Wibbenmeyer et al. 1982), the Dillingham Quadrangle (Anon. 1987), Togiak (M.D. Fleming & S.S.Talbot, unpubl. 1982), and the Yukon Delta National Wildlife Refuge (S.S. Talbot et al. unpubl. 1986). Northwestern Alaska has been mapped by Craighead et al. (1988) and Nodler et al. (1978), with smaller areas mapped at Anvik/Bonasila (D.D. Osborne et al., unpubl. 1986), Buckland area (Adams & Connery 1983), Cape Krusenstern (Faeo 1993), Gates of the Arctic National Park (Wesser in prep.), Nulato Hills (Meyer & Spencer 1983), Kobuk Valley (Wesser 1994), and Selawik National Wildlife Refuge (Markon 1988). In northern Alaska, major mapping projects have occurred in the Arctic National Wildlife Refuge (Walker et al. 1982; Markon 1989; Jorgenson et al. 1993); the National Petroleum Reserve - Alaska (Morrissey & Ennis 1981; Spencer & Krebs 1982); and the Prudhoe Bay region (Walker & Acevedo 1987).

Large-scale studies of rather small areas are scattered throughout Arctic Alaska. For the Aleutian Islands, vegetation maps exist for Bogoslof I. (Byrd et al. 1980), Buldir I. (Byrd 1984), Amchitka I. (Amundsen 1972), Atka I. (Friedman 1984), and Simeonof I. (S.S. Talbot et al. unpubl. 1984). Other maps of western Alaska include St. Paul Island and Pribilof Is. (G.V. Byrd & N. Norvell, unpubl. 1988). In northern Alaska, large-scale maps include Atkasuk (Meade River, Komárková & Webber 1980), Prudhoe Bay (Walker et al. 1980), Barrow (Walker 1977; Webber 1978); Markon 1992), Imnavait Creek (Walker et al. 1989; Walker in press), Mirth-Mancha (Mouton & Spindler 1980), and Okpilak River delta (Spindler 1978).

Most of the intermediate scale maps and many of the large-scale maps reflect the structure of the vegetation and are sometimes supplemented with ecological information. A statewide vegetation classification (Viereck et al. 1992) has been developed, but has not been consistently applied in tundra regions, and there is an unevenness in coverage and mapping scale. Despite these shortcomings, it should be possible to use intermediate scale maps of large areas, and large scale maps of small areas, as guides to interpret Advanced Very High Resolution Radiometer (AVHRR) (1.1-km pixel resolution) digital data from the NOAA (National Oceanic and Atmospheric Administration) satellites.

Canada (S.C. Zoltai)

Vegetation of arctic Canada has not been mapped on a systematic basis This may be due to the fact that no single government agency is responsible for inventorying the natural vegetation. This resulted in a large number of botanical or floristic studies in small areas scattered throughout the arctic without an effort to synthesize them into vegetation maps of large regions, except on a very broad, general level (Anon. 1966, 1971). Broad-scale generalizations were based on such regional studies (e.g. Bliss 1979; Edlund 1983).

In the absence of a systematic effort, vegetation mapping has been opportunistic. Botanists attached to the Geological Survey of Canada have produced a number of vegetation maps (Barnett et al. 1975; Edlund 1982a,b,c, 1990; Tarnocai et al. 1976; Thomas et al. 1979; Vincent & Edlund 1978; Woo & Zoltai 1977). A landscape-vegetation map of Labrador, including its arctic-alpine part, was prepared by the Lands Directorate (Lopoukhine et al. 1977). Environment Canada also instituted a program of landscape and vegetation mapping (Anon. 1980), but this initiative was not pursued. Additionally, as a first step in evaluating areas for potential national parks, vegetation maps were prepared for Parks Canada, mainly as unpublished reports (J.P. Kelsall et al. in 1970; V. Woo & C.S. Zoltai in 1977, C.S. Zoltai et al. in 1979, 1980a,b, 1981 and 1983), but also as publications by the Canada Wildlife Service (Zoltai et al. 1987; Zoltai et al. 1992). Other mapping projects were carried out by universities resulting in the mapping of small areas (Arkay 1972; Beschel 1970; Muc & Bliss 1977; Muller 1963; Ritchie 1962). During the 1970s and 1980s, proposed pipeline developments initiated a number of vegetation studies, but these did not result in mapping projects. In addition to the mapped areas, there are dozens of small areas where the vegetation was analyzed and classified. Such information, along with the already mapped areas, could be used for ground reference information for satellite-derived classifications.

As most of the vegetation maps were created to describe specific areas, there was little effort made to develop a common vegetation mapping system for all of arctic Canada. The detail of the vegetation units was dictated by the scale of mapping; most units combined vegetation morphology and common species into their legend. Such terms as high shrubs, low shrubs, dwarf (prostrate) shrubs, graminoids, wet meadows, etc., were commonly used in combination with species. The amount of bare soil, when created by cryoturbation or desert processes, was often indicated.

Greenland (C. Bay)

Only a few research institutions in Denmark have dealt with vegetation mapping in Greenland, mainly the Greenland Botanical Survey (GBS), Greenland Environmental Research Institute (GERI), and the Geographical Institute, University of Copenhagen. No strategy for mapping the vegetation of all Greenland exists. However, in the last decades, regional vegetation mapping has been carried out in different parts of Greenland as part of biological projects that had objectives other than vegetation mapping, such as environmental monitoring of oil exploration, impacts of sheep farming, and studies of foraging dynamics of herbivores. Different techniques have been used, and both biologists and geographers have been involved, resulting in maps of different scale and size. Only a small part of the vegetated areas of Greenland is mapped in any detail.

In Northeast Greenland, the Ministry for Greenland initiated environmental investigations in the early 1980s in connection with a planned oil exploration on Jameson Land. This project included mapping of the largest lowland in High-Arctic Greenland. Totally, 265 detailed maps at 1:25 000 scale, each covering 25 km^2, were produced using aerial photograph interpretation (Bay & Holt 1986). This was the largest and most detailed mapping project ever carried out in Greenland. SPOT-1 and Landsat TM (Thematic Mapper)-based vegetation maps of selected areas in Jameson Land were later produced in order to compare methods (Mosbech & Hansen 1994). The conclusion was that satellite-based vegetation mapping was inadequate for mapping of vegetation classes covering less than a few hundred m^2. However, it was possible to distinguish 10 vegetation classes using the satellite data compared to 14 classes using aerial photos. In 1988-1990, a privately sponsored 3-yr mapping project was carried out in the National Park in North and Northeast Greenland, using a NOAA-satellite-based approach (Bay 1992; Bay & Fredskild 1990; Hansen & Søgaard unpubl.). This gave information on distribution of important biological areas, such as vegetated areas with large populations of terrestrial herbivores. In addition, ground reference data were obtained for a SPOT-satellite-based vegetation classification (Bay & Fredskild 1991). The vegetation index distinguished seven categories, but since the vegetation is very patchy and mosaic-like, the interpretation was difficult. False-color aerial photographs at 1:86 000 scale from most North and Northeast Greenland are available for future mapping projects.

In North Greenland, false-color aerial photographs magnified to a scale of 1:20 500 were interpreted as part of an environmental reconnaissance (Aastrup et al. 1986).

In West Greenland, three areas have been mapped using aerial photographs or SPOT data as part of a management plan for a local community and for projects concerning distribution of caribou and muskoxen habitats. A vegetation mapping project covering most of southern West Greenland is under preparation in connection with monitoring caribou and muskoxen habitats. Initially, it will be based on NOAA data, and for more detailed vegetation maps, SPOT satellite data will be used.

In South Greenland, the vegetation of the protected Qingua-Valley has been mapped based on both aerial photos and Landsat MSS data, and a comparison of the methods has been performed (Feilberg & Folving 1990). Aerial photos and analysis of satellite data have also been used in minor areas in South Greenland in connection with monitoring the impact of sheep farming.

F.J.A. Daniëls (in Walker & Markon in press) recently proposed a framework for mapping all of Greenland at small scales using six broad units based on the occurrence of classes of vegetation derived according to the Braun-Blanquet approach (Westhoff & van der Maarel 1978).

Iceland (E. Einarsson)

Vegetation mapping in Iceland started relatively late, but it is one of the few circumpolar countries to develop a map scheme for all its lands. In 1955, the Department of Agriculture of the University Research Institute, now the Agricultural Research Institute, started the field work for a 1:40 000-scale map of the actual vegetation of the grazing land Gnúpverkaaréttur in South Iceland, most of it found at an altitude above 300 m (Jóhannesson & Thorsteinsson 1957). The purpose was to provide information about the plant communities, determine the carrying capacity of the lands, evaluate their quality for agricultural use, and to provide a basis for wise planning and use of the land. The legend units, defined by S. Steindórsson, 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.

In 1961, a plan was developed to extend the mapping to the entire country, using the same legend and scale, which would result in a total of 289 maps. This ambitious work continued for 20 yr under the direction of Thorsteinsson and Steindórsson in the Agricultural Research Institute (Steindórsson 1981; Thorsteinsson 1981) At the beginning, the emphasis was on mapping the central highlands, which have for centuries been used for sheep grazing, but too often overgrazed, resulting in serious and extensive vegetation damages and soil erosion. From 1968, vegetation mapping was carried out in the lowlands as well, for the same purpose as earlier and for comparison of the highland and lowland areas. The mapping in the lowlands required extending the legends to include six main vegetation complexes: dryland vegetation, half bogs, bogs, fens, aquatic vegetation and land without vegetation. Land with mosaics of vegetation is classified as complex vegetation. The main vegetation complexes are divided into 15 orders and 91 sociations. This work resulted in maps of most of the uninhabited central highlands and some parts of the inhabited lowlands, but during the 1980s funding gradually declined. A total of 64 maps, mainly in the central highlands, have been published at a scale of 1:40 000 by either the Icelandic Survey Department or the Cultural Fund (Gudbergsson 1981; Steindórsson 1981; Thorsteinsson 1981). Another 32 maps at the same scale have been completed, but funds for publication are lacking. These maps were made with the help of a computer and the data reside in a digital database. Additionally, 28 maps, mainly of lowland areas, have been published at 1:25 000 scale, eight at 1:20 000 scale and a few at 1:10 000 scale. A total of about 60 % of Iceland is thus covered by vegetation maps in various stages of publication.

From 1991 to 1993, a group of specialists worked on a program to set up a geographic information system in Iceland (Thorsteinsson et al. 1993). Part of the group was devoted to vegetation mapping and is currently producing two experimental vegetation maps of part of South Iceland at 1:25 000 scale. The group recommended that the vegetation mapping of the country should be continued and completed within the next 10 yr by the Icelandic Museum of Natural History, as the Agricultural Research Institute is no longer interested in continuing the project.

So far, no vegetation map for all of Iceland has been made. The Icelandic Museum of Natural History has decided to make one in the near future, probably at 1:500 000 scale. This map will show the potential natural vegetation of the country, rather than the actual vegetation. A recently published satellite image of Iceland at 1:600 000 scale may be of a great help. Iceland is also found on the *Vegetation Map of the Council of Europe Member States* at 1:3 000 000 scale, and the *Council of Ministers Map of Physical Geographic Regions*. These maps are mainly based on natural vegetation.

Svalbard and Scandinavia
(A. Elvebakk & B.E. Johansen)

The classification presently used in Norway is that of the *Vegetation Region Map of Norway* made by botanists from four universities of Norway (1:1 500 000; Dahl et al. 1986). A simplified version was published by Moen (1987). A similar vegetation zone map was also produced for Svalbard (Brattbakk 1986), where the 'High Arctic' is defined as composed of a *Papaver dahlianum* zone and a *Salix polaris* zone, and the 'Mid Arctic' with a *Dryas octopetala* zone and a *Cassiope tetragona* zone.

Such vegetation zone maps do not show the spatial distribution of vegetation types, but instead areas with characteristic sets of vegetation types thought to reflect climatic conditions. Many areas are defined on the basis of species occurrences, as the distribution of species is better known than the distribution of vegetation types. Thus, it would be appropriate to use the terminology 'climatic-phytogeographical maps' as used by Tuhkanen (1984). The classic study of Fennoscandia by Ahti et al. (1968) includes the northern, middle, and southern boreal zones, a transitory hemiboreal zone, and the temperate zone. All alpine areas are called oroarctic. The circumboreal maps of Tuhkanen (1984) follow the same system, but include also a hemiarctic zone north of the boreal area.

Elvebakk (1985) mapped the zones of Greenland, Svalbard and adjacent part of Arctic Russia on a very coarse scale. The nomenclature adopted the major division of the Arctic in polar desert and arctic tundra as used by Aleksandrova (1980), and combined it with a subdivision of the arctic tundra in three parts parallel to the Fennoscandian division of boreal areas. Later Elvebakk (1989) made a more detailed zone map of Svalbard based on phytogeography, including a subdivision of the middle arctic tundra zone. The nomenclature is the same as in Elvebakk (1985), and this system was adopted by the standard Norwegian flora (Lid & Lid 1994) and by the Flora Nordica project - except that the hemiboreal zone will be renamed the arctoboreal zone.

Only minor parts of Svalbard have been mapped using satellite data. Øritsland et al. (1980) tested the use of Landsat MSS data in the Isfjorden area, and Spjelkavik & Elvebakk (1989) used Landsat TM data to detect reindeer winter grazing areas on mountain plateaus in the Gipsdalen area, and Elven et al. (1990) presented a vegetation map of Bünsow Land, also in central Spitsbergen. This study also included a hierarchical classification key for satellite data interpretation. Spjelkavik (1994) compared satellite based mapping with traditional methods based on aerial photographs. Finnmark in northernmost mainland Norway has been more extensively mapped by use of remote sensing data. Today the whole Finnmark county and the northernmost parts of Tromsø are mapped based on Landsat TM data (Johansen in Walker & Markon in press).

More detailed large-scale maps were produced during the Norwegian MAB (Man and the Biosphere) project. Five areas on Svalbard (Reinsdyrflya and

Lapponiahaløya in the north, Brøggerhalvøya and Lågdalsflya in the west, and Adventdalen in the central part) were mapped based on traditional use of aerial photographs and phytosociological principles (Brattbakk 1981, 1984, 1985a,b,c). The map scales range from 1:10 000 to 1:50 000. Thannheiser (1992) mapped areas in the north at 1:100 000 scale. In mainland Norway, the Norwegian Institute of Land Inventory keeps an updated list of all vegetation and land-use maps, and in the area defined as arctic there is only a series of three agricultural land-use maps.

Russia (S. Kholod & B.A. Yurtsev)

The St. Petersburg workshop was the first time since the 1975 International Botanical Congress in Leningrad that western scientists have had the opportunity to view all the major maps produced for the Russian Arctic. Some maps were previously classified for military reasons (e.g. maps of the Taimyr Peninsula; Shchelkunova 1975), and others have only recently been finished, including, northern Yakutia (Andreev & Shcherbakov 1989), and the Chukotsk peninsula (A.N. Polezhayev, unpubl. 1993). Unlike large regions of the Arctic in the western hemisphere, all of Arctic Russia has now been mapped at a relatively fine level of detail.

Vegetation mapping in Russia has old traditions connected with the names of V.B. Sochava and E.M. Lavrenko. The major centers of the vegetation mapping are the Komarov Botanical Institute (St. Petersburg), Institute of Geography of Siberia and the Far East (Irkutsk) and Moscow State University. Small-scale vegetation maps, created in these institutions, reflect all the vegetation north of the polar treeline, most notably the *Map of Vegetation of the European part of the USSR* (Scale 1:2 500 000; Isachenko & Lavrenko 1979), *Map of Vegetation of the West Siberian Plain* (Scale 1:1 000 000; Ilyina et al. 1976), *Geobotanical Map of the Nonchernozem Zone of the Russian Soviet Federative Socialistic Republic* (Isachenko et al. 1976), and the *Vegetation Map of the USSR for the Higher School* (scale 1:4 000 000; Belov et al. 1990). Most small-scale maps, covering the northern territories of Russia and created in the last 20 yr, were compiled according to a unified methodology. For example, on all of the above maps, the tundra zone, which is south of the polar desert or the high-arctic tundra subzone (*sensu* Yurtsev et al. 1978; Yurtsev 1994, in Walker & Markon in press), is subdivided into three subzones: arctic tundra, northern (typical) tundra, and southern tundra, and within each of them the regional variants are distinguished (e.g. Kola, East-European, Ural, West Siberian, etc.). A number of vegetation maps were created for separate parts of the Russian Arctic, such as: Kanin-Timan and Malozemelsk region (scale 1:1 000 000; Gribova et al. 1975), Novaya Zemlya (scale 1:7 000 000; Gribova 1975), the West Siberian Arctic (scale 1:1 000 000; L.I. Meltzer in Walker & Markon in press, and Yakutia (scale 1:5 000 000; Andreev & Shcherbakov 1989). The modern status of knowledge on the arctic vegetation of the European Russia is mirrored in the *Vegetation Map of Europe* (scale 1:2 500 000) being created now under the aegis of International Union of Biological Sciences (IUBS) and European Economic Community (EEC) (Neuhäusl et al. 1990).

Of special interest are the correlated ecology-phytocoenology map of Asian Russia (scale 1:7 500 000; Buks et al. 1977), where the mapped vegetation units are correlated with the duration of vegetative period and the total sum of active positive temperatures (> +10 °C); and the *Landscape Map of Northern Siberia* (scale 1:1 000 000; Melnikov & Moskalenko 1991) where the interconnections between the basic vegetation units and the geological, geomorphic and permafrost conditions are shown.

Middle-scale maps include the following: *Map of Vegetation and Forages of the Taimyr National Circuit* (scale 1:500 000; Shchelkunova 1975), *Map of Vegetation and Pastures of the Chukotka Autonomous Circuit* (scale 1:200 000; Polezhayev 1993, manuscript map), *Map of the Vegetation of the Northern Areas of Yakutia* (scale 1:500 000; Shchelkunova 1964-1965). The large-scale vegetation map of Chukotka was generalized up to scales 1:1 000 000 and 1:2 500 000 (Polezhayev unpubl.), displaying various meso-, macro- and megacombinations of plant communities. Similarly, Shelkonova's map of Taimyr vegetation, with formations as basic vegetation units (Shchelkunova 1975) was the product of the generalization of the original map, scale 1:1 000 000, showing the distribution of plant associations and groups of associations.

For the last two decades, large-scale vegetation maps have been made for many northern areas of Russia. The vegetation of small intensive study plots has been mapped, providing insight to the connections between the vegetation and environmental factors as well as into the features of the horizontal structure of the vegetative cover. Intensive study plots have been mapped in different zonal units of Taimyr (Matveyeva 1978), East European tundras (Katenin 1972), and Chukotka tundra areas (Katenin 1974, 1981, 1988). Recently, large-scale vegetation maps have been made for numerous protected areas (e.g. Wrangel State Reserve: Kholod 1989), where large-scale vegetation mapping is performed using air photographs at 1:25 000 to 1:50 000 scale.

Russian phytogeographers and geobotanists have been instrumental in defining phytogeographic subdivisions and vegetation mapping. Aleksandrova (1980) divided the circumpolar Arctic (and Antarctic) into geobotanical areas. The first vegetation map of the circumpolar Arctic was compiled by S.A.Gribova in the *Russian Atlas of the Arctic* (Treshnikov 1985). Maps of floristic subdivisions and latitudinal phytogeographic zonation of the circumpolar Arctic were created by Yurtsev et al. (1978), Rebristaya & Yurtsev (1985), and Yurtsev (1992, 1994).

The status of vegetation mapping in arctic Russia was reviewed in a series of papers at the workshop (Walker & Markon in press): Western Siberian Arctic (L.I. Meltzer; N.G. Moskalenko; I.S. Ilyina & T.K. Yurkovskaya); Taimyr Peninsula (R.P. Shchelkunova); Arctic Yakutia (V.O. Perfilieva & K.A. Volotovskyi); Lena River delta vicinity (K.A. Volotovskyi); and Chukotka (A.N. Poleshayev; A.E. Katenin).

The mapping methods employed on most of the Russian maps follow those used by the Geography and Cartography Department at the Komarov Botanical Institute and may lend themselves to standardization across other parts of the Arctic. The recently completed vegetation map of Europe, which was compiled at the Komarov, serves as a model of the type of map that could be created for the circumpolar Arctic (Neuhäusl et al. 1990).

Two new major Russian initiatives are compiling and editing Russian arctic vegetation maps: (1) *The Ecological Atlas of the Russian Arctic* organized by the Research Institute for Protection of Nature of the Arctic and the North will consist of over 400 maps and involves over 60 institutions (I. Safronova in Walker & Markon in press). The vegetation portion of the atlas will consist of 15 maps to be produced by the Komarov Institute. (2) The Arctic Environmental Database project is organized by Moscow State University, the World Conservation Monitoring Centre, and the Scott Polar Research Institute, Cambridge (A.P. Kapitsa et al. in Walker & Markon in press); O.A. Novoselova in Walker & Markon in press; C. Smith in Walker & Markon in press). The project will describe the biodiversity resources and the threats to their conservation, as well as other environmental phenomena that reflect the links of arctic ecosystems to global and regional ecological processes. The data base will be compiled and made available through a GIS facility established at Moscow State University.

Approach to making a new arctic vegetation map

The participants at the St. Petersburg workshop agreed that a new map should be derived from an electronic map data base that contains the latest state of knowledge and could be updated as new information comes available. Currently there is a need for two types of vegetation maps, one that displays the circumpolar distribution of biomass, and a second depicting regions with characteristic sets of vegetation types based on plant physiognomy and floristic composition. The first is important for numerous studies related to global carbon budgets and climate change and can be derived relatively quickly using remote-sensing technology. The second map requires the synthesis of existing vegetation information contained in many maps plus mapping of previously unmapped regions of the Arctic.

A proposed method was developed for the synthesis map at a small scale (compiled at about 1:5 000 000 scale and reduced to 1:7 500 000 scale). Regional experts would manually interpret regions with similar assemblages of vegetation. This would be done from combinations of aerial photographs and satellite images. Map-polygon boundaries would be interpreted from existing vegetation maps and guided by landscape units as they appear on false-color AVHRR images. The map would be based on the best information available and no field effort would be involved. Separate teams of scientists would work on vegetation maps for each of the circumpolar countries. Frequent communication between representatives from each country would be necessary to ensure uniformity of the maps. The separate maps would be assembled and recast into a single map with some simplification where necessary. Remote sensing and GIS technology now make map creation a dynamic process. The raw data can be continually updated and maps modified based on new information.

A framework for a three-level hierarchic legend was proposed for the map following a combined floristic-physiognomic-ecological approach (Sochava 1962). A derivative of Yurtsev's (1994) north-south floristic zones would form the highest level of the hierarchy. The second level of the hierarchy would be derived from Yurtsev's east-west floristic sectors. The lowest level of the mapping would be based on physiographic, geomorphic, and geologic boundaries that enclose areas with similar vegetation assemblages. The maps would employ matrices of supplemental information to characterize each map unit in terms of dominant phytosociological units, dominant and differential plant species, characteristic parent material, and geomorphic situation.

Conclusion

The large amount of vegetation mapping done in all of the circumpolar countries is a valuable base for reinterpreting and synthesizing the vegetation of the circumpolar region into a single map. Russia, which covers the largest portion of the arctic region, also has the most complete coverage at useful scales. On the other hand, the Canadian Arctic still has large regions that have not been mapped. Presently, there is a confusion of terminology, legends, scales, mapping methods, and uneven distribution of mapping effort across the Arctic. The heritage of vegetation mapping and the legends developed at the Komarov Institute may serve as useful models for a unified approach to a circumpolar map. The first challenge will be to develop a legend and map terminology that all the circumpolar countries can agree on. This is no easy task because many of the terms commonly used in Russia have very different interpretations in the West. Toward this goal, the attendees agreed to meet again in Arendal, Norway in 1995 to discuss the issue of the unified vegetation legend. The attendees, who had primarily arctic tundra expertise, agreed that they would focus on the region north of treeline. A similar project is needed for the boreal forest region.

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