

**PROCEEDINGS OF THE FOURTH INTERNATIONAL WORKSHOP
CONSERVATION OF ARCTIC FLORA AND FAUNA (CAFF) FLORA GROUP**



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Cover photo: View from Villingadalsfjall (elevation 844m) looking south to Malinsfjall (750m) on the island of Vidoy, Faroe Islands. In the Palaeogene the island was geographically close (100-120 km) to East Greenland. Photo by Anna Maria Fosaa.

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Welcome to the Fourth International Conservation of Arctic Flora and Fauna Flora Group Workshop

Halla Poulsen, Prime Minister's Office, Department of Foreign Affairs, Tórshavn, Faroe Islands gave the welcome speech on May 15, 2007 at the Fisheries Laboratory, Tórshavn.

It is a great honour to welcome you to the Faroes. You probably arrived yesterday and last night, so you haven't seen much of the country yet, but I really hope you have the opportunity to do so over the next few days. One thing you will have noticed already, though, is the changing of the weather. We say that it's possible to experience all four seasons in one day in the Faroes, and our islands are also known as the "Land of Maybe." This is due to the weather of course. Most activities here depend on the weather. The weather and concerns about climate are also probably the biggest common denominator amongst the Arctic countries. We all know extreme weather, it being snow, frost, wind, or rain. This is the reason why we have a need for arrangements like the Arctic Council. The challenges of changing weather and climate can best be addressed as a common concern. Only by gathering information from all parts of the Arctic will we be able to see the bigger picture and take action to respond accordingly.

The priorities of the Arctic Council are to protect the environment, promote sustainable utilization of natural resources, prevent pollution, protect the marine environment, and conserve biological diversity. The Faroese government supports the efforts of the Arctic Council in all these areas.

We are situated in a very fragile environment and are dependent on the ocean and its resources. We take very seriously the issues of global warming and the consequences it may have for the North Atlantic Current. If the North Atlantic Current slows down, weakens, or changes direction, cold water will flow in from the north, and this can have a radical effect on the entire marine ecosystem around the Faroes, and it will ultimately have economic consequences for the Islands since our main export is fish.

The political system in the Faroes is finally waking up to the issue. The Faroese government is in the process of discussing with the Danish government how best the Faroes can commit to the Kyoto Protocol. The fact that it is being considered in the first place is largely due to media attention fuelled by scientists. And speaking of scientists, we are very proud to have fostered the winner of the Nordic Council of Ministers' Nature and Environment Prize 2006, Professor Bogi Hansen. He won the prize for his extensive research in oceanography and his ability "to convey knowledge about climate change in a clear and enthusiastic manner which makes it readily understandable to the general public as well as scientists and politicians." Hansen's personal engagement has played an active role in putting climate change and the environment on the political agenda in the Faroes.

Awareness of the environment is also growing on the local community level. Only last week the municipality of Tórshavn had its annual Environment week. Tórshavn, with its 18,000 to 20,000 inhabitants, is the largest city in the Faroes and subsequently has the largest impact on the local environment. Ships arrive here, businesses reside here, and every day hundreds of people drive to Tórshavn from the surrounding areas and islands for work, and drive home again at night. The fact that the municipality takes the environment seriously and is committed to generating awareness, especially among the younger generation, is very promising.

In the Arctic Council working groups, the Faroes take active part in the Arctic Monitoring and Assessment Programme (AMAP), the Protection of the Arctic Marine Environment (PAME), and the Conservation of Arctic Flora and Fauna (CAFF) at the moment. At the last Senior Arctic Officials SAOs meeting in Tromsø last month, it was my pleasure to listen to the presentations from the working groups. Very impressive projects are ongoing and others are in the pipeline. The work of these groups is the core of the Arctic Council, and the science and information you generate fills gaps in our knowledge of how we humans influence our own environment and its biodiversity.

Having species diversity in mind, the Faroese landscape may not seem too exciting from a distance, but a walk in the mountains will soon reveal the subtle diversity and beauty of the Arctic mountain vegetation in the Faroe Islands. As climate change is one of the major threats to the mountain vegetation, plants as indicators of climate change are important research projects. The work of the CAFF Flora Group is a valuable contribution to understanding our environment in this century. With these words I will let you get to work. You have a lot of work ahead of you, so I will conclude by wishing you a fruitful and educational stay in the Faroes. Thank you.

Introduction

Stephen Talbot

The forces of climate change, resource development, and population increasingly threaten the vast and somewhat fragile ecosystem of the Arctic and present many challenges to the Arctic States as well as to the world. During the next few decades, the Arctic will continue to be affected by these forces from both within and outside the region, with important consequences to wildlife resources and to indigenous peoples. These forces are dynamic, with resulting feedback to the global hydrologic and atmospheric systems.

In order to integrate Arctic interests into global conservation efforts, cooperation and a shared knowledge base is necessary among the countries with arctic lands. Toward this end, arctic botanists from eight Arctic States—Canada, Denmark (including Greenland and the Faroe Islands), Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States—convened at the Fourth International Conservation of Arctic Flora and Fauna (CAFF) Flora Group Workshop held from May 15-18, 2007 in Tórshavn, Faroe Islands.

This report provides a summary of the individual workshop presentations in the form of edited extended abstracts and papers. Presentations addressed ongoing scientific work concerning arctic flora and vegetation, such as regional vegetation studies in western North America, Alaska, Faroe Islands, Greenland, and Newfoundland; perspectives in floristics; methods related to ecological land classification, integrated optical-radar, Global Observation Research Initiative in Alpine (GLORIA) Environments, and the Circumpolar Arctic Vegetation Map (CAVM); permafrost studies; flora and vegetation databases; and the creation of the Circumboreal Vegetation Map (CBVM). Specialists from outside the CAFF Flora Group membership were invited to participate. In addition, Microsoft PowerPoint presentations at the workshop are available on the World Wide Web (see: <http://arcticportal.org/en/caff/caff-expert-groups/caff-flora-expert-group-cfg/4th-international-workshop>).

One of the major reasons for the Faroe Islands workshop was to plan for the Circumboreal Vegetation Map (CBVM). Vegetation maps have numerous application uses for Arctic and boreal scientists and managers. They are important for impact studies on wildlife such as caribou, musk ox, and bird life. For example, an estimated 97 % of the North American population of bird species breeds in the boreal forest. Many of North America's most rapidly declining birds are among those most reliant on the boreal forest for their survival. Another important application of vegetation maps is analysis of feedback mechanisms in models, such as increased emission of greenhouse gases, and for use in global models.

The need for such a Circumboreal Vegetation Map was discussed at the Second International Workshop on Circumpolar Vegetation Classification and Mapping held in Tromsø (Sommarøy), Norway, in June 2004. This need was further discussed at the Third CAFF Flora Group Workshop in Helsinki, Finland, in May 2005, and a proposal for funding was initiated. An organizational meeting was held in Fairbanks, Alaska, in March 2006 and a funding proposal was further developed; attendees at this meeting were: Teresa Hollingsworth (Boreal Ecology Cooperative Research Unit, Pacific Northwest Research Station, U.S. Department of Agriculture Forest Service, Fairbanks), Stephen Talbot (U.S. Fish & Wildlife Service, Anchorage), and Donald "Skip" Walker (University of Alaska Fairbanks). At the CAFF XI Biennial Meeting in Yllas, Finland, in March 2006, the CAFF National Representatives endorsed the CBVM. This approval was followed by an endorsement by the Senior Arctic Officials representing the eight Arctic States. In the interim, the CAFF Flora Group received support from Environment Canada, Faroe Islands Homeland Government, and U.S. Department of State to fund the Fourth International CAFF Flora Group Workshop. This workshop helped pave the way for a larger Circumboreal Vegetation Map (CBVM) workshop in Helsinki, Finland, scheduled for 3-6 November 2008. Funding for the CBVM workshop was secured from the Nordic Council of Ministers by Finland.

Scientific work of the CAFF Flora Group is ongoing and evolving—some particular items that were also addressed in this workshop were (1) action items for the CAFF Flora Group documented in the CAFF 2006-2008 Work Plan (CAFF 2006, an electronic copy of the work plan is available at <http://archive.arcticportal.org/255/01/work-plan-all.pdf>); (2) developing a vision for the proposed Circumboreal Vegetation Map (CBVM); and (3) developing ideas for new action items for 2008-2010.

The attendees of the Fourth International CAFF Flora Group Workshop adopted the following resolution at the close of the workshop:

Resolution from the Fourth International CAFF Flora Group Workshop, May 15-18, 2007 Tórshavn, Faroe Islands

Whereas the distribution, characteristics, and history of arctic and boreal flora and vegetation are of essential importance with regard to (1) the knowledge of how circumpolar terrestrial ecosystems interact with climate and contribute to the changing earth system; (2) the conservation of biodiversity of these regions; (3) the increasing exploration and development of circumpolar nations; and (4) the education about the arctic and boreal region, be it resolved that the international community of arctic and boreal vegetation scientists and botanists undertake the joint tasks to:

(A) Develop (i) a uniform modern interactive Circumarctic Flora, including species pages with taxonomic, ecological, and distribution information for all Arctic vascular plants, mosses, and lichens; (ii) an Arctic Vegetation Database as well as a list of arctic plant community types; and (iii) digitized arctic herbarium information that can be accessed through one common Arctic portal.

(B) Compile, edit, and publish a Circumboreal Vegetation Map (CBVM) depicting the distribution and boundaries of boreal vegetation south of the arctic zone, by using recent and traditional vegetation classifications and maps, remote sensing tools at a scale of approximately 1:7,500,000, and a legend that is accepted by the international community of plant scientists.

(C) Support biodiversity monitoring efforts in the arctic and boreal regions of the world, with projects such as the Global Observation Research Initiative in Alpine environments (GLORIA), local floras, and Panarctic vegetation change.

(D) Form a CAFF Flora Group Education/Outreach Subcommittee to address the urgent need to bring young scientists into the fields of arctic and boreal floristic studies and vegetation analysis and mapping, and to educate the public about the value of these efforts.

Furthermore, we request the endorsement of the Nordic Council of Ministers for these projects and ask their assistance in announcing that the cooperation, interest, and scientific expertise of the international community is welcome in the development of these resolutions.

Finally, be it resolved the undersigned scientists develop the organizational mechanisms to accomplish the above stated tasks and, in particular, produce draft products by the Boreal Workshop in 2008 in Helsinki, Finland, when the CAFF Flora Group will convene again.

—Attendees at the Fourth International CAFF Flora Group Workshop, Faroese Museum of Natural History, Botanical Department, Tórshavn, Faroe Islands

All of the CAFF Flora Group work carried out is in line with the larger goals of CAFF, which are to: (1) conserve arctic flora and fauna, their diversity and their habitats; (2) protect the Arctic ecosystem from threats; (3) develop improved conservation management, laws, regulations and practices for the Arctic; (4) collaborate for more effective research, sustainable utilization, and conservation; and (5) integrate Arctic interests into global conservation flora. Conservation of Arctic Flora and Fauna is one of five expert working groups of the Arctic Council, an intergovernmental forum for addressing many of the common concerns and challenges faced by the Arctic states. Currently, the five working groups of the Arctic Council are the Arctic Monitoring & Assessment Programme (AMAP); the Conservation of Arctic Flora & Fauna (CAFF); the Emergency Prevention, Preparedness & Response (EPPR); the Protection of the Arctic Marine Environment (PAME); and the Sustainable Development Working Group (SDWG).

The CAFF Flora Group was initially established to support CAFF priorities including the Arctic Climate Impact Assessment, the Circumpolar Protected Areas Network, and circumpolar monitoring. In previous workshops, pertinent terms were defined and study areas designated (see Proceedings of the First International CAFF Flora Group Workshop: <http://www.caff.is/cfg>). The main objectives of the CAFF Flora Group are to (1) seek international opportunities to support the conservation needs of the biodiversity of arctic flora and vegetation; (2) create conservation partnerships within the Arctic; (3) support research and education for conservation partnerships; (4) exchange published information and unpublished data concerning arctic flora and vegetation; and (5) develop cooperative botanical activities for the CAFF annual work plan. The CAFF Flora Group (CFG) also works cooperatively with IUCN (World Conservation Union) Species Survival Commission as the IUCN Arctic Plant Species Specialist Group.

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Altitudinal Zonation of Vegetation in Continental West Greenland

Birgit Sieg & Birgit Drees

The vegetation of arctic mountain complexes is still unexplored to a great extent. However, detailed knowledge about terrestrial ecosystems is needed for predictions and observations of climate change in the Arctic. Knowledge of the Arctic is an urgent research request, as polar regions show an above-average temperature rise and play a substantial role in accelerating global warming. Mountain vegetation, especially, provides good opportunities to monitor changes as the steep environmental gradients in mountains induce only short migration distances for species and thus lead to a fast response of vegetation to a changed climate. Apart from biomonitoring projects, fundamental data about vegetation (e.g., uniform classification system, bioindicator values) are also needed for other future research projects and nature conservation.

Because of insufficient knowledge about mountain vegetation in the Arctic, an altitudinal zonation hypothesis was formulated for the Circumpolar Arctic Vegetation Map (CAVM) to describe vegetation in areas with elevations above 333 m a.s.l. (CAVM Team 2003, Walker et al. 2005). The CAVM Team hypothesized that the latitudinal bioclimate subzones are reflected in altitudinal vegetation belts, based on similarities between environmental conditions along the altitudinal and latitudinal gradient (e.g., summer temperatures, growing season). Corresponding to a difference of 2 °C in mean-July temperature between adjacent latitudinal vegetation subzones and deduced from an adiabatic lapse rate of 6 °C per 1,000 elevation meters, an altitudinal extent of 333 elevation meters is presumed for each altitudinal vegetation belt. However, this hypothesis needs to be proved since many differences in environmental conditions between the altitudinal and latitudinal gradient exist (e.g., concerning precipitation, wind velocity, photo-period, and frost weathering).

In Greenland, vegetation is confined to the ice-free, mostly narrow areas along the coast. All five bioclimate vegetation subzones of the CAVM are developed in Greenland (Fig. 1). The vegetation zonation not only follows a north-south gradient, but also a coast-inland gradient that results from generally lower summer temperatures at the coast. However, as the concept of the latitudinal bioclimate subzones is only applicable to lowland sites and since nearly 80 % of the ice-free land in Greenland consists of mountainous areas, the vegetation characterization of the latitudinal bioclimate zones can only be applied to a small part of the country. Despite the high percentage of mountain areas in Greenland, nearly all vegetation studies concentrate on the more easily accessible lowland parts of the country and contain just a few (if any) vegetation relevés of higher altitudes. A

comprehensive characterization and delimitation of altitudinal vegetation belts is not available. Therefore, information about the largest part of Greenland's vegetation is mainly based on a hypothesis.

To address the outlined demands for research on arctic mountain vegetation the Altitudinal Zonation of Vegetation (AZV)-Project was initiated in the year 2002. The project aims to develop a model of altitudinal vegetation belts on the basis of a detailed regional study in continental West Greenland. Such a model would characterize mountain vegetation with regard to flora, vegetation types, vegetation pattern, and habitat conditions and would investigate the differentiation of these vegetation characteristics along the altitudinal gradient.

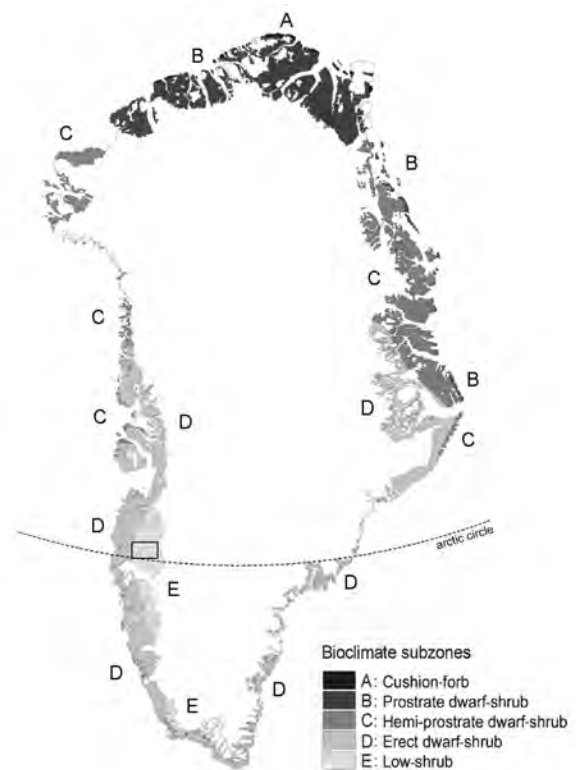


Fig. 1. Bioclimate subzones of Greenland as described by the Circumpolar Arctic Vegetation Map (CAVM Team 2003; modified by Sieg et al. 2006). The rectangle indicates the study area of the Altitudinal Zonation of Vegetation (AZV)-Project.

The AZV-Project study area is located in the inland of West Greenland (Fig. 1) and consists of three research sites: Kangerlussuaq (67°00'N, 50°40'W), Angujårtorfik (66°40'N, 51°30'W), and Qaqortorssûp (66°34'N, 52°13'W). Kangerlussuaq is located at the head of the Søndre Strømfjord and Qaqortorssûp, 70 km to the southwest at the transition to the subcontinental-oceanic region. The main research site, Angujårtorfik, represents the central part of the

continental region. All research sites are mountainous with altitudes up to 700 m (Kangerlussuaq), 1,070 m a.s.l. (Angujârtorfik), and 1,330 m a.s.l. (Qaqortorsûp). They are all assigned to the noncarbonate mountain complex of Subzone E, which is characterized by low-shrub vegetation in the lowlands (CAVM Team 2003). According to the altitudinal zonation hypothesis of the CAVM, four altitudinal vegetation belts (e-b) can be expected. All research sites are characterized by gneissic bedrock and a lowarctic-subarctic continental macroclimate with a slight continentality gradient from east to west.

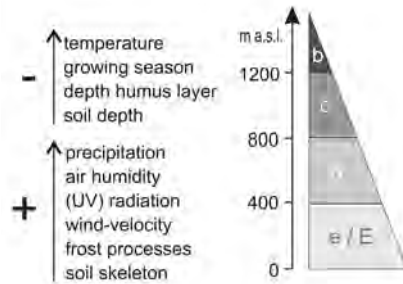


Fig. 2. Preliminary altitudinal vegetation belts in the study area according to the Altitudinal Zonation of Vegetation (AZV)-Project (Sieg 2007, modified). Names of vegetation belts (e-b) are adopted from the Circumpolar Arctic Vegetation Map (CAVM Team 2003).

Expeditions to the research sites were carried out in the summers of 2002, 2003, and 2006. For the first time arctic mountain vegetation was comprehensively investigated in accordance with the principles of the Braun-Blanquet approach. About 650 vegetation relevés were analyzed in homogeneous stands covering all habitats in different altitudes. For each plot, all vascular plants, bryophytes, and lichens, as well as habitat conditions (e.g., soil conditions, aspect, slope) were recorded. Samples of all cryptogams and of critical vascular plants were collected for final identification in the laboratory. The relevés were compiled in a database (Turboveg for Windows) and arranged in community and synoptic tables following the principles of the Braun-Blanquet sorted table method. Vegetation types are described, syntaxonomically classified, and typical habitat conditions are outlined.

Four mapping areas covering different altitudinal ranges (175-235/535-620/905-965/1,245-1,310 m a.s.l.) were established in two of the research sites. The vegetation of these mapping areas is considered to be representative of the particular altitudinal belts since all common habitat types and their typical plant communities with respect to these belts are present. In these areas detailed vegetation maps showing aspect and slope of each homogeneous patch of vegetation were constructed.

From vegetation maps and relevés created in the AZV-Project study, idealized toposequences of

vegetation types were derived that were equivalent to toposequences in the CAVM. In contrast to this original form of the toposequences used in the latitudinal vegetation zonation, not only the soil moisture gradient, but also slope aspect was considered in the AZV-Project study because it is a key environmental factor of mountain habitats. Consequently, six habitat types (south-facing slope, north-facing slope, ridge, snowbed, zonal, depression) were distinguished. The developed idealized toposequences of vegetation types are an important tool for the distinction of altitudinal belts, as well as for their comparison with the latitudinal vegetation subzones depicted in the CAVM.

The results of the classification show that new syntaxa mainly occur in higher altitudes or belong to the already described but not yet classified low-shrub vegetation. This vegetation comprises the *Calamagrostio lapponicae-Salicetum glaucae*, the *Plagiomnio elliptici-Salicetum glaucae*, and the *Carici spaniocarpae-Salicetum glaucae*. New associations from higher elevations are mainly graminoid dominated vegetation types (*Pediculari flammeae-Caricetum bigelowii*, *Thuidio abietini-Kobresietum myosuroidis*, *Tortello arcticae-Caricetum rupestris*). Regarding all vegetation types, nine new subassociations and eight new variants are distinguished. For three established associations the nomenclature is revised (*Caricetum saxatilis*, *Cassiopetum hypnoidis*, *Hylocomio splendentis-Cassiopetum tetragonae*). The other treated plant communities include further vegetation types of snowbeds (*Aulacomnium turgidum-Luzula confusa* community, *Phippsietum algidae-concinnae*), erect dwarf-shrub heaths (*Empetro hermaphroditum-Betuletum nanae*, *Ledo decumbentis-Betuletum nanae*, *Rhododendro lapponici-Vaccinietum microphylli*), fens (*Caricetum rariflorae*, *Saxifrago nathorstii-Kobresietum simpliciusculae*), fell fields (*Carici nardinae-Dryadetum integrifoliae*), and scree vegetation (*Sphaerophoro globosi-Racomitrietum lanuginosi*). The analysis of the relevés also shows that bryophytes and lichens play a decisive role in classification, ecology, and altitudinal differentiation of plant communities; therefore, they should always be considered in arctic vegetation studies. A comprehensive treatment of classification and ecology of vegetation types is published in Sieg et al. (2006).

In a second step, the suitability of plant species and vegetation types for characterization and delimitation of altitudinal vegetation belts was evaluated. Concepts of altitudinal indicator species and plant communities are presented and suitable indicators are selected. According to their different performances along the altitudinal gradient, the 77 selected altitudinal indicator species are divided into four categories: general indicator species, indicator species with narrow phytocoenological amplitude, those with change in activeness, and those of limited indicator value. The altitudinal indicator values of plant communities are

derived from their limited altitudinal distribution range and elevation forms, as well as from replacements of communities or change of their habitat-type spectra along the altitudinal gradient. The vegetation pattern was discerned by idealized toposequences and abundance of vegetation types in different altitudes.

Today, heathland is the predominant vegetation type in lowland temperate vegetation zones up to 200 m a.s.l., plant communities are derived from their limited altitudinal distribution range and elevation forms, as well as from replacements of communities or change of their habitat-type spectra along the altitudinal gradient. The vegetation pattern was discerned by idealized toposequences and abundance of vegetation types in different altitudes.

Based on indicator species, indicator plant communities, and vegetation pattern, four preliminary altitudinal vegetation belts with boundaries at 400, 800, and 1,200 m a.s.l. are distinguished (Fig. 2). The short names of these belts were adopted from the altitudinal zonation hypothesis of the CAVM. The altitudinal borderlines were assessed by field observations and selective analyses (vegetation relevés, species lists) from different altitudes. Moreover, they were preliminarily tested by statistical analyses of floristical transects.



Fig. 3. In the research site Qaqortorsúp, mountains rise up to 1,330 m a.s.l. Studies in this area concentrated on the highest altitudinal vegetation belts c and b in continental West Greenland.

The lower two belts are dominated by erect dwarf-shrub heath vegetation with *Rhododendro-Vaccinietum* and *Ledo-Betuletum* as indicator communities. The low altitudinal belt e is differentiated by the occurrence of low-shrub vegetation, which is represented by the three already mentioned associations of *Salix glauca* scrubs occurring in three different habitat types (zonal sites, riparian, south-facing slopes). The middle altitudinal belt d is differentiated from the lowlands by occurrence of snowbed communities on north-facing slopes and by several altitudinal indicator species. Elevation forms and change in habitat-type preferences of some vegetation types are also characteristics for distinction between belts e and d. For example in belt d, the *Hylacomio-Cassiopetum* is not only restricted

to scattered snowpatches but occurs abundantly on north-facing slopes. In contrast to the lowlands, the *Carici-Dryadetum* is not only found on extremely wind-exposed ridges but replaces the *Empetro-Betuletum* and *Arabido-Caricetum* on less extreme ridges. The high altitudinal belt c is dominated by graminoid and prostrate dwarf-shrub vegetation of the classes *Salicetea herbaceae* and *Carici-Kobresietea*. Belt c is differentiated from mid altitudes (belt d) by many indicator species, elevation forms, and changes in habitat-type preferences of plant communities, as well as by a distinct change in growth forms and substitution of vegetation types. The newly described *Tortello-Caricetum* and *Pediculari-Caricetum* are restricted to this belt. Generally, snowbed species and communities show a high activeness since snowbed species occur in many different vegetation types and several well-developed snowbed communities are present (*Phippsietum*, *Cassiopetum hypnoidis*, *Pediculari-Caricetum*). It is shown that differences between belts d and c are more pronounced than between belts e and d. This boundary might be comparable to the transition between the Low and the High Arctic.

In the final year of the project an enhanced model of altitudinal vegetation belts will be elaborated that can be used for monitoring approaches and extrapolation purposes (Drees & Sieg, in prep.). To accomplish this, the remaining vegetation types of south-facing slopes and the vegetation of belt b will be analyzed and classified.

South-facing slopes of low and mid altitudes are characterized by dry, graminoid-dominated vegetation that locally can cover vast areas in the investigation area. In belt e this arctic steppe vegetation (*Arabido holboellii-Caricetum supinae*) primarily alternates with dry willow-copses (*Caricispaniocarpae-Salicetum glaucae*) that are restricted to the lowlands. These xero- and thermophile vegetation types, which are syntaxonically combined in the *Calamagrostietea* (cf. Daniëls et al. 2000), are confined to shallow, gravely to fine-grained soils where they are subjected to strong insolation and desiccation in summer. The habitats of the arctic steppe complex with its strongly extrazonal climate constitute the "hotspot" of the investigation area (Elvebakk 2005a). Steppe vegetation comprises a large quantity of species that are restricted to these vegetation types and thus considerably enhances the biodiversity of the vegetation of continental West Greenland. Since insolation and stress due to water deficiency decrease with increasing altitude, the *Arabido-Caricetum* is replaced by the *Carici-Dryadetum* in exposed sites and by the *Thuidio-Kobresietum* in more sheltered sites. A detailed and comprehensive analysis of the collected data, especially with regard to altitudinal differentiations and altitudinal indicator species, is in progress (Drees & Daniëls, in prep.).

Since the analysis of belt b in the summit areas of the highest mountains is not finished yet, only field observations can be presented here: vascular plant cover in these areas is sparse whereas bryophytes, lichens, stones and bare soil are dominant (Fig. 3). Vascular species such as *Silene acaulis*, *Saxifraga* spp., and *Luzula confusa* show a high activeness, while the dominant plants of belt c, such as *Carex* spp. and *Dryas integrifolia* of *Salix herbacea*, are very scattered or absent. A comprehensive treatment of vegetation in belt b will be published within a short time (Sieg et al., in prep).

Up to now a large part of the data used to assess borderlines of vegetation belts originated from north-facing slopes because south-facing slopes were less comprehensively investigated. Field observations indicate that borderlines on south-facing slopes are raised by at least 50 elevation meters; therefore, altitudes of the borderlines will be further examined with special emphasis on their altitudinal alterations at different expositions. An improved localization of altitudinal borderlines will be achieved by analyzing 65 altitudinal transects. Each of these transects consists of numerous plots which were systematically selected along the mainly north-south directed transect-lines. In these plots, the presence and abundance of altitudinal indicator species and indicator plant communities were recorded. A statistical evaluation of this data will serve to find discontinuities along the altitudinal gradient and thus help to specify the altitudinal position and dimension of the vegetation belts.

The results of the ongoing work contributing to the AZV-Project are supposed to improve the extrapolation of altitudinal vegetation belts for the entire continental region of West Greenland and provide a first, small-scale vegetation map of this area (Drees & Sieg, in prep.). Applying the model of altitudinal vegetation belts to the whole continental region of middle West Greenland seems to be reasonable because the three research sites were distributed over the total west-east extent of this region. Furthermore, overall similar environmental conditions (climate, bedrock, topography) in this region justify such an extrapolation. The AZV-Project, along with other recent efforts that mainly address a more detailed characterization and mapping of vegetation in other arctic areas, (e.g., Elvebakk 2005b, Reynolds et al. 2005) will contribute to an improvement of the CAVM.

The enhanced model will also be the basis for a final, detailed comparison of altitudinal vegetation belts with latitudinal subzones of the CAVM. The toposequences of the model can easily be compared with the well-known toposequences of latitudinal zonation concepts of the Arctic (e.g., Elvebakk 1999, Razzhivin 1999). The vegetation maps allow a first comparison with vegetation maps from other areas in Greenland (Bay 1998, Stumböck 1993). This will provide information about the accuracy of

the altitudinal zonation hypothesis of the CAVM. A high correspondence between altitudinal belts and latitudinal zones would allow extrapolating vegetation data to poorly known and remote mountain ranges in continental arctic territories.

Apart from extrapolation purposes, the model comprises three constituent parts that provide criteria for detecting vegetation change in future biomonitoring projects. These are altitudinal indicators (species and vegetation types), detailed vegetation maps of each altitudinal vegetation belt, and the present-day boundaries of these belts. Repeated investigations of these criteria after a given period of time might detect changes in vegetation that can possibly be tied to climatic changes. Recording the vegetation of the mapping areas and systematically investigating vegetation along altitudinal transect-lines, with consideration of altitudinal indicator species and plant communities, will constitute important research methods for monitoring changes.

It can be concluded that the AZV-Project provides fundamental data about arctic mountain vegetation and gives a picture of the present status of the ecosystem that are both essential for future monitoring studies and other research efforts in the Arctic.

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Vegetation of the Faroe Islands in a Changing Environment

Anna Maria Fosaa

Introduction

The vegetation of the Faroe Islands has undergone various changes since the last ice age. In the first period, natural climate fluctuations had the greatest impact on vegetation. After human settlement, the influence of humans was the main impact. The vegetation in the islands changed from a vegetation rich in shrubs (*Salix* spp. and *Juniperus communis*) and tall herbs to the tundra like vegetation we know today, where shrubs and tall herb vegetation are restricted to inaccessible places. Today, heathland is the predominant vegetation type in lowland temperate vegetation zones up to 200 m a.s.l., while *Racomitrium* heath and open grassland with low vegetation cover dominate the alpine zone from 400 m a.s.l. to the mountaintop. A low-alpine transition zone with grassland as the main vegetation type is found between these two zones. The main impacts on vegetation today are due to sheep grazing and agriculture, as well as to invasive species and climate change.

Vegetation Changes During the Holocene Period

The recent flora invaded the islands after the last ice-age, 10,000-12,000 years ago. The climate in the Faroe Islands in the Preboreal period (10,000-9,000 B.P.) was described as arctic continental, based on the presence of *Betula nana* (Jóhansen 1972, 1985). This species disappeared shortly as the climate changed towards more oceanic conditions. In this period (Boreal time 9,000-8,000 B.P.), species such as *Juniperus communis* and *Salix* spp. took over, together with Poaceae and Cyperaceae, which covered the lowland at that time. The climate became wetter in the Atlantic period (8,000-5,000 B.P.) with evidence of strong leaching of the soil. Peat was formed and *Calluna vulgaris* invaded. *Juniperus communis* and *Salix* spp. decreased but did not disappear completely (Fig.1). When the climate became drier again (Subboreal 5,000-2,500 B.P.), the two species increased again.

In the period from Subboreal (5,000-2,500 B.P.) to Subatlantic (2500 B.C.-A.D. 0), the vegetation changes are described as a decline in tall-herb vegetation and shrub, with an increase in the distribution of *Calluna vulgaris* (Jóhansen 1985).

It was previously believed that the decline in *Juniperus* and *Salix* spp. was due to human settlement. However, newer results based on macrofossil studies showed that the woodland species were already retreating before peatland and heathland species prior to human settlement, and that the settlement only accelerated the degradation process initiated by climate change (Hannon 2000, Hannon et al. 2001).

The two settlements (A.D. 650 and A.D. 825) described in the literature (Jóhansen 1972, 1979, 1985) have further changed the vegetation with a decline of tall-herb and dwarf-shrub. Thus, unaffected original vegetation survived only in places inaccessible to sheep on rocks, cliffs, and in crevices.

Climate Development During the Last Century

The climate in the Faroe Islands is extremely oceanic, controlled by the sea temperature (Crawford 2000). The location of the islands in the path of the warm North Atlantic Current makes the temperature more than 5 °C higher than it would have been without the oceanic heat transport (Seager et al. 2002). Air temperature observations from Tórshavn show a general warming from the beginning of regular observations in 1873 until around 1940. This warming was followed by a cooling until around 1980 and then a warming again since then (Fig. 2). This development is somewhat similar to the changes in global mean temperature, but the cooling from 1940 to 1980 was much more pronounced in the Faroes than for the globe as a whole, while the subsequent warming has been weaker in the Faroes.



Fig. 1. *Juniperus communis* is a rare plant in the Faroe Islands.

The oceanic climate in the Faroe Islands is strongly influenced by the warm North Atlantic Current and by the proximity to the low-pressure track in the North Atlantic region. Consequently, the climate is humid, variable, and windy. The warmest months in the Faroe Islands are July and August with a mean temperature of 11 °C (lowland), and the coldest month is February with a mean of 4 °C (lowland). The mean precipitation in the Faroe Islands is 1,500 mm annually (lowland). The precipitation reflects the topography of the islands, with the coastal areas receiving around 1,000 mm per year and increasing to more than 3,000 mm in the central parts (Cappelen 2003).

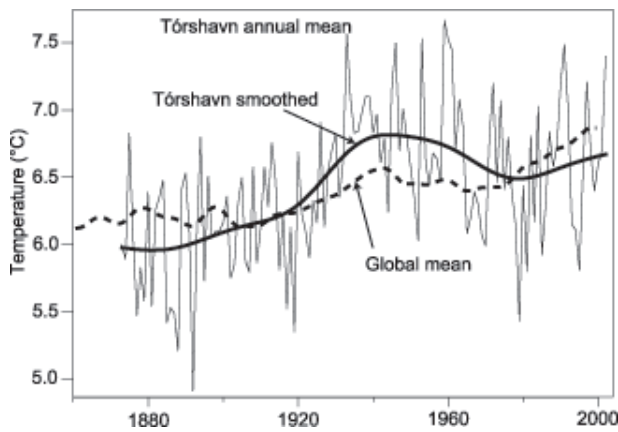


Fig. 2. Air temperature in the Faroe Islands and global mean during the last 130 years. Annual mean (thin lines) and smoothed (Gauss filtered) (thick continuous curve) temperature from Tórshavn, Faroe Islands (source: Cap-pelen 2003). Global mean temperature (dashed thick curve) (adapted from: <http://www.ipcc.ch/present/graphics.htm>) adjusted so that the 1961-1990 average coincides with the average of the Tórshavn temperature for the same period.

The Present Vegetation

Despite the lack of trees (Fig. 3), the islands are situated south of the limit of tree growth, since the mean temperature for the warmest month in the Faroe Islands is higher than 10 °C. This isotherm is usually used to define the limit for tree growth and also the lower limit of the alpine zone in the temperate areas (Billings and Mooney 1968, Troll 1973, Körner 1998).

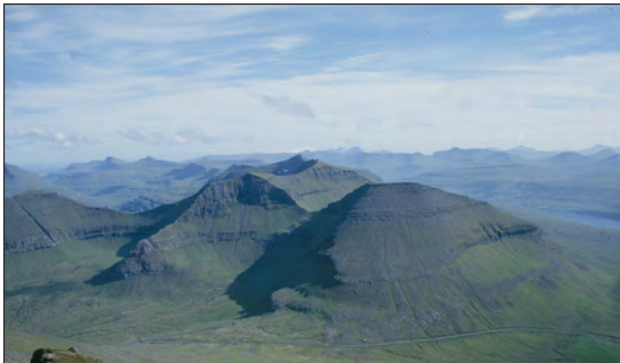


Fig. 3. View from the highest mountain of the Faroe Islands, over the treeless islands.

Böcher (1937, 1940) and Ostenfeld (1905-1908) described the vegetation of the Faroe Islands from sea level to the high mountain. Three vegetation zones were defined (Böcher 1937). These three vegetation zones were also described in a quantitative study by Fosaa (2004). The results from this study showed that the vegetation in the temperate lowland zone is dwarf shrub heath vegetation (Fig. 4) with two plant communities (*Calluna vulgaris*-*Nardus stricta* community and *Empetrum nigrum*-*Calluna vulgaris* community). This vegetation type ranges from lowland up to 200 m a.s.l. and is restricted to south-facing transects only. Above this vegetation

type, we find the low alpine vegetation zone with moist grassland vegetation. This vegetation type is defined based on the three communities (*Thymus praecox*-*Vaccinium myrtillus* community, *Nardus stricta*-*Potentilla erecta* community, and *Galium saxatile*-*Anthoxanthum odoratum* community) restricted to this altitude. This vegetation zone is replaced by the alpine vegetation zone at 400 m a.s.l. Since the moist dwarf shrub vegetation is missing on north-facing slopes, the moist grassland vegetation covers the altitudes from lowland up to the alpine zone on the north-facing transects. The alpine zone is characterized by two main vegetation types: (1) open grassland vegetation with the four plant communities (*Koenigia islandica* community, *Festuca vivipara*-*Agrostis capillaris* community, *Bistorta vivipara*-*Festuca vivipara* community, and *Deschampsia flexuosa*-*Rhytidiadelphus loreus* community) and (2) *Racomitrium* heath vegetation (Fig. 5) with three communities (*Racomitrium lanuginosum* community, *Racomitrium lanuginosum*-*Salix herbacea* community, and *Racomitrium fasciculare*-*Alchemilla alpina* community).



Fig. 4. Dwarf shrub heath in the lowland temperate zone.

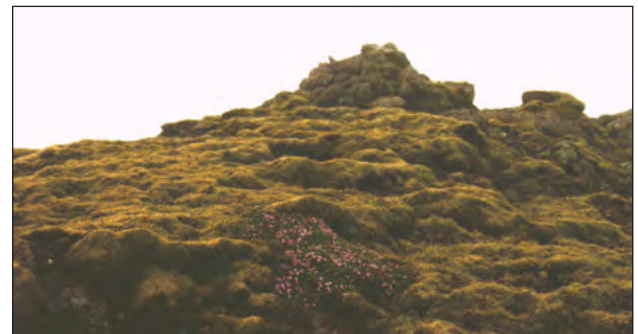


Fig. 5. *Racomitrium* heath in the alpine vegetation zone.

The position of the three vegetation zones defined by Fosaa (2004) largely agrees with the climate zones as defined by Humlum & Christiansen (1998), as well as with Christiansen & Mortensen (2002), based on temperature and peri-glacial activity. They propose a low arctic zone from 200 m a.s.l. and an arctic zone from around 400 m a.s.l. The lower boundary of the low arctic zone corresponds to the upper limit of the moist dwarf shrub vegetation and the lower limit of the moist grassland vegetation (Fosaa 2004), while the arctic zone ranges from the upper limit of the

moist grassland and the lower limit of the *Racomitrium* vegetation and open grass vegetation to the top. With a lapse rate of 0.8 °C per 100 m (Köppen 1920), the 10 °C isotherm is found to be in the temperate zone.

Comparing these results (Fosaa 2003) to earlier studies on Faroese vegetation zones, Böcher (1937) found these vegetation zones at considerably higher altitudes. In the recent investigations, the border between the temperate and the low alpine zones, as well as the border between the low alpine and the alpine zones are found to be around 100 m lower than in the older studies. This lower border between the low alpine and the alpine zone could be due to cooling. If we take the cooling of 0.25 °C during the period from Böcher (1937) to the recent studies, a downward shift in the vegetation zones would be expected. With a lapse rate of 0.8 °C, a cooling of 0.25 °C should lead to a lowering of the alpine zone around 30 m. The length of time between these two studies should also be sufficient for species to migrate such a distance (Grabherr et al. 1995).

Environmental Impact on the Vegetation

The main impact on vegetation since the last ice age (in the first period) has been related to fluctuating climate (Jóhansen 1985, Humlum & Christiansen 1998), and later, impacts were influenced by human settlement (Jóhansen 1985, Hannon et al. 2001), with most of the impact due to sheep grazing. The grazing pressure in the area is pronounced, with 70,000 grazing sheep in the last decades, and grazing most likely accounts for the major impact on vegetation.

In a new red list for vascular plant species in the Faroe Islands (Fig. 6), it is possible to categorize 74 vascular species into six International Union for the Conservation of Nature and Natural Resources (IUCN) categories (Fosaa et al. 2005). These data were built on information in floras (Jóhansen et al. 2000), as well as information from the Museum of Natural History in Tórshavn and the Botanical Museum in Copenhagen. This procedure was used because no regular monitoring of the vegetation has been established yet in the area; therefore, 25 species were categorized as “data deficient,” as there was not enough information for these species.

Factors affecting plants were also investigated, and it was found that major effects on plants came from sheep grazing and agriculture, as well as from other human activities and climate change. The plant species were divided into the following five biotopes: mountains, stones, heaths, wetland/freshwater, and seashores/sea. Most of the red-listed species were found in the wetland/freshwater biotope, whereas the other biotopes had similar occurrences of red-listed species. The most threatened species were found in the lowland (Fosaa et al. 2005). Examples of threatened freshwater species are *Utricularia vulgaris*,

which is found in only one lake and *Drosera rotundifolia*, which is found in only a few localities (Fig. 7).

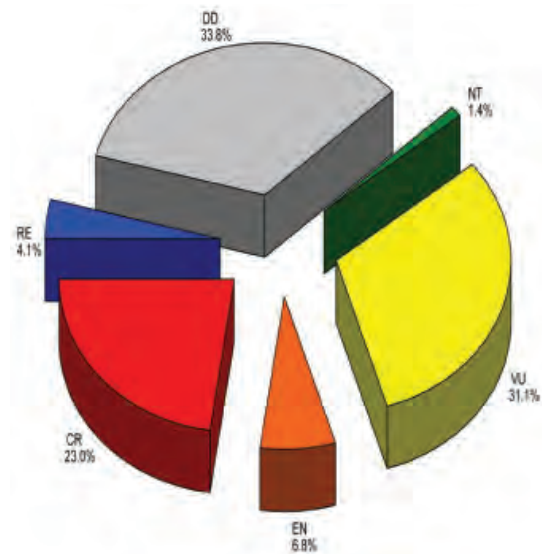


Fig. 6. The 74 red listed species in the Faroe Islands (data deficient [DD], extinct [RE], critically endangered [CR], threatened [EN], vulnerable [VU], nearly threatened [NT]).



Fig. 7. The carnivorous wetland species *Drosera rotundifolia* is only found in few places.



Fig. 8. *Ranunculus glacialis* is only found on the highest mountains in the Faroe Islands.

Papaver radicum and *Ranunculus glacialis* (Fig. 8) are plant species restricted to the high mountains of the islands. These are examples of species that are vulnerable in a climate-warming regime. Invasive species are also a threat to the local flora of the islands. An example of such an invasive species is *Mimulus guttatus*, which in the latest decades has taken over many river banks around the islands.

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Exploring the Alaskan Black Spruce Ecosystem: Variability in Species Composition, Ecosystem Function, and Fire History

T.N. Hollingsworth

In this overview, I present extensive studies looking at the structure and function of the black spruce (*Picea mariana*) ecosystem of the boreal region of interior Alaska. One of the studies provides a classification of black spruce communities, the most abundant forest type in the region. Other studies examine large-scale processes that drive this community classification. This work helps lay the foundation for an appropriate vegetation mapping project in boreal Alaska.

Scale-Dependent Environmental Controls Over Species Composition in Alaskan Black Spruce Communities

The classification of black spruce plant communities in interior Alaska is the first published Braun-Blanquet classification done in interior Alaska. Black spruce communities occur in a variety of environmental conditions and are extremely adapted to fire disturbance. We described three black spruce community types and five subtypes based purely on floristics. We also related these communities to important environmental variables, and found that a complex soil drainage gradient underlies the community patterns seen in Alaskan boreal black spruce forests (see Hollingsworth et al. 2006). We defined our plant communities and subtypes as:

1. Acidic black spruce/lichen forest (*Picea mariana*/*Cetraria islandica*): fruticose lichens and many species of mosses dominate this community. It occurs in areas with an underlying mineral soil pH < 5.5 in both the uplands and lowlands of boreal Alaska. Although this community type exists in both wet and dry areas, there is one subtype that is restricted to wet areas:

(a) Wet, acidic black spruce muskeg (*Picea mariana*/*Ledum decumbens*/*Sphagnum girgensohnii*): this is an open black spruce subtype that occurs in low-nutrient, permafrost soils.

2. Nonacidic black spruce/rose/horsetail forest (*Picea mariana*/*Rosa acicularis*/*Equisetum* spp.): this community is dominated by vascular species with the occasional presence of white spruce (*Picea glauca*). It occurs in well-drained areas of both the uplands and lowlands of boreal Alaska. It has two subtypes, one that is restricted to wet areas, and one that is restricted to drier areas.

(a) Wet, nonacidic black spruce/larch fen (*Picea mariana*/*Larix laricina*/*Chamaedaphne calyculata*): this subtype is restricted to

minerotrophic lowlands and is easily identifiable by the presence of Alaskan larch (dead or alive). The active layer can be shallow, but permafrost conditions are more variable than in the wet, acidic subtype. It is important to note that there is some overlap in species, such as *Betula nana*, *Rubus chamaemorus*, and *Eriophorum vaginatum*, with the wet, acidic subtype. These species are indicative of the moisture status of the site and not acidity.

(b) Dry nonacidic black spruce forest (*Picea mariana*/*Cladina stellaris* - *Peltigera malacea*): this subtype occurs in xeric conditions, almost exclusively in the uplands, or at higher elevations.

Many community and ecosystem level studies in interior Alaska have focused on the uplands and floodplains in close proximity to Fairbanks, Alaska. By expanding our study area to include a larger spectrum of structural and functional variability, we see that the black spruce communities of interior Alaska are related to the underlying pH of the parent material, as well as to differences in site drainage. The strong correlation between species composition and mineral soil pH has been observed in the Alaskan Arctic (Walker and Everett 1991).

Plant Community Composition as a Predictor of Regional Soil Carbon Storage in Alaskan Boreal Black Spruce Ecosystems

To be widely accessible and useful, vegetation mapping must not only include structural differences in plant communities, but also reflect functional ecosystem differences. Here, I ask what is the relationship between black spruce community patterns and ecosystem processes by examining the relationship between floristic composition and ecosystem parameters, such as soil carbon pools, the carbon-to-nitrogen (C/N) ratio of live black spruce needles, and normalized basal area increment (NBAI) of trees in black spruce communities of interior Alaska (Hollingsworth in press). I show that variability in ecosystem parameters in black spruce of interior Alaska exceeds the documented variability across a broad range of ecosystem types from around the Fairbanks area. The acidic black spruce/lichen forest (*Picea mariana*/*Cetraria islandica*) communities had significantly more carbon in the organic soil horizon than the nonacidic black spruce/rose/horsetail forest (*Picea mariana*/*Rosa acicularis*/*Equisetum* spp.) but did not differ in any other measured ecosystem parameter. Species composition was as important as

abiotic variables, such as topographic position, slope, and soil moisture, in predicting soil carbon storage, and in particular, *Sphagnum* plays an integral role in determining soil carbon amounts in black spruce communities. In conclusion, among the community properties analyzed, the presence of key groups of species, overall species composition, and diversity of certain functional types, especially *Sphagnum* moss species, are important predictors of soil carbon sequestration in the black spruce forest type.

Wildfire Legacy Effects Versus Environmental Controls in Alaska's Mature Black Spruce Forests: the Ghost of Disturbance Past

When considering a circumboreal vegetation mapping project of the boreal forest, one of the most important factors to consider is the treatment of large-scale disturbances, such as fire, and how they shape the vegetation patterns on the landscape. The current landscape of the boreal forest is a mosaic of vegetation that reflects both the relationship between vegetation and environment and legacies of previous disturbances. Therefore, understanding the long-term effects of fire on vegetation composition, and in particular, how the legacy of fire shapes the composition and distribution of boreal plant communities, is an important factor when designing regional and global vegetation maps.

In the boreal forest, fire is a key regulator of both the structure and functioning of forest communities; however, the composition of mature late-successional communities is often attributed to environmental influences, such as topography, and considered to be independent of fire history. Black spruce stands resulted from either a single, stand-replacing fire, multiple fire events creating multiple cohorts, or continuous recruitment after fire, with intervals at approximately 100 years. In addition, fire history (severity and time since disturbance) was highly correlated to the species composition of both the acidic black spruce/lichen forest (*Picea mariana*/*Cetraria islandica*) and the nonacidic black spruce/rose/horsetail forest (*Picea mariana*/*Rosa acicularis*/*Equisetum* spp.). It is clear that the legacy of fire has a lasting effect on the vegetation composition of mature black spruce stands at the level of community subtypes (i.e., wet, acidic black spruce muskeg [*Picea mariana*/*Ledum*] spruce subtype; wet, nonacidic black spruce/larch fen [*Picea mariana*/*Larix laricina*/*Chamaedaphne calyculata*]; and dry, nonacidic black spruce forest [*Picea mariana*/*Cladina stellaris* - *Peltigera malacea*]). Most likely this high correlation at the subtype level is due to the intrinsic relationship between fire severity and site drainage and moisture. Based on the results, four mechanisms are presented that could lead to varying successional trajectories following fire.

1. Low Ground Burn Severity and High-Legacy Mechanism: low ground burn severity coupled with

effective re-establishment of prefire vegetation always regenerates the prefire vegetation. These factors co-occur in the nonacidic wet subtype and both of the dry subtypes. Low ground burn severity fires always lead to regeneration of the same prefire community subtype because the understory species survive fire and regenerate vegetatively, with no long-term change in species composition. This mechanism occurs most frequently in the wet, nonacidic black spruce/larch fen (*Picea mariana*/*Larix laricina*/*Chamaedaphne calyculata*), which has the longest time between fires and shows little evidence of severe ground fires due to high soil moisture.

2. High Ground Burn Severity and High and Recruitment Mechanism: this mechanism is specific to dry subtypes, where dry soils and shallow organic depths contribute to the greater likelihood of a severe ground fire. Severe ground fires produce a mineral soil seedbed that is viable for seedling recruitment and establishment by the pre-fire species. Consequently, the dry subtype is maintained after fire.
3. High Ground Burn Severity and Shift in Environment Mechanism: a shift in species composition away from the black spruce ecosystem is most likely to occur when severe ground fire changes the starting conditions or abiotic factors, and/or the relative abundances of the survivors enough to shift a wet subtype to a dry subtype. This shift can occur in both acidic and nonacidic communities.
4. High Burn Severity and New Tree Species Mechanism: the mechanisms described previously all assume that black spruce re-establishes, so differences among community subtypes develop as a result of changes in the understory species composition. However, if a new dominant tree established itself after fire, it could cause a shift to a new ecosystem type, for example, white spruce or aspen. This is most likely to occur if high crown severity reduces seed input from black spruce and/or if high ground severity or environmental change from climate warming favors the establishment of a different dominant tree species.

These mechanisms are extremely important when thinking about a large-scale mapping effort because they depict areas on the landscape that could be susceptible to shifts in species composition post-fire and, therefore, should be considered during the mapping process.

In this paper, I present a cohesive study on the black spruce communities in interior Alaska. These communities are named, correlated with important environmental variables, distinguished based on ecosystem parameters, and related to the fire history of that community. Although mapping was not done

as part of this project, it is clear that this is the first step that needs to be taken in order to extensively map areas of the boreal forest. To be useful to a broad audience, a circumboreal vegetation map must name the units based on species composition and the correlated environmental factors and landscape-level disturbance patterns.

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Vegetation of Newfoundland

W.J. Meades

Introduction

The Island of Newfoundland (106,000 km²) is primarily dominated by forest (56%), heathland (19%), peatland (14%), water (10%), and agricultural and cleared land (1%) (Anon. 1974). Despite the relatively small land cover, the complexity of climate and geology has given rise to considerable ecological variability and diversity of flora and vegetation types (Damman 1965). The ecological subdivisions of the island are illustrated in Fig. 1, and their descriptions follow Damman (1983). The Western Ecoregion [I] is characterized by boreal forests dominated by balsam fir (*Abies balsamea* (L.) Mill.), where fire has been excluded due to the wet maritime climate. In contrast, the Central Ecoregion [II] is characterized by boreal forest dominated by black spruce (*Picea mariana* (Mill.) B.S.P.), with varying mixtures of balsam fir due to fire disturbance associated with the subcontinental climate of the island's interior. The Northern Ecoregion [III] is similar to the Central Ecoregion, but it is differentiated by a shorter growing season caused by spring ice flows brought down from the Arctic by the Labrador Current.

The Northern Peninsula Ecoregion [IV] is also dominated by fir forests, but this region lacks many southern tree species, such as yellow birch (*Betula alleghaniensis* Britton), white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), and trembling aspen (*Populus tremuloides* Michx.), and for the most part, is underlain by limestone soils. The Avalon Forest Ecoregion [V] represents a small (500 km²), humid forested area situated in sheltered valleys of the Avalon Peninsula that escaped fires that devastated most of the forests of eastern Newfoundland. The Maritime Barrens Ecoregion [VI] occurs throughout southern Newfoundland and is characterized by extensive heaths and blanket bogs, with forest restricted to the most sheltered valleys. Although the wet maritime climate is not conducive to wild fires, settlement by Europeans over the last 500 years has decimated the marginal forests that previously occurred on upland sites.

The Eastern Hyper-Oceanic Barrens Ecoregion [VII], as the name implies, has a distinct climate characterized by high fog frequency, strong winds, and mild winters with little protective winter snow cover. The region is characterized by extensive blanket bogs and moss heaths, dominated by heath moss (*Racomitrium lanuginosum* (Hedwig) Bridel), and has a strong affinity to similar moss heaths in oceanic regions throughout the North Atlantic. The Long Range Barrens Ecoregion [VIII] represents the farthest northern extension of the Appalachian Range in North America with tree line occurring at the 600-700 m elevation range. Alpine

heaths dominate the vegetation, with characteristic species such as diapensia (*Diapensia lapponica* L.), alpine azalea (*Loiseleuria procumbens* (L.) Desv.), highland rush (*Juncus trifidus* L.), northern firmoss (*Huperzia selago* (L.) Bernh. ex Schrank & Mart.), and *Thamnolia vermicularis* (Sw.) Ach. ex Schaer.). The Strait of Belle Isle Ecoregion [IX] is dominated by rocky tundra with forest limited to isolated patches of wind-shaped scrub less than 2 m in height. This ecoregion is unique because of the southern limit of many arctic species and the occurrence of endemic calciphiles on limestone gravels. Nomenclature of plant species follows S.J. Meades et al. (2000) - vascular plants; Brodo et al. (2001) - lichens; Flora North America, Vol. 27 (2007) - bryophytes; Rose & Lindquist (1994) - insects; and Davis & Meyer (1997) - fungi.

This paper provides a brief overview and synthesis of vegetation classifications that have been developed for insular Newfoundland over the last 50 years and provides a point of entry into more detailed treatments in the literature.

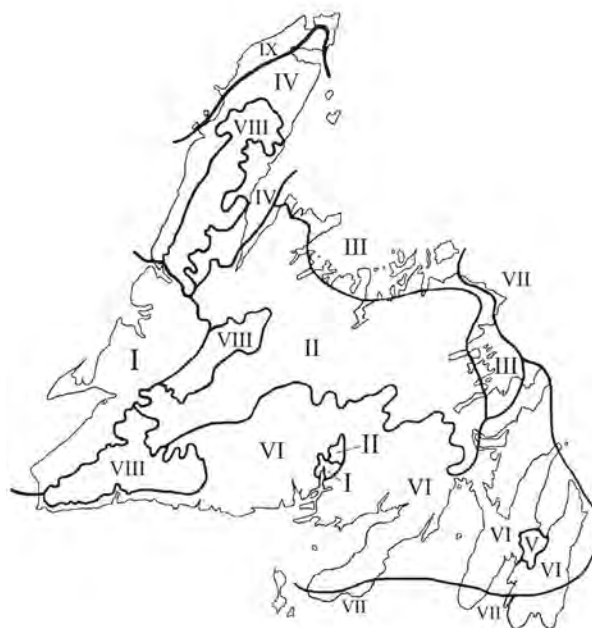


Fig. 1. The ecological subdivisions (I-Western Ecoregion; II-Central Ecoregion; III-Northern Ecoregion; IV-Northern Peninsula Ecoregion; V-Avalon Forest Ecoregion; VI-Maritime Barrens Ecoregion; VII-Eastern Hyper-Oceanic Barrens Ecoregion; VIII-Long Range Barrens Ecoregion; and IX-Straight of Belle Island Ecoregion) of insular Newfoundland (modified from Damman 1983).

Peatlands

The peatlands of Newfoundland are predominantly bogs and fens. Wells and Pollett (1983) described six bog and three fen types. Wells (1996) described two additional associations. The morphological bog types include: domed (raised) bog, plateau bog, blanket

bog, basin bog, slope bog, and string bog. The fen types are: slope fen, ladder fen, and ribbed fen. The vegetation associations of the bogs and fens of Newfoundland are as follows:

Bog associations:

1. Kalmio-Sphagnetum fusci (Pollett and Bridgewater 1973)
2. Vaccinio-Cladonietum-boryi (Pollett and Bridgewater 1973)
3. Corniculario-Ocrolechietum frigidae (Wells 1996)
4. Scirpo-Sphagnetum magellanici (Wells 1981)
5. Scirpo-Sphagnetum tenelli (Wells 1981)
6. Scirpo-Ochrolechietum frigidi (Wells and Pollett 1983)

Fen associations:

1. Calamagrostio-Sphagnetum fusci (Pollett and Bridgewater 1973)
2. Chamaedaphno-Sphanetum angustifolii (Wells 1996)
3. Scirpo-Sphagnetum papilloso (Pollett and Bridgewater 1973)
4. Potentillo-Campylietum stellati (Pollett and Bridgewater 1973)
5. Scirpo-Sphagnetum stricti (Wells 1981)

Forests

The forests of Newfoundland are boreal coniferous dominated by mixtures of black spruce, balsam fir, white spruce (*Picea glauca* (Moench) Voss), and eastern larch (*Larix laricina* (DuRoi) K. Koch). White pine, which at one time was common, has been considerably reduced by cutting and by the introduction of white pine blister rust (*Cronartium ribicola* J.C. Fisch.) from Europe. Red pine (*Pinus resinosa* Aiton) is restricted to about a dozen sites with very coarse-textured soils. Hardwood species, such as white birch (*Betula papyrifera* Marshall), yellow birch, and trembling aspen, are present in low abundance in most stands, but only occur as distinct cover types after disturbance or in unstable habitats, such as in river flood plains and talus slopes. As mentioned in the introduction, the composition and distribution of boreal forests types in a maritime climate is largely controlled by the frequency and intensity of wild and anthropogenic fires. The moist coastal portion of the island tends to be dominated by balsam fir associations and the drier interior by black spruce. The predominant disturbance agents of the fir forests are defoliating insects, particularly the eastern spruce budworm (*Choristoneura fumiferana* Clem.) and hemlock looper (*Lambdina fiscellaria*

fiscellaria Guenée). In-depth descriptions of the forest associations and subassociations can be found in Damman (1964, 1967) and Meades (1986). The following vegetation associations have been described for the forests of Newfoundland:

- Balsam fir forest association: Abietum balsameae (Damman 1964)
- Black spruce forest association: Piceetum marinae (Damman 1964)
- Hardwood association: Betuletum papyriferae (Damman 1964)
- *Kalmia*-conifer forests associations: Kalmio-Piceetum (Damman 1964), Cladonio-Piceetum (Damman 1964), Ledo-Piceetum (Damman 1964)
- Black spruce-bog forest associations: Sphagno robustae-Piceetum (Damman 1967), Sphagno fuscae-Piceetum (Damman 1967)
- Black spruce-fen associations: Carici-Piceetum (Damman 1967), Alneto-Piceetum (Damman 1964), Osmundo-Piceetum (Damman 1967)
- Alder and maple thickets: Alnetum rugosae (Damman 1964), Lycopodio-Alnetum (Damman 1967), Aceretum spicatae (Damman 1967)

Heathlands

The 2 million hectares of heath in Newfoundland represent some of the most extensive heath formations below the subarctic in North America (Fig. 2). There are many ecological parallels with the European dwarf-shrub heaths, but there are also some botanically and ecologically distinct differences. Botanically, the dominance of endemic North American shrubs, such as sheep laurel (*Kalmia angustifolia* L.), lowbush blueberry (*Vaccinium angustifolium* Aiton), rhodora (*Rhododendron canadense* (L.) Torr.), and Labrador tea (*R. groenlandicum* (Oeder) Kron & Judd), make these heaths phytosociologically distinct. Ecologically, the Newfoundland heaths appear to be fairly stable even after fire is relaxed, while European heaths reforest relatively quickly. Culturally, unlike Scottish heather (*Calluna vulgaris* (L.) Hull), the dominant Newfoundland heath shrub, *K. angustifolia*, is toxic to livestock, and, therefore, grazing by livestock or wild animals does not significantly affect successional trends. On the other hand, the more exposed heaths are dominated by Amphi-Atlantic species, such as black crowberry (*Empetrum nigrum* L.), partridgeberry (*Vaccinium vitis-idaea* L.), threetoothed cinquefoil (*Sibbaldiopsis tridentata* (Sol. ex Aiton) Rydb.), common juniper (*Juniperus communis* L.), and wavy hairgrass (*Deschampsia flexuosa* (L.) Trin.), along with circumboreal mosses and lichens, which create considerable affinities with European heath classifications developed by Böcher (1940, 1943) and

DuRietz (1942a, 1942b). A more in-depth description of the Newfoundland heaths and a comparison of North American and European heath phytosociological classifications are presented in Meades (1983).

The general distribution of forest cover and six heath types described for Newfoundland are presented in Figure 2. The vegetation associations for these types are as follows:

- Alpine heath: *Diapensio-Arctostaphletum alpinae* (Meades 1973)
- *Empetrum* heath: *Empetro-Potentilletum tridentatae* (Meades 1973)
- Moss heath: *Empetro-Rhacomitrium lanuginosae* (Meades 1973)
- *Kalmia* heath: *Kalmietum angustifoliae* (Meades 1973)
- Limestone heaths: *Empetretum nigrae* (Meades 1983), *Potentilletum fruticosae* (Meades 1983)

- Serpentine heath: *Lycnetum alpinae* (Meades 1983)

These heath associations also have numerous subassociations reflecting environmental variation in exposure, moisture, nutrients, and disturbance, for which descriptions can be found in the original references cited above. Ahti (1959) also described some Newfoundland heaths and their importance for caribou habitat.

Origin and Successional Relationships of Forest and Heath Vegetation

One cannot observe the fragmented forest-heath landscape of southern and eastern Newfoundland without wondering how this landscape evolved. Some sites still have remnants of former forest surrounded by dwarf shrub *Kalmia* heath, which suggests secondary succession after disturbance that has all but stalled. Lawns of *Empetrum*, which appear to represent a primary succession beyond the limit of forest growth,

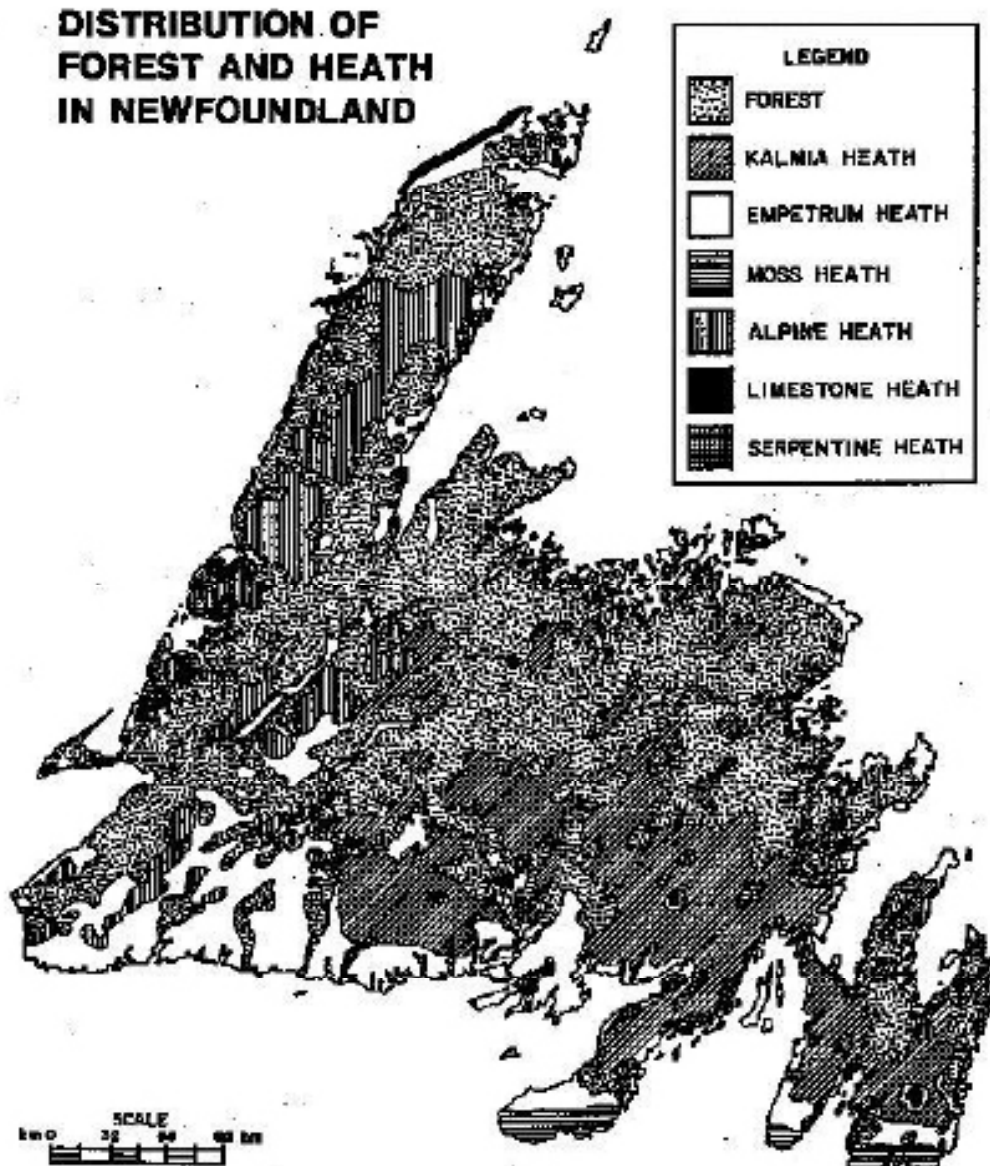


Fig. 2. Distribution of forest and heathland types in insular Newfoundland (Meades 1983).

dominate more exposed coastal headlands and ridges.

There are three basic pathways for the origin of ericaceous dwarf shrub heaths from forest on acidic soils in Newfoundland (Fig. 3). The first pathway follows an increase in fire frequency, where forests start to regenerate to fire-adapted black spruce stands after an initial fire but are wiped out by a second fire before trees can reach seed age. In the absence of a seed source over extensive areas, dwarf shrubs form the dominant vegetation. The second and probably least frequent pathway occurs where crown fires kill the trees but do not create sufficient scarification of the forest floor to promote adequate tree regeneration. The third pathway occurs where balsam fir (a species poorly adapted to fire) formed extensive natural monocultures in the wet maritime climate of eastern Newfoundland. In this situation, a single fire can decimate forests over extensive areas. The introduction of anthropogenic fires by European settlers over the last 500 years, and, more particularly, the introduction of railways in the mid 1800s, accelerated the formation of extensive heaths in an ecosystem that was not fire-adapted.

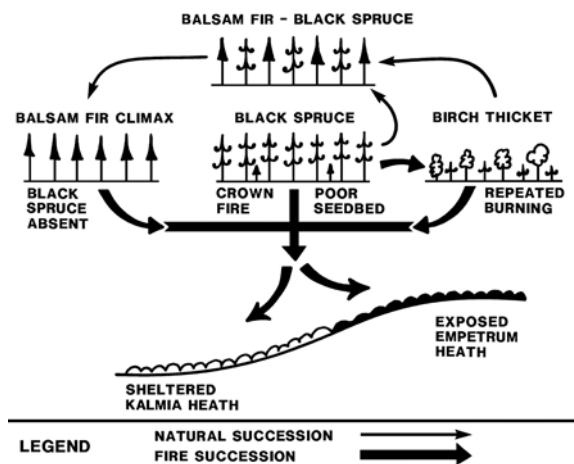


Fig. 3. Potential successional pathways for the succession of forest to *Kalmia* and *Empetrum* heath types.

While the origin of the *Kalmia* heath can be explained, their future successional status is more problematic. Investigations by Meades (1986) concluded that the ecotone between conifer forests and *Kalmia* heath has considerable stability due to the convergence of three ecological conditions. First, in the exposed landscape of open heaths, the seed viability in remnant forest islands and individual trees is considerably reduced, and the seed relay into the heath is limited to an average of 2-3 tree heights per rotation. Secondly, the substrates created by *Kalmia* litter are not conducive to the successful germination of tree seeds even when they are introduced artificially. Finally, even where conifer seedlings have established or have been planted in afforestation trials, height growth is limited to a few centimeters/year and diameter growth to a few millimeters/year. Limitations on height and diameter growth are thought to be due to

aggressive competition with shrubs for nutrients and the immobilization of nitrogen in the *Kalmia* humus (Damman 1971). Collectively, these conditions suggest that the *Kalmia* heaths are stable within the context of centuries.

Upon completion of my earlier heathland classification studies (Meades 1973), I concluded that the upland and coastal *Empetrum* heaths were equivalent to European natural, hard-ground heath formations that were probably never forested. However, subsequently, the discovery of "relic" logs that were comparable to extant growth at lower elevations under an *Empetrum* heath near tree line (about 300 m) convinced me that the situation was much more complex (Fig. 4). These "relic" logs strongly suggest that, within the last 100-200 years, the tree line was about 100 m higher than present, and the cultural decimation of the landscape through the introduction of fires caused a treeline drop. Climate may have also been a contributing factor because a similar latitudinal retreat of tree line has been documented for northern Quebec in the "little ice-age" of the early 1800s (Payette et al. 1982). Therefore, it is my conclusion that only the alpine heaths, characterized by the *Diapensio-Arctostaphyletum alpinae*, and the moss heaths, dominated by the *Empetretum-Racomitrietum lanuginosae*, represent true primary successional associations that were never forested. However, the term "alpine heath" is somewhat of a misnomer, since there are extremely exposed conditions at sea level in both southern and northern Newfoundland where these heaths occur on coastal headlands.

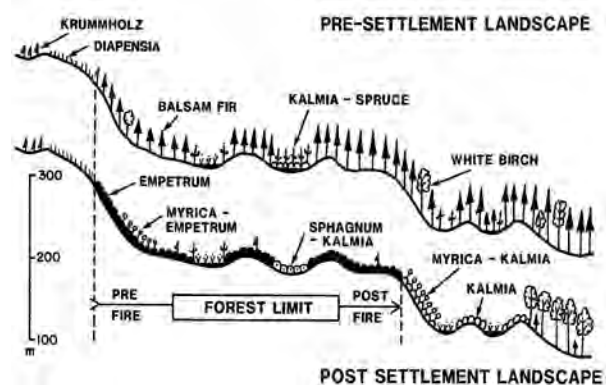


Fig. 4. Treeline drop in eastern Newfoundland in the post-settlement period.

In summary, most of the *Kalmia* heaths and *Empetrum* heaths on acidic soils in Newfoundland are derived from land that was once dominated by coniferous forest and subsequently decimated by anthropogenically accelerated fires and, to a lesser extent, harvested for fuel and building material in the post-European settlement period. The moss heaths and alpine heaths are stable types beyond the climatic limits of forest growth. The limestone heaths occur on basic soils where the acidic humus layer characteristic of *Empetrum* heaths is broken by wind

erosion and subject to extreme soil frost activity. This unstable substrate, in the form of sorted frost polygons and stripes, provides a suitable habitat for numerous shrub and herb calciphiles that would otherwise be overtaken by taller shrub and tree species. The serpentine heaths are rock barrens with very limited and specialized vegetation cover that is restricted to mainly screes and flat gravels derived from serpentine rock. The concentrations of magnesium and nickel are thought to be prohibitive to the growth of forest and other vegetation types (Roberts 1980). Collectively, the serpentine and limestone heaths provide habitat for over 130 endemic plant species referred to as the "Gulf of St. Lawrence endemics" (Morisset 1971).

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Effects of Reindeer Grazing on Boreal Lichen Rich Understory Vegetation and Its Socio-Economic Impacts

Henry Väre

Introduction

Herding semidomestic reindeer has been very important both economically and socially for the people of northern Fennoscandia. At one time, annual activities of the herdsman and their families were dictated by the rhythm of nature, as families were dependent on reindeer for their livelihood. Although this old pastoral way of life has ceased, nature still dictates the life of those whose livelihood is mainly dependent on reindeer herding.

Today, the number of full-time herders, who together with their families still obtain their main livelihood from reindeer herding, is about 800 in Finland. Most full-time herders are Saamis. There are about 6,000 Saamis living in Finland today. However, that number is dependent on how one defines who is a true Saami. About 600 of them are reindeer herders. The number of reindeer owners is about 5,000. In Finland anyone living within the area of reindeer husbandry has the right to own reindeer, in contrast to Norway and Sweden, where only Saamis are legally permitted to keep reindeer. The vast majority of reindeer owners practice reindeer husbandry as a supplement to agriculture and forestry. From an economic standpoint, reindeer herding is very important to the Saami people.

The annual total revenue from reindeer husbandry in Finland is estimated to be 60 million Euros. The main product is meat. In 1999-2000, 93,000 reindeer were slaughtered, producing 2.1 million kilos of meat. In addition to meat production, reindeer are also an extremely valuable resource for both summer and winter tourism, as they are one of the main attractions for foreign tourists.

The total area of reindeer husbandry in Fennoscandia is 423,000 km² and is located in the north. In Finland the area is 123,000 km², constituting one-third of the total surface area of the country. Reindeer husbandry is under the jurisdiction of the Ministry of Agriculture and Forestry in Finland. The country is divided into 14 different earmark districts, with 56 herding cooperatives. The responsibility of the cooperatives is to protect the reindeer stock, to sustain and promote reindeer husbandry, and to prevent reindeer from causing damage and from trespassing on the territories of other cooperatives. In Finland the semiofficial administrative board of the herding cooperatives has 16 members, and it organizes the annual Reindeer Parliament at the beginning of June. The duties of the organization are to administer reindeer husbandry in Finland, to promote reindeer husbandry and related research, and to manage relations between reindeer husbandry and the rest of society. It also approves

new reindeer earmarks and maintains a register of them. The office is located in Rovaniemi in northern Finland, and it publishes a journal for reindeer herders named *Poromies*.

Herding History

The semidomestic reindeer (*Rangifer tarandus tarandus*) was most probably bred from its ancestor, the wild mountain reindeer (*R. tarandus fennicus*), but when and where reindeer herding started remains unknown. According to one theory, reindeer herding first started in Siberia, and it then spread to the Saami areas. Another explanation suggests that the Saami discovered the domestication of reindeer themselves, independently of reindeer husbandry in Siberia.

A considerable proportion of the present semidomestic reindeer population in Finland lives north of the range of the wild mountain reindeer. Their population is restricted to the central eastern part of the country. The size of the wild mountain reindeer population increased during the 1990s, but the population and home range area is still very small compared to that of the semidomestic reindeer. The *Rangifer* genus, which includes both Eurasian reindeer and North-American caribou, inhabits the circumpolar northern boreal zone and Arctic areas. It is calculated that the total number of reindeer is about 3 million individuals.

It has been estimated that reindeer herding in Fennoscandia is about 2,000 years old. According to archaeological finds, reindeer herding may have appeared simultaneously with deer hunting. The emergence of reindeer husbandry as a source of livelihood probably began in central Norway in the 11th century. Large-scale herding then spread to the east. The total population of reindeer in the 14th and 15th centuries in central Lapland was quite small compared with that of areas in eastern Lapland and westernmost Norwegian and Swedish Lapland. However, there is little historical information about reindeer populations in Fennoscandia until the 16th century. Undoubtedly, the reindeer already moved between summer and winter ranges during an earlier era of herding, and the numbers of reindeer were obviously determined naturally by winter range resources (mainly by the availability of *Cladonia*, reindeer lichens). A similar behavioural pattern has also been suggested for the caribou in North America. In the 16th century, Finnish, Norwegian, Russian, and Swedish peoples penetrated the last frontiers of territory originally inhabited by the Saami. Since then, the policies of the dominant powers have played an increasing role in regulating the migration patterns of reindeer in the area.

In 1751 the northern border between Sweden (which then included Finland) and Denmark (which included Norway) was negotiated. The reindeer Lapps were permitted to cross the border, and as a consequence, the Saami of what today is Norway also began to use winter ranges in present-day Finland, in both the Enontekiö and Inari areas, and even further south in the Karesuando area in Sweden. This resulted in increased reindeer populations in these regions. As a consequence, Finnish reindeer-herding Lapps began to complain about overgrazing. Finland was separated from Sweden in 1809 and united with Russia. At first, this was obviously not so important to the reindeer Lapps since the Russian authorities were hardly interested in their traditional migratory patterns. The situation changed when the border between the Grand Duchy of Finland and Sweden was closed to the reindeer Lapps in 1889. The border between Norway and Sweden, too, was progressively closed to reindeer in the 20th century. Thereafter, reindeer herding was obliged to live with unnatural borders, with the routes between summer and winter ranges being closed. As a result, the number of reindeer decreased, especially in eastern Finnmark, Norway, as 50,000 Norwegian reindeer used to have their winter ranges in the Inari and Utsjoki areas, Finland. However, in Finland the number of reindeer owned by reindeer-herding Lapps did not change. Since at least some of the summer ranges had previously been situated in coastal Norway, and the winter ranges were in Finland, the Finnish pastures now had to be used all year round. The closure of the border affected Finland the most, above all the reindeer-herding Lapps of the Utsjoki area.

At the beginning of the 12th century, the number of reindeer in Finland was slightly over 100,000, and by 1959-1960 it had reached 140,000. Short-term fluctuations in the reindeer stock have occurred over the century. During the 1970s and 1980s the number increased rapidly and reached 285,000. This was considerably in excess of the highest permitted number in those days. The increase was made possible by winter feeding, vaccines, and a decrease in the number of predators (especially the bear, the glutton, the wolf, and the golden eagle) and by the use of motorized vehicles for herding. Reindeer husbandry today is thus a livelihood that uses modern technology.

In the Kola Peninsula of Russia, reindeer herding has roughly a similar early history as to that in Finland. Later, during the 1930s and 1940s, large areas in the western parts of Russia were evacuated as a result of Stalin's policy, and as a consequence, the reindeer stock decreased. At the beginning of the 1940s there were about 9,000 reindeer in the Lapland Nature Reserve by the Finnish border, and in the 1960s there were 14,000, but recently there were only 500-600. In total, there are about 40,000 reindeer in the Kola Peninsula, mainly in the central and eastern areas,

with some 2,000 animals in the Pechenga area close to Finland and Norway. The number of reindeer has increased in northernmost Norway from 53,000 in 1950 to 180,840 in 1990. The population density in the more extreme areas of the winter ranges of Finnmark, which neighbors Finland, is, however, less than one animal per square kilometer—considerably less than in Finland.

Due to the development of herding practices and the increase in the reindeer population, the pastures in Finland today are heavily grazed. Over vast areas, the number of reindeer has exceeded the productivity of lichens in the winter pastures. This is a major problem that currently awaits a solution. Reindeer are dependent on lichens only during the winter, especially late winter, when other sources of food are scarce. In seasons when the ground is not covered with snow, they eat a variety of plants, and in autumn, fungi are also an important source of nourishment. The bad pasturage conditions are evidenced by the fact that the slaughter weight of calves has decreased in areas where the winter ranges are most heavily exploited. Consequently, the reindeer have to be fed with hay or imported lichen during the winter. This practice started in 1974, and it is the most significant single contributory factor to maintaining the present high number of reindeer. The maximum number of reindeer was consequently lowered from a previous 220,900 animals to 203,700 over the current 10-year period. On average there are 1.8 animals per square kilometer, but the herds are not naturally evenly dispersed. Because of the uneven herd dispersal, the pastures in the other Nordic countries and in the Kola Peninsula are now in a better condition.

Overgrazed Pastures in Finland

In the Nordic countries, an understory rich in reindeer lichens is found on dry, oligotrophic sandy soils, usually under a pine canopy. It is particularly such forests that are heavily grazed by reindeer. In the first Finnish national forest inventory (1921-1924), the lichen-rich *Cladonia* forest type accounted for about 12 % of the forested land, but in the third inventory (1951-1953), this forest type accounted for only 1 %. In Finland, pastures are located in the northern boreal zone.

Several authors have described the effects of reindeer grazing on vegetation. Many studies are speculative in nature, however, since exclosures have been only rarely used (for literature see Väre et al. 1995, 1996). In lack of ungrazed control areas, it is impossible to say which of the characteristics of vegetation are due to reindeer grazing and which are natural. Succession in vegetation takes place slowly, and in Finland it takes at least 60 to 80 years after fire for vegetation to reach climax stage dominated by *Cladonia stellaris* (see Väre et al. 1995).

The effects of grazing by reindeer on the vegetation

structure of dry, oligotrophic heaths was studied by comparing ungrazed and grazed sites using exclosures established 30 to 50 years earlier. These sites were compared to "natural" pine heath forests all around Finnish Lapland and the Kola Peninsula. Forests of the western Kola Peninsula are practically ungrazed. The dominant tree species was *Pinus sylvestris*, with some stands including undergrowth of *Betula pubescens* and *Picea abies*. The study sites were situated in intermediate parts between oceanic and continental sectors of the northern boreal zone. The altitude of the study sites varies between 100 m and 280 m above sea level, the mean being about 200 m. The mean annual temperature is -1.2 °C, effective temperature sum (the sum of daily average temperatures > 5 °C) 750 °C (600-950 °C), and the annual rainfall 450 mm.

Remote sensing revealed a sparse lichen cover in birch and pine forests and on treeless heaths over large areas of eastern and northern Finland. The line of Finnish-Russian border, or more precisely of the reindeer fence that follows the border, can clearly be distinguished in a satellite composite image (Väre et al. 1996). The main consequence of grazing is the reduction of lichens, especially of *Cladonia stellaris*, and an increase of bryophytes and bare patches of soil. Also, other reindeer lichens (formerly genus *Cladina*) are replaced by other lichen species, such as minute cup lichens (*Cladonia* spp.), *Placynthiella uliginosa*, *P. oligotropha*, and *Trapeliopsis granulosa*, and by bryophytes, such as *Dicranum* spp. and *Pleurozium schreberi* (see Väre et al. 1995). The biomass of vascular plants, mainly *Calluna vulgaris*, *Empetrum nigrum*, and *Vaccinium vitis-idaea*, was reduced at grazed sites, although their coverage was not influenced. Biomass is given in Table 1.

The effects of grazing on ground vegetation were studied also by nonmetric multidimensional scaling (NMDS), by analyzing the vegetation coverage incorporated by abiotic and other biotic data. Ungrazed reindeer lichen dominated sites and bryophyte rich sites were at the extremities in the NMDS ordination space and extensively grazed sites in between. These ungrazed lichen rich sites were characterized by certain *Cladonia* species and by *Flavocetraria nivalis*, and by one bryophyte, *Polytrichum piliferum*. High Al and Fe concentrations and pH were observed in the same area of the NMDS ordination space. Bryophyte rich sites had abundant *Barbilophozia hatcheri*, *Hylocomium splendens*, and *Pleurozium schreberi*, and in addition, certain dwarf shrubs such as *Ledum palustre* and *Vaccinium myrtillus*. High Mn concentration, species number, coverage of bare ground, and thick humus layer were observed in the same area with bryophytes, together with low Al, Fe, and pH. Most species were fairly indifferent with regards to habitat choice in these dry, oligotrophic Scots pine forests, but the species diversity increased towards bryophyte rich sites (Väre et al. 1995).

At grazed sites coverage of lichens and bryophytes was about the same, totaling on average 64 %. The coverage of dwarf shrubs was generally about 20 %. Floristically, the grazed sites were characterized by a low coverage of *Cladonia stellaris* (4 %), a high coverage of *C. arbuscula*, *C. uncialis* (in total 36 %), and a relatively high coverage of *Dicranum* spp. (7 %) compared with ungrazed sites (0.25 %). *Calluna vulgaris* was characteristic dwarf shrub.

At the fenced ungrazed sites the dominant species was *C. stellaris* (63 % coverage), and the total coverage of lichens was 92 %. At the adjacent grazed sites the total coverage of lichens was 75 %, and the coverage of *C. stellaris* was only 4 %. The total coverage of mosses was 1 % and 12 % in ungrazed and grazed sites, respectively. Among mosses, *Dicranum* spp. especially benefited from grazing.

Discussion

As forest fires are today controlled, the trampling and grazing of lichens by reindeer is one major factor regulating the vegetation cover in the northern boreal zone, and it has led to a significant alteration in the plant cover of the forest floor in Finland. Other factors are clear-cutting and ploughing of the forests.

It has been assumed that in most areas of Finnish Lapland, *Cladonia stellaris* would be the dominant species without grazing (see Väre et al. 1995). Grazing changes vegetation towards a so-called "first reindeer lichen stage" that naturally occurs 30 to 40 years after fire where *Cladonia arbuscula* would be the dominant species. When grazing pressure increases, it has been natural to assume that grazing would lead to the increase of ephemeral crustose lichens (e.g., *Placynthiella uliginosa*, *P. oligotropha*, *Trapeliopsis granulosa*), minute cup lichens (*Cladonia* spp.), and ephemeral bryophytes (e.g., *Pohlia nutans*, *Polytrichum piliferum*), thus making vegetation similar to early successional stages after fire (see Väre et al. 1995). Our study indicates that this shift may occur only in xeric sites, whereas in most sites, grazing brings along increased abundance of forest bryophytes (*Dicranum* spp., *Pleurozium schreberi*). In Finland these bryophytes are traditionally regarded as indicators of more productive forest site types. Many authors in North America assume that bryophytes follow reindeer lichens in post-fire succession at the age of about 150 years (see Väre et al. 1995), in an extent that these forests have been called "Pleurozium woodland." This increase in bryophytes may be dependent on site factors or geographical area and climate (see Väre et al. 1995). The recovery of *Cladonia stellaris* vegetation is very slow; in northern latitudes it takes 60 to 80 years before it reaches the climax stage of the forests.

It was a new and somewhat surprising observation that reindeer grazing favors forest bryophytes.

	Ungrazed		Grazed		p-value, df = 7		
	x	SE	x	SE	Grazing	Site	Interaction
Biomass/%							
Lichens	790	130	86	16	0.000	0.023	0.513
Bryophytes	7	4	21	13	0.123	0.007	0.757
Dwarf shrubs	38	12	14	4	0.005	0.006	0.451
Bare ground	9	4	20	6	0.040	0.020	0.079

Table 1. Biomass ($g\ dw\ m^{-1}$) of bryophytes, lichens, and dwarf shrubs and bare ground coverage (coverage in %) at ungrazed and grazed sites; the p-values indicate level of significance between ungrazed and grazed sites, between sites, and their interaction effect.

Bryophytes as the favorite was obvious both in the ordination and in a more compelling way when exclosures were compared with adjacent grazed areas. No signs of increased bryophyte abundance were evident at ungrazed sites, where reindeer lichens, especially, spatially displace lichens of “first reindeer lichen stage” (mainly *Cladonia* spp.) and tiny bryophytes (like *Barbilophozia* spp., *Pohlia nutans*, and *Polytrichum* spp.).

The effects of reindeer grazing have not been directly investigated in forest vegetation, but several authors have speculated on the effects of grazing in extant vegetation (see Väre et al. 1995, 1996). Most studies have delimited the vegetation type by the dominance of lichens in the forest floor. Bryophyte rich sites are easily excluded from the survey, or regarded as belonging to a different vegetation type than slightly grazed vegetation rich reindeer lichens. Consequently, when scientists assumed that they were comparing sites with different grazing pressure, they may have been comparing more xeric sites (assumed strongly grazed) to less xeric sites (assumed slightly grazed). It was assumed that the decrease in estimated area of the Finnish *Cladonia* site type in Lapland in forestry surveys from 1922 to 1956 was due to a narrowing concept of the *Cladonia* site type. However, our recent study indicates that the abundance of bryophytes may have increased due to increasing reindeer numbers (Väre et al. 1995, Väre et al. 1996).

High cover of bryophytes is regarded as an indicator of more productive forest sites in Finland. In our study sites there was hardly any corresponding change in timber productivity, albeit of increased bryophyte abundance. Pine tree volume did not depend on species composition of the understory vegetation. Classifying bryophyte rich sites to more productive types reflects the belief that vegetation is controlled only by abiotic environment and disregards any role of herbivory.

Stereocaulon is known to characterize the initial stage of lichen stands or disturbances in the lichen carpet. In our study, *Stereocaulon* was abundant only on one

site. This area of Finland is known to be characterized by *Stereocaulon* in grazed stands, but it also seems to be fairly rare here, as it is in Sweden. In certain areas of continental Canada, *Stereocaulon* displace *Cladonia stellaris* in succession of *Picea mariana* forests (see Väre et al. 1995).

Most of the species occurring at the study sites were wide-ranging generalists that are well adapted to minor environmental changes in their habitat. Lichens and bryophytes, especially, enable comparisons between continents by means of lichen synusiae, since the similarity of lichen flora in distant areas is greater than that of vascular flora (see Väre et al. 1995). Comparisons between sites may become biased, however, if successional stages are not recognized. Heavy grazing resulted in heterogeneous, patchy occurrences of species. In our study there was a difference both in species abundance and in species composition. Various *Cladonia* species easily invade at sites where the soil has been disrupted, in the present case by reindeer.

Socio-Economic Impacts

Trampling and grazing by wild reindeer (*Rangifer tarandus fennicus*) is suspected to have influenced the Fennoscandian tundra at least as strongly as prudently managed winter grazing by semidomesticated reindeer (*R. tarandus tarandus*). Today, reindeer herding is not prudent in Finland, however. The number of semidomestic reindeer has for a long time been over the carrying capacity. Since the beginning of the 1900s, vaccines, predator control, manipulation of reindeer population size, control of age and sex ratios, and especially winter feeding all allow for a higher reindeer population. However, the ranges do not support continuous high numbers in the far north, and mass starvation occurs periodically. Starvation has already forced lower reindeer numbers in Finland.

The most important and most challenging task today is to find a way to integrate diverse interests regarding reindeer pastures. In order to maintain a vigorous reindeer husbandry, it is necessary to resolve the

problem of both the quality and the sufficiency of the pastures. An extensive proportion of the reindeer-herding area consists of coniferous woodland, and it is thus commercially exploited by forestry. These two sources of livelihood are often in conflict, as efficiency demands extensive clearing and ploughing of the soil for conifer seedling recruitment, which tends to lower the quality of the pastures. Other conflicts are caused by the mining industry and increasing tourism, especially in areas that are important for calving. The third major problem is the question of legal ownership of the pastures in the reindeer-herding area. Currently, areas are owned by the state, but there are dissenting opinions that are waiting to be addressed. A fourth problem is the conflict between nature conservation and reindeer herding. The reindeer is an important source of food for the big predators, mainly the glutton, bear, wolf, and golden eagle. In 1997, about 3,400 reindeer were found killed, mainly by these big predators. These are protected endangered species, but they cause herders economic losses, and thus reindeer are often illegally hunted and killed. The fifth major problem is perhaps currently the greatest. The age distribution of herdsmen is very biased towards the older classes, and there are too few young persons continuing their work. Thus, the problems concern matters that are also socio-economic and political in

origin. Durable development requires stable herding conditions with pastures of good carrying capacity. Therefore, the main task is to develop a system of optimal usage that will permit the ranges to be adapted for various purposes and still maintain the economy of reindeer herding as an important goal. In the future, new threats may arise. Possible climate warming will have a huge impact on reindeer husbandry.

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Flora Conservation, or Towards a System of Sustainable Use of Biodiversity in Sweden

Mora Aronsson

Introduction

There is a long tradition of nature conservation in Sweden, but since the last decade with the entrance of Sweden into the European Union (EU), there has been a shift in environmental goals from conservation to sustainable use. However, there are some important tools currently in place for conservation:

- National Red List of Threatened Species – Three generations of Red Lists have been made the last decade and are an important record in all work concerning biodiversity.
- Encyclopedia of Swedish Flora and Fauna – The encyclopedia provides knowledge and baseline information on species in Sweden. The project will last for 20 years and will describe all Swedish multicellular species. It will be published in both a book series and on the Internet.
- Environmental goals – The Swedish government has presented 16 goals that will lead future work on the environment, especially biodiversity.
- Habitats Directive and Natura 2000 – The Habitats Directive is the European Union’s legislation on preserving biodiversity in the European Union with a network of protected areas, Natura 2000, and is established and working in Sweden.
- Species Gateway – This is an Internet portal for reporting, storing, and presenting observations on species (<http://artportalen.se/>).
- Action Plans for Species and Habitats – Plans are ongoing or under preparation for nearly 500 species in Sweden.

These tools are just the starting point for understanding biodiversity and for addressing conservation issues. These ongoing activities are challenging, but the real challenge is to evaluate how effective we are in our work thus far and assess current and future needs. In the European Union (EU) Habitats Directive there are statements about how an evaluation system might be established, but no details. For the last five years, intense work has been going on to create a reporting system for the EU that would tell the status and direction of biodiversity in the Union. A very important question to answer is, “How much is enough?” (i.e., establishing “reference values” for the range of habitat and species). Each country in the EU should state their area of habitat concern, or how big a population is that is needed

to preserve the EU Habitats Directive’s concept of “favorable conservation status” for the future (see: http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm). In the 2007 report on conservation status of the habitats and species in the EU Habitats Directive, member states have to establish reference values for the range of habitat and species, area of habitat, and population of species. In the next report in 2013, the concept of reference values will possibly expand to allow for more parameters.

Establishing Reference Values

In Sweden, the approach for establishing reference values was in two steps:

1. The first step (Fig. 1) was to sort out all the cases where the reference value (i.e., “How much is needed for “favorable conservation status?”) and the actual value (i.e., “What are the values at the moment?”) were the same. In most cases the two values are the same for most of the habitat ranges and for a rather large part of the area for habitat and population of species.
2. The second step was to set the reference value on all that should have a higher value than present. This work was based on as much relevant data as possible: historical data, distribution analysis, connectivity, viability analysis, potential vegetation, and more.

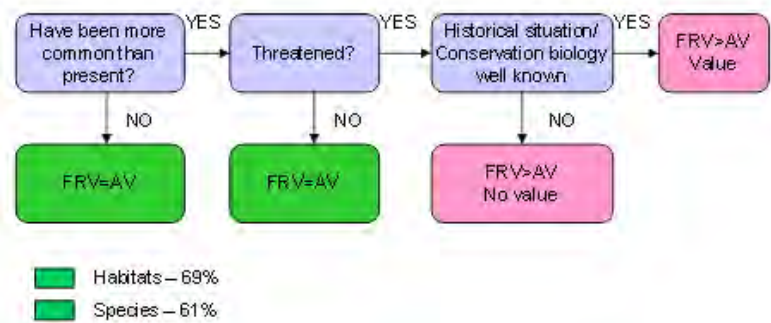


Fig. 1. Shows the first step in establishing reference values (FRV = favorable reference value; AV = actual value).

Evaluation of Conservation Status

The system to evaluate conservation status for habitats and species in the EU Habitats Directive was created from several years of discussions and expectations made by the 25 EU member countries. The guidance was very general in the Directive and it was up to the European Commission and EU member states to interpret the evaluation.

Conservation status for habitats and species in the

EU Habitats Directive has four parameters that should be reported for each habitat and each species:

Evaluation for Species (Fig. 2):

1. Range
2. Population
3. Habitat for the species
4. Future prospects

Evaluation for Habitats (Fig. 3):

1. Range
2. Area
3. Structures and functions
4. Future prospects

For each parameter, each member state should report an actual value and a trend for the range, population, and area of reference value. A color scheme indicating conservation status is assigned to each of the four

species or habitat parameters (see Figs. 2 and 3, green = favorable status; amber = unfavorable status - inadequate; red = unfavorable status - bad; white = unknown or insufficient information). The last step in the evaluation is to combine the results of the four parameters and obtain the final result for the species or the habitat.

During 2007 all EU member states should report the conservation status of habitats and species. The European Commission will compile the results to be included in a EU report in the summer of 2009.

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Parameter	Conservation Status for Species			
	Favourable ('green')	Unfavourable - Inadequate ('amber')	Unfavourable - Bad ('red')	Unknown (insufficient information to make an assessment)
Range	Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference range'	Any other combination	Large decline: Equivalent to a loss of more than 1% per year within period specified by MS OR more than 10% below favourable reference range	No or insufficient reliable information available
Population	Population(s) above 'favourable reference population' AND reproduction, mortality and age structure not deviating from normal (if data available)	Any other combination	Large decline: Equivalent to a loss of more than 1% per year (indicative value MS may deviate from if duly justified) within period specified by MS AND below 'favourable reference population' OR More than 25% below favourable reference population OR Reproduction, mortality and age structure strongly deviating from normal (if data available)	No or insufficient reliable information available
Habitat for the species	Area of habitat is sufficiently large (and stable or increasing) AND habitat quality is suitable for the long term survival of the species	Any other combination	Area of habitat is clearly not sufficiently large to ensure the long term survival of the species OR Habitat quality is bad, clearly not allowing long term survival of the species	No or insufficient reliable information available
Future prospects (as regards to population, range and habitat availability)	Main pressures and threats to the species not significant; species will remain viable on the long-term	Any other combination	Severe influence of pressures and threats to the species; very bad prospects for its future, long-term viability at risk.	No or insufficient reliable information available
Overall assessment of CS	All 'green' OR three 'green' and one 'unknown'	One or more 'amber' but no 'red'	One or more 'red'	Two or more 'unknown' combined with green or all 'unknown'

Fig. 2. Evaluation matrix for species (CS = conservation status).

Parameter	Conservation Status for Habitat			
	Favourable ('green')	Unfavourable – Inadequate ('amber')	Unfavourable - Bad ('red')	Unknown (insufficient information to make an assessment)
Range	Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference range'	Any other combination	Large decrease: Equivalent to a loss of more than 1% per year within period specified by MS OR More than 10% below 'favourable reference range'	No or insufficient reliable information available
Area covered by habitat type within range	Stable (loss and expansion in balance) or increasing AND not smaller than the 'favourable reference area' AND without significant changes in distribution pattern within range (if data available)	Any other combination	Large decrease in surface area: Equivalent to a loss of more than 1% per year (indicative value MS may deviate from if duly justified) within period specified by MS OR With major losses in distribution pattern within range OR More than 10% below 'favourable reference area'	No or insufficient reliable information available
Specific structures and functions (including typical species)	Structures and functions (including typical species) in good condition and no significant deteriorations / pressures.	Any other combination	More than 25% of the area is unfavourable as regards its specific structures and functions (including typical species)	No or insufficient reliable information available
Future prospects (as regards range, area covered and specific structures and functions)	The habitats prospects for its future are excellent / good, no significant impact from threats expected; long-term viability assured.	Any other combination	The habitats prospects are bad, severe impact from threats expected; long-term viability not assured.	No or insufficient reliable information available
Overall assessment of CS	All 'green' OR three 'green' and one 'unknown'	One or more 'amber' but no 'red'	One or more 'red'	Two or more 'unknown' combined with green or all 'unknown'

Fig. 3. Evaluation matrix for habitat (CS = conservation status).

Evaluation of Monitoring Local Floras in Arctic Russia

Sergey A. Balandin

Introduction

I would like to tell you briefly about the Russian experience of creating a network of biodiversity monitoring sites in the Asian Arctic at the level of "local floras." By the term "biodiversity," I refer to the diversity of life on levels of organization above the level of organism. Usually we can speak about taxonomic biodiversity (kingdoms [plants, animals, fungi etc.], phyla, classes, orders, familia, genera, species etc.) and biodiversity of communities (in local, regional, or global level); species diversity is the number of species. By the term local floras, I refer to plant taxonomic biodiversity on the local (landscape) level, or a sample of the floristic situation in a given geographical locality: a local flora is a checklist of plants of any landscape. The concept includes a comparative analysis of local floras in a network created to permit the determination of zonal floristic trends, gradients of taxonomical parameters, and the spatial structure of species diversity of local and regional floras.

These investigations were executed under the management and active participation of one of the outstanding Russian botanists, Boris Yurtsev (1932-2004), together with researchers of the Far North Vegetation Laboratory of the Komarov Botanical Institute of the Russian Academy of Sciences (St. Petersburg, Russia).

The first practical results of this long-term research are described in three publications (Yurtsev et al. 2001, 2002, 2004).

Monitoring Biodiversity at the Level of Local Floras: Significance and Principles of Creating a Network of Biodiversity Monitoring Sites

The use of quantitative methods in comparative floristic geobotany has long been a tradition in Russia. One of the first approaches toward monitoring biodiversity in Arctic and high-mountain floras was by Russian taxonomist and botanist-geographer, Alexander Tolmatshev (1903-1977), who fostered an interest in these problems among his pupils and followers, one of whom was Boris Yurtsev. One of the basic levels of long-term monitoring of plant biodiversity is the level of local or elementary flora, which roughly corresponds to the flora of a landscape (Yurtsev 1992, 1997).

In Russian scientific literature dealing with comparative floristics, the term "local flora" (Sheljag-Sosonko 1980, Yurtsev 1982, Tzvelev 1988) is understood as the full territorial set of plant species of a given geographical site. In the same sense, the terms "test

of flora" (Yurtsev 1975) and "flora of the surroundings of the geographical site" are quite often used.

Individual species, populations, processes, or plant communities are usually considered an object of phytomonitoring. An understanding of local floras as basic units of biodiversity monitoring developed within the framework of the scientific school of comparative floristics of A.I. Tolmatshev, in which the above-named concepts were formulated and demonstrated for the first time. The qualitative structure of flora is conservative, and if the scale of predicted global climate changes is taken into account, it is possible to expect fundamental changes, even in the set of local flora species, and not just in their levels of abundance.

Without carrying out stratification with floristic division into districts of an investigated territory, confident delimitation of elementary natural regional floras (ENRF), as a rule, is impossible. Therefore, selectively constructed tests of a flora should generally be local, as the technique of studying them coincides with the technique of revealing ENRF. In general, local floras probably coincide with ENRF, although its demonstration would require continuous, detailed inspection of the entire territory.

The Convention on Biological Diversity at the Rio de Janeiro Summit in 1992 assumes not only an estimation of the biodiversity of countries and natural regions, but also a periodic reassessment or monitoring of the same parameters on which the estimation of concrete local floras in different time intervals was carried out. Different time conditions of local floras are compared by using the same measures of similarity as those used for comparing local floras at different sites and time intervals.

Therefore, an inventory should be carried out with the task of subsequent reinventory in mind. For previously investigated floras, where inventory was not conducted in the manner referred to above, it is desirable to monitor after an investigation and include, for example, the exact location of rare species and prepare an estimation of species activity (e.g., the role of a species in the vegetation of a landscape). The main components of species activity (Yurtsev 1968) are commonness or rarity of species, breadth of ecological amplitude, distributional occurrence, and general number of individuals of a species in the landscape.

As in the limits of phytochoria (= phytogeographical regions) with an identical macroclimate, a patchiness of landscapes is observed, reflecting distinctions in

a set and a parity of relief form and lithology. The network of sample sites for monitoring should be representative, not only of the biochorological diversity of territory, but also in the relation to ecotopes. Hence, a certain density in the network of monitoring sites is required.

For monitoring climatogenic change in biodiversity, a special value is calculated by fixing the distribution and condition of indicator species that are found in the concrete territory close to one climatic border; consequently, they are sensitive to climate changes.

Creating a Network of Biodiversity Monitoring Sites in the Russian Arctic

One of the basic levels of long-term monitoring of plant biodiversity is at the level of local floras, or the concrete florae, approximately corresponding to floras of landscapes. It is possible to allocate six basic functions to a network of biodiversity monitoring sites, with these functions revealing spatial, temporal, and space-time trends of biodiversity. These six basic functions are used to:

1. Reveal trends in biodiversity distribution of plant cover at the landscape level (including a variety of sites, ecotopes, and biotopes).
2. Analyze the factors causing biodiversity distribution, both recent (particularly climatic) and historical.
3. Forecast changes in biodiversity trends in plant cover of defined regions for different climate change scenarios.
4. Reveal and analyze long-term changes in the system (climate-vegetation cover).
5. Accumulate a long-term (in a geochronological scale) series of direct observations of such processes as evolution (phylogenesis), florogenesis, phylocoenogenesis, endogenous successions, etc.
6. Reveal changes in certain species (such as species at risk and relicts) and their geographical populations and provide direction on necessary measures to prevent their extinction.

A database of the biodiversity monitoring sites in the Asian Arctic has been created from data collected since 1955 by the Far North Vegetation Laboratory of the Komarov Botanical Institute. This database includes 130 principal local floras and 30 additional local floras supplementing a spectrum of ecotopes in the event that any "irreplaceable" ecotopes are absent in the principal local floras of the same phytochoria chosen from approximately 500 local floras. The distribution of local floras included in the network of the biodiversity monitoring sites in the Russian Arctic is shown on the map in Fig. 1.

The database provided the opportunity to select local floras for inclusion in a network of monitoring. This

selection was made by following certain principles, of which the most important are: (1) ensuring that all botanical-geographical areas and its divisions are represented such as a certain sector of a subzone; and (2) including the presence of unique botanical items such as relic species or complexes of species, local endemics, and plants of rare ecotopes. Additionally, valuable to the purposes of biodiversity monitoring are local floras of ecotones and botanical-geographical boundaries. The vegetation cover (flora, vegetation) of these boundary areas may react sensitively to climate changes since contrasting and vicarious biogeographical elements (zonal, sectoral—e.g., continental and oceanic) usually coexist or adjoin here; therefore, the species which drop out due to climate change may quickly be replaced by species from the adjoining climatic area.

An important requirement for local floras is sufficient species diversity. Estimation of this important parameter can serve as data for species richness in comparison with other local floras of the same botanical-geographical area having similar landscape conditions and ecotopes. The inclusion of data on the period (date and duration) of investigation of a local flora and names of the collectors are necessary. Some additional factors to be considered for inclusion in local flora sites in a biodiversity network are:

1. Distribution of species by their activity
2. Ecological-coenotical characteristics of each species at site of investigation; this is especially important for indicator species
3. Precise topographical data on the most valuable floristic finds
4. Level of knowledge on species composition of other plant taxonomic groups (especially bryophytes and lichens)

It is also very valuable if the same site is geobotanically surveyed and if there exists a significant number of geobotanical descriptions or lists of species of partial floras or coenofloras.

Selection Criteria of Local Floras in a Biodiversity Monitoring Network

A. Reasons for selection

1. Representativeness of a (floristic) subzone or district
2. Uniqueness (rare ecotopes, rare communities, finds of rare relic species, endemics)
3. Ecotonal position at a boundary of zones, subzones, or districts

B. Completeness of species composition

1. Estimating numbers of species richness by comparing to other local floras of the same area

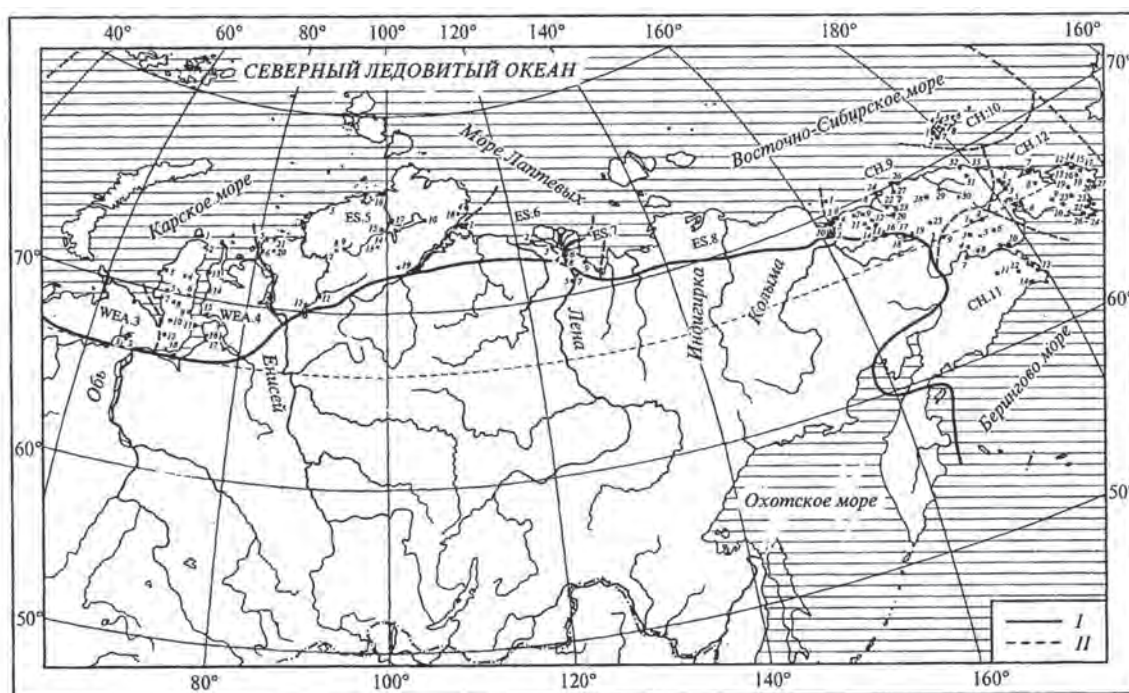


Fig. 1. The distribution of local floras included in the network of the biodiversity monitoring sites in the Russian Arctic.

2. Continuation and dates of investigation—not less than 2 weeks

C. Presence of annotations of the floristic list

1. On the commonness and/or rarity of each species or its landscape activity (breadth of ecological amplitude, occurrence of distribution/sporadicness, general number of individuals in the landscape)
2. On the distribution of ecotopes or plant communities
3. Exact place information of especially rare species

D. Additional information

1. Investigation of bryophyte and lichen composition
2. Presence of vegetation characteristics (quantity of descriptions, presence of a large-scale vegetation map, etc.)

Key Components of Principal Local Floras

A local floras database includes the list of local monitoring sites and essential data about each site. For each local flora included in the network of biodiversity monitoring sites, the following key components should be completed:

1. The standard name of the local flora site
2. Topographical and geographical position
3. Geographical coordinates
4. Dates and duration of investigation

5. Collectors
6. Size of the investigated site (as a radius or distance between extreme points along a straight line) on a map
7. The botanical-geographical zone and subzone (or boundary between these zones and subzones) to which it belongs
8. Name of the floristic district
9. Characteristics of vegetation, relief, landscape, lithology (presence of the acidic, basic, silicate, carbonate rocks, etc.) with literature references
10. Range of absolute and prevailing heights in the local flora territory
11. List of vouchered species and specimens deposited in herbaria
12. Degree to which collections have been processed (labeling, identification of specimens; completely or in part processed)
13. Number of species and subspecies in local floras
14. Bibliographic reference: presence and character of publications: (a) list is published completely; (b) interesting finds; (c) data have resulted in a sketch of the vegetation, etc.
15. Reasons for inclusion of local floras in a network of biodiversity monitoring sites
16. The author (compiler) of the list and date of compilation with indication of the latest updates and additions
17. The author (compiler) of the database data entry and date it was completed

The database is created in a special version of the information system IBIS, developed by Andrey Zverev from Tomsk State University. Analysis of biodiversity spatial trends on the basis of the local flora network is illustrated, based on four parameters of the local flora sensitivity to thermoclimatic zonation. These parameters are:

1. Ratio of three thermoclimatic factors (latitudinal, longitudinal, and latitudinal-altitudinal) in local floras
2. Number of circumpolar species in the local floras; it is known that there is an increase from south to north in Arctic regions
3. Ratio between numbers of Asteraceae and Poaceae species—the two largest families of northern flora—of which Asteraceae generally disappear in the northernmost subzone - high arctic tundras (= polar deserts)
4. Number of ligneous species (woody plants in the broad sense)

It is noted that zonal changes for some parameters are distinct and unequal in six of the analyzed subprovinces within three provinces of the Arctic floristic region. For instance, the ratio of circumpolar species (1:3) and the ratio of the leading families Asteraceae/Poaceae by the number of species is almost constant from the south northwards in four subprovinces of the Chukotka Province (Continental Chukotka, South Chukotka, the Wrangel Island, and Beringian Chukotka). The situation is quite the opposite in the two western subprovinces of the Asian Arctic, Yamal-Gydan and Taimyr. The Taimyr and Beringian Chukotka subprovinces are remarkable in an increased ratio of cryophytic plants (2:3 even in the hypoarctic subzones) at the expense of a decrease in hemicryophytes (1:4).

Thus, the most sensitive parameter to zonal climate changes—primarily the quantity of summer warmth—was the parameter of the ratio of the three latitudinal divisions of flora cryophytes: (arctic, meta-arctic, and arctic-alpine species), hemicryophytes (hypoarctic and hypoarctic-mountain species), and non-cryophytes (boreal, arctic-boreal, boreal-mountain, polyzonal, etc.). Moreover, these features in separate sectors are sharply shown here.

Gradients of Taxonomic Parameters of Local and Regional Floras in the Asian Arctic

Comparative cartographic analysis has been performed on 93 local floras in the biodiversity monitoring site network in the Russian Arctic. Under comparison are flora taxonomic parameters, such as species diversity, families/species structure, the composition of the taxonomical spectrum at the family level, the relation (index) of the two leading families Cyperaceae /Poaceae by numbers of species, and the proportion of the main mega-taxa such as phyla

and classes of vascular plants. Local floras in six subprovinces of the Arctic floristic region (Yurtsev 1994) using the same parameters were compared with the mean figures for local floras of the same subprovinces (Yamal-Gydan, Taimyr, Continental Chukotka, Wrangel, South Chukotka, and Beringian Chukotka). Most of the parameters reveal a latitudinal (zonal) trend, but in different longitudinal sectors, their range and intensity are as a rule dissimilar. In some parts of the zonal transects, the gradient of certain parameters—more often in the hypoarctic group of subzones—is poorly expressed; sometimes it is replaced by a macro-mosaic of the local floras by the given parameters, particularly in the Chukotka sector—and a weak zonal trend exhibits itself against the background of a mosaic of local floras. In general, the longitudinal gradient has a step-by-step, block-like character. Differences between Yamal-Gydan and the Chukotka subprovinces, as well as the intermediate features in the Taimyr subprovince, are interpreted in terms of dissimilarities in their florogenesis: the Late Pleistocene Age of the former which passed through the destructive effect of Quaternary glaciations and sea transgressions and the continuous development of the Chukotka flora as one of the central parts of Beringia since the Late Neogene. The latter is more balanced and richer as a multispecies system.

Spatial Structure of Species Diversity of Local and Regional Floras

The floristic analysis involves data on 96 local floras from six subprovinces of the Arctic Floristic Region in the biodiversity monitoring network at the landscape level. Results of this analysis show that:

1. The subzonal position of the local floras in the monitoring sites is determined. Greater species diversity of local floras (1.5-2. times greater) is shown from subzones in Chukotka as a part of Beringia in comparison to the youngest Yamal-Gydan (West Siberian) subprovince.
2. Five complementary approaches to the arctic-boreal ecotone—the area of overlapping marginal parts of the ranges of cryophilous and non-cryophilous, mostly boreal species—are suggested with gradual (step-by-step) reduction of robust woody life forms, particularly of gymnosperms that dominate the neighboring taiga (boreal) zone. From the southern hypoarctic tundra subzone northwards, the height of the dominant woody plants decreases resulting in their life stratum decreasing.
3. Factors controlling taxonomic diversity (first, species diversity) and its increase and support are systematized. The methodology is based on the structured concept (model) of a regional flora as a set of concrete or local floras (a sort of “cells” of plant cover). It permits the use of two main techniques: (a) mapping concrete values of the respective parameters of local

floras in the form of circle diagrams or figures in circles; and (b) creating a table with mean values reflecting the magnitude and dispersal of concrete parameters.

4. Taxonomic analysis of the richest local floras of five subprovinces was performed, which revealed factors of increasing species diversity, such as the age of flora, the history of its formation, and the continuous development on the territory against the background of the natural history of the country, as well as the differentiation of its climate and the matrix of habitats, including lithology. The analysis indicated that the richest regional floras in Beringia had a long history of continuous development with long alternating periods of contrasting climate phases and the highest diversity of habitats. The richest local floras quite often include parts of two to three landscapes and/or a combination of acidic and basic rocks; sometimes they have a unique meso- or macrohabitat with relict plant complexes such as extensive steppe bluffs in Chukotka tundra or plant groupings around thermic-mineral hot springs; or, among common, species-rich meso- or macrohabitats but not ubiquitous, intrazonal ones—sea coast associations or well-developed flood-plains with deep thawed or locally absent permafrost and some allochthonous elements in the partial floras. The combination of the above factors may be in different combinations.
5. Species diversity depends on the level of local flora richness (special species diversity) and on spatial diversity of local floras within the phytochorion. An important parameter of special species diversity is the mean species diversity of local floras. The factors of spatial diversity are illustrated by comparative analysis of local floras of various subprovinces. Herein belongs: (a) share of species diversity of local floras forming species diversity of subprovince or a subzone within it, that is, the normalized species diversity-recorded for all individual local floras (a1) and the mean one for the subprovince (a2), the error of the mean (b), or (c) share of species diversity from species diversity of a subprovince. It was shown that the percentage of species diversity of local floras is more or less constant for a certain subzone of different subprovinces despite an apparent difference in absolute numbers among subprovinces. Other parameters include the distribution of the rarest species among local floras, as well as the mean difference in species diversity of all pairs of local floras within the phytochorion, combined with the number of local floras per phytochorion.

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Panarctic Flora Project Update

Presented by Lynn Gillespie on behalf of David Murray and Reidar Elven

The first goal of the Panarctic Flora (PAF) project is to prepare an authoritative annotated checklist of all arctic vascular plant species. The following information is given for each species:

1. Accepted name, basionym, synonyms, and type information
2. Chromosome numbers and ploidy level
3. Geographic distribution, status, and frequency in both phytogeographic and bioclimatic zones
4. Notes including comments and discussion on taxonomic and nomenclatural problems and proposed solutions

The PAF team has and continues to confront several major challenges in writing the checklist. The first challenge is reconciling up to three different regional taxonomies. Species boundaries, levels of recognition, and names have often varied considerably among the countries of North America, Europe, and Russia. The second challenge is incorporating the many taxonomic and nomenclatural changes based on new, molecular phylogenetic data. The morphological-based angiosperm classification is now undergoing major changes at all taxonomic levels, including the splitting up of large familiar families (e.g., Scrophulariaceae) and common arctic genera (e.g., *Potentilla* split into five genera). The third challenge is reconciling the taxonomy and nomenclature with several major concurrent flora projects. In particular, Flora North America (FNA) volumes are being published at the rate of two to three per year. At the end of 2006 following the publication of *Poaceae* (volume 24), the PAF team began checking for taxonomic differences and determining if changes in the checklist were

necessary. A fourth challenge is the lack of good, workable taxonomic treatments for several common arctic genera. For example, *Papaver* has been a nomenclatural and taxonomic nightmare. By using molecular data, Heidi Solstad (Oslo) sorted out the arctic members of the genus *Papaver* and is now writing up her results. Solstad's data support six Poppy species in the Canadian Arctic Archipelago in contrast to the two generally recognized previously.

The PAF checklist is currently a large electronic document (more than 1,000 pages). All taxa have now been treated. Work is progressing on the editing of the document with the final incorporation of new taxonomic and nomenclatural changes. The goal is to produce version 1.0 of the PAF checklist as a working World Wide Web document in the very near future. The document is too large and the text probably too subject to revision for a hard copy version to be practical. A web document will allow for the incorporation of changes based on comments from users, taxonomic revisions, and new FNA volumes. New web versions of the checklist will be released as changes in the data necessitate newer versions.

Upon completion of the checklist, editors will begin to add keys to species and infraspecific taxa so that users of the checklist can more easily identify taxa.

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Botanical Research in Arctic Canada: Floristics and Systematics

Lynn Gillespie

Current and proposed plant systematic and floristic research in Arctic Canada is outlined:

1. Flora of the Canadian Arctic Archipelago project
2. Flora of the Canadian Arctic (proposed International Polar Year [IPY] project)
3. Fieldwork activities
4. Arctic grass research
5. Other collaborative projects and initiatives

Flora of the Canadian Arctic Archipelago Project

The Flora of the Canadian Arctic Archipelago project is a comprehensive flora and interactive identification guide to the 349 vascular plants of the Canadian Arctic Islands in a CD-ROM format (Fig. 1). For each species and subspecific taxon, the following information is given: nomenclature (including synonymy and types), description, cytology, distribution, habitat, ecology, traditional knowledge, and a discussion of taxonomic difficulties and relevant literature. Color photographs, illustrations, and distribution maps are also provided for each species. The DELTA (DEscription Language for TAXonomy) format used in the guide allows for easy, interactive identification.

This collaborative project was initiated and led by Dr. Susan Aiken, Canadian Museum of Nature (until her recent retirement in 2005), and involved numerous authors. Dr. Aiken was inspired to produce a modern synthesis of the flora of Canada's Arctic Islands as a replacement for Porsild's *Illustrated Flora of the Canadian Arctic Archipelago* (Porsild 1957, 1964), which is an excellent, standard flora of the area but now much outdated. This new flora was published in December 2007 as a CD-ROM by NRC Research Press, National Research Council of Canada, Ottawa (<http://pubs.nrc-cnrc.gc.ca/eng/books/index.html>). The CD-ROM contains the first complete version of the "new" flora of the Canadian Arctic Archipelago and is fully revised with new data, discussions, photos, and updated maps that supercede all previous web releases (Fig. 1).

Flora of the Canadian Arctic (Proposed Project)

The Flora of the Canadian Arctic project proposes to document all vascular plant species in the Arctic ecozone of Canada and to make this information widely available. The proposal was initially written as an International Polar Year (IPY) submission and was conceived by L. Gillespie and L. Consaul,

Canadian Museum of Nature. Co-applicants on the IPY submission included L. Brouillet (Institute of Plant Research [IRBV], Université de Montreal), B. Bennett (NatureServe Yukon), E. Angulalik, and K. Darren (Kitikmeot Heritage Society, Cambridge Bay), plus numerous international and Canadian collaborators. The proposal was accepted as an international IPY project but did not receive IPY-Canada funding. Currently, research is taking place and progress is being made on several components of the proposed project, but work on other components is on hold until adequate funding is secured.

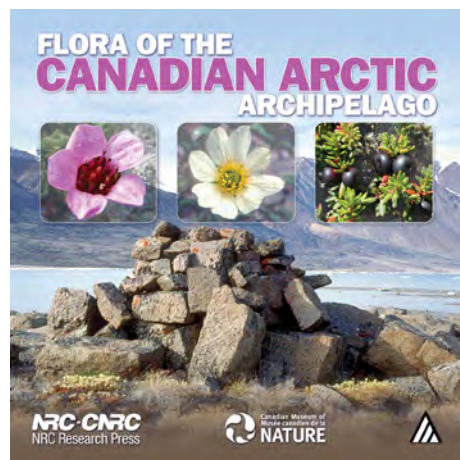


Fig. 1. CD-ROM cover of *Flora of the Canadian Arctic Archipelago: Descriptions, Illustrations, Identification, and Information*. The CD-ROM may be cited as: Aiken, S.G., Dallwitz, M.J., Consaul, L.L., McJannet, C.L., Boles, R.L., Argus, G.W. Gillett, J.M., Scott, P.J., Elven, R., LeBlanc, M.C., Gillespie, L.J., Brysting, A.K., Solstad, H. & Harris, J.G. (2007): *Flora of the Canadian Arctic Archipelago: descriptions, illustrations, identification, and information retrieval*. [CD-ROM] NRC Research Press, National Research Council of Canada, Ottawa.

The main components of the proposed Flora of the Canadian Arctic project are:

1. Producing the Canadian Arctic Flora
2. Developing a Northern Canada Plant Database
3. Conducting fieldwork
4. Documenting and analyzing patterns of diversity in space and time
5. Undertaking traditional knowledge research
6. Developing the Arctic Flora Canada web portal

Canadian Arctic Flora

This component proposes to create the Canadian Arctic Flora. This flora would incorporate all vascular plants

above tree line in Canada, approximately 800 species, more than twice as many as treated in the *Flora of the Canadian Arctic Archipelago*. We propose to publish the flora in several formats: hard-copy book, CD-ROM, and as a web-based E-flora. All versions would include species taxonomy, descriptions, distribution maps, keys, illustrations, information on ecology, etc. In addition, CD-ROM and E-flora versions would feature interactive identification and many color images illustrating habitat, habit, and diagnostic features. The E-flora version would also allow for constant updating as new information becomes available. A secondary goal would be the production of a field guide to plants of the Canadian Arctic, a user-friendly field guide for amateurs produced in hard copy and interactive web versions.

Northern Canada Plant Collection Database

Our proposed Northern Canada Plant Collection Database would be a cyber-database network of herbarium specimen data from the Northwest Territories (NWT), Nunavut, and the Yukon. Databases in a GBIF-compatible format housed in multiple institutions across Canada (and internationally) would be electronically linked and would be fully accessible with interactive search and mapping capabilities. This format would allow for continuous updating by each partner institution as new collections and new information on taxonomy and ecology become available.

While this component requires the most funds to fully implement, several advances have been made over the last year. The collections of the National Herbarium of Canada (vascular plant collection-CAN) at the Canadian Museum of Nature, which holds the largest collection of arctic plant specimens in Canada, would serve as the base of the network. Databasing of Nunavut and Northwest Territories (NWT) vascular plant specimens at CAN is about one-third complete and work is ongoing. We have established a network of partner institutions interested in becoming part of the Northern Canada Plant Collection Database network and in sharing data via an Arctic Plant Web Portal. Interested partners include: Agriculture and Agri-Food Canada, which holds the second largest collection of arctic plants in Canada and is particularly rich in plants of the Yukon; Université Laval, with a database of 90,000 records from northern Québec-Labrador; Parks Canada; and the Canadian University Biodiversity Consortium, which has recently received major funding to establish a web-based database of university biological collections.

This Northern Canada Plant Collection Database would serve multiple functions: as a research tool for the understanding of arctic flora; as a tool to highlight areas in the Canadian Arctic needing further botanical exploration; as a source of data for analyses of diversity patterns; and as baseline data for long-term,

broad-scale monitoring programs. The database and distribution maps would be made available as a source of data for secondary analyses with geo-spatial and environmental models, such as predictive analyses of floristic change in climate change modeling.

Fieldwork (see Fieldwork Activities below)

Documenting Patterns of Diversity

One long-term aim of the Flora of the Canadian Arctic Project is to use data from the Northern Canada Plant Collection Database and knowledge from the development of the Flora of the Canadian Arctic. This data and knowledge will help determine the present status of arctic plant diversity and distribution by quantifying spatial and temporal variability patterns of plants in the Canadian Arctic. This baseline data will aid in understanding past and present changes in the distribution and diversity of arctic plants and may also help predict broad-scale changes in arctic vegetation resulting from environmental change. Data on rare species, ecological dominants, and herbivore food plants will be particularly important in conservation and ecosystem management plans. As the base of the food chain in terrestrial arctic ecosystems, changes in the distribution of arctic plant species may have direct impacts on the survival and well-being of herbivores and, thus, indirect impacts on the well-being of Northerners. One of the main, long-term strategies of plants in adapting to climate change is change in distribution, including range shifts. Accurate knowledge of present day species ranges and the ability to detect changes in these ranges is of prime importance.

To determine the present status of plants in the Canadian Arctic, we propose to carry out comparative analyses of plant collection data to identify patterns in diversity and distribution, including species of special interest and areas of maximum diversity ("hotspots," ongoing research with S. Talbot, U.S. Fish and Wildlife Service). Geospatial analyses will be used to correlate patterns of diversity and distribution of arctic plants with environmental variables. By using information from our analyses as baseline data, we are exploring the feasibility of establishing a program to monitor broad-scale changes in plant distribution at representative sites across the Arctic.

Undertaking Traditional Knowledge Research

Our proposed Flora of the Canadian Arctic Flora IPY project included a traditional knowledge research component that was to be carried out in partnership with the Kitikmeot Heritage Society, Cambridge Bay. The goals of the research component were to document plant use by Inuit in the Central Arctic, document Inuit names for plants and terms used in plant gathering and use, and to further the preservation of the Central Arctic Inuit dialect. Funding is needed to carry out this

part of the project.

Arctic Flora Canada Web Portal

The proposed Arctic Flora Canada web portal at the Canada Museum of Nature would serve as the outreach and educational component of the project. The portal would be the central access point for the Northern Canada Plant Collection Database, the Flora of the Canadian Arctic E-flora, research products, and information on current research and fieldwork. An attractive, user-friendly interface with levels of increasing complexity would encourage use by the Canadian public and other northern countries, as well as by botanists and polar researchers internationally. Users would have access to such features as: Arctic Plant Species Pages, including numerous images, distribution maps, and ecological information; real-time interactive database search and mapping; and images of type specimens. Funding is required to implement this web portal.

Fieldwork Activities

We plan to undertake fieldwork in the Canadian Arctic with the following goals:

- Explore botanically unknown or little known areas
- Focus on areas most affected by climate change

- Complete inventories of a select set of localities
- Initiate long-term monitoring of the local flora

Over the next several years we plan fieldtrips to northern Baffin Island, south-central Ellesmere Island, southern Axel Heiberg Island, southwestern Victoria Island and the adjacent mainland, and other areas of continental Nunavut.

An analysis of collections from the National Herbarium of Canada (CAN) and the Vascular Plant Herbarium at Agriculture and Agri-Foods Canada (DAO) that were databased for the Flora of the Canadian Arctic Archipelago project revealed several areas in the Canadian Arctic for which there are few or no collections (Fig. 2). Rather surprisingly, large areas of northern Baffin Island and parts of Ellesmere and Devon Islands were determined to be very poorly collected. Botanists have also neglected large parts of continental Nunavut, especially in recent times. Several new national parks here are in need of botanical inventory work, for example, Ukkusiksalik (Wager Bay).

Collecting baseline floristic data is of prime importance given that climate change is already occurring in the Arctic, and this ecozone is predicted to be the one that will be most affected. A warming climate will result in northward range expansion of native flora and the likely spread of non-native weeds. One area of the

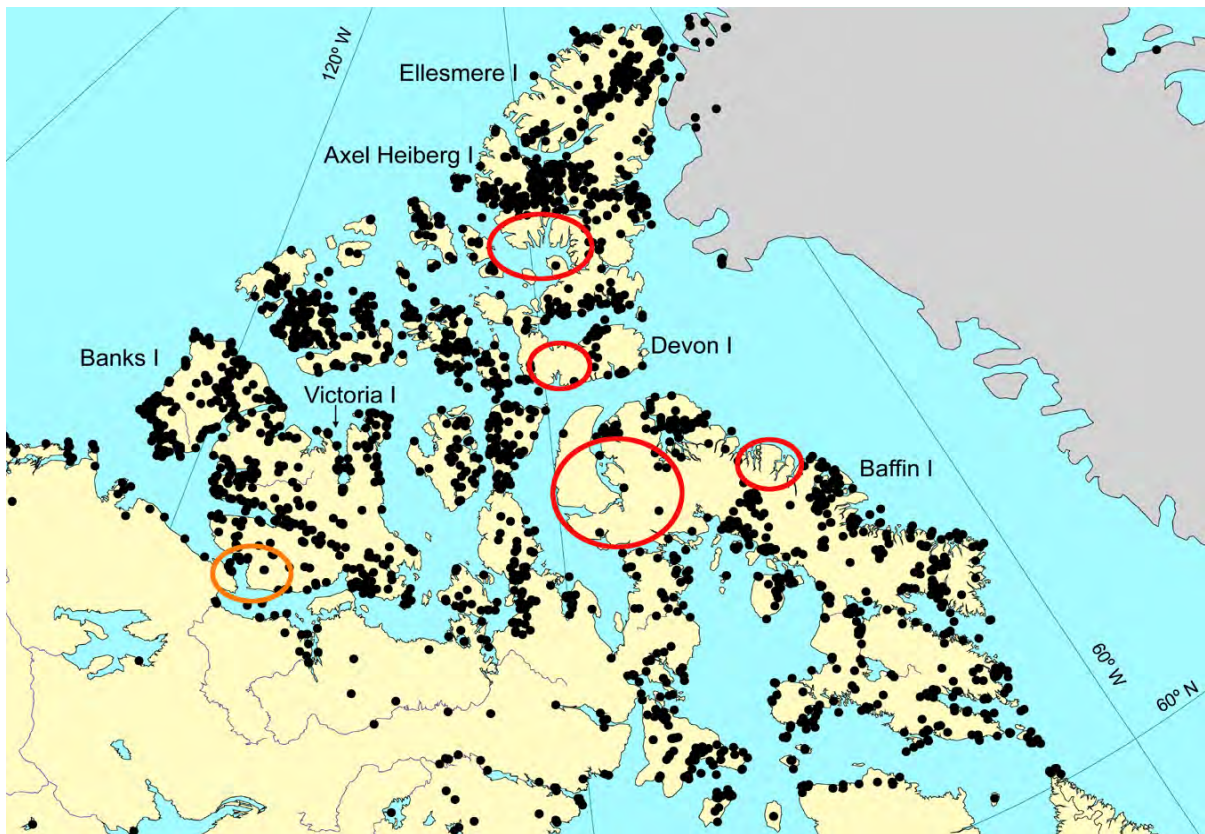


Fig. 2. Map of the Canadian Arctic showing the location of all collections databased for the Flora of the Canadian Arctic Archipelago (FCAA) project. Red circles indicate four areas for which few collections were available; the orange circle highlights an area of botanical interest in southwestern Victoria Island where vegetation change should be monitored.

arctic islands that is likely to be first and most heavily impacted is southwestern Victoria Island given its short distance to the mainland and the relatively rich mainland flora (Fig. 2, see orange area).

We now have complete inventories of about 20 sites across the Canadian Arctic Islands. Over the next several years we aim to increase the number of sites to 40 or more to enable increased, in-depth comparisons of flora diversity across the Arctic and to establish baseline data for a possible long-term monitoring program.

Arctic Grass Research

Research on arctic grasses has been a main focus at the Canadian Museum of Nature for more than 20 years. Most recently, this research has focused on species circumscription, phylogeny, and floristics of bluegrasses (*Poa*) and alkali grasses (*Puccinellia*).

Intensive research on alkali grasses of the Canadian Arctic has helped delimit species in this taxonomically difficult genus and has revealed a complex relationship between diploid and polyploid species (Consaul et al. 2005, 2008a, 2008b, 2008c). In the course of this research, several species new to science have been discovered, including a new diploid and a new octoploid species from Banks Island (Consaul et al. 2008a, 2008b, and unpubl.).

Our worldwide molecular phylogeny of *Poa* and related genera placed the arctic species in a broad phylogenetic context and has revealed a hybrid origin for several arctic species (Gillespie & Soreng 2005, Gillespie et al. 2007, Gillespie et al. unpubl.). The boreal-subarctic seashore species *Poa eminens* appears to be an ancient intergeneric hybrid (Gillespie et al. 2006, and unpubl.). The widespread circumarctic species *Poa abbreviata*, not previously suspected to be a hybrid, was shown to be of intersectional hybrid origin (Gillespie et al. 2006, and unpubl.).

Canadian Museum of Nature researchers and collaborators have contributed several floristic treatments of arctic grass genera to Flora North America, including *Puccinellia* (Davis & Consaul 2007) and *Phippsia* (Consaul & Aiken 2007). In addition, research on *Poa* is currently underway for the Flora of northern Quebec-Labrador (Flore du Quebec-Labrador nordiques).

Other Collaborative Initiatives

Several ongoing and proposed initiatives involving arctic plant collections and conservation in Canada are outlined below.

Funding has been secured to initiate a Northwest Territories Plant Collection Database, a collaborative effort led by Suzanne Carriere, Government of NWT,

Environment and Natural Resources, Yellowknife, NWT, Canada. The goal is to create a centralized NWT collection database to serve as a research tool for biologists and environmental science professionals that is based particularly in northern Canada. Botanists are currently databasing and imaging all NWT plant specimens at the Vascular Plant Herbarium at Agriculture and Agri-Foods Canada.

The Canadian University Biodiversity Consortium (www.canadianbiodiversity.org) recently received major funding for cataloguing Canadian biodiversity, integrating the information, and making it universally available. The focus of this project is on databasing plant, insect, and mycological collections at universities across Canada. Another focus is to increase infrastructure to house collections, including a new building to house the L'Herbier Marie-Victorin, the largest herbarium in Quebec and the third largest in Canada. This cataloguing effort is the first large and broadly supported initiative in Canada for establishing a cyber-database of biological collections and has the potential to expand into a Canadawide biological database.

Marilyn Anions, NatureServe Canada, is currently seeking funding for the proposed project, "Conservation Status Ranks for the Vascular Plants of the Northwest Territories and Nunavut, Canada."

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Panarctic Checklist of Lichens

Hörður Kristinsson

The idea to compile a checklist of lichens and bryophytes for the whole Arctic region came up at the Conservation of Arctic Flora and Fauna (CAFF) Flora Group meeting in Helsinki in March 2001. The CAFF members expressed that an atlas similar to *The Atlas of Rare Endemic Vascular Plants of the Arctic* (Talbot et al. 1999) should be prepared for lichens and bryophytes since they are also a very important part of Arctic flora. The CAFF members also expressed that a complete list of lichens and bryophytes for the Arctic should be approached in a similar way as the Panarctic Flora Checklist that had been initiated by the Panarctic Flora (PAF) working group led by Reidar Elven. At a later stage, rare and endemic species to the Arctic should be filtered out of that list. It was also agreed that Hörður Kristinsson, Icelandic Institute of Natural History, should lead the work on lichens. Later, René J. Belland, University of Alberta, Edmonton, Canada, took the responsibility for the checklist of arctic mosses.

A simple Microsoft Access database was constructed to store the data. The definition of the southern limit of the Arctic was the same as had been worked out by Arve Elvebakk, Boris Yurtzev, and Reidar Elven for the Panarctic Flora Checklist. Applying a sectorial division of this checklist was also adopted from the

PAF group, and the data were stored separately for each region (Fig. 1). The main references used for the different regions are:

- North America: Thomson 1984, 1997 and Brodo 2001
- Greenland: Hansen, unpub. database
- Arctic Iceland: Kristinsson, unpub. database
- Svalbard, Norway: Elvebakk & Hertel (1997)
- Arctic Norway: Timdal 2002 (online database)
- Russian-Siberian Arctic: Andreev et al. (1996)

Besides these main references, about 100 other publications and websites have been used to compile the checklist of lichens and bryophytes. The *Panarctic Lichen Checklist* was opened online in Oct. 2006 (see: http://archive.arcticportal.org/276/01/Panarctic_lichen_checklist.pdf) and updated in Dec. 2006 (Kristinsson et al. 2006). A list of lichens for separate regions can be accessed by selecting map/intermap/distribution map, and then by clicking on the desired region. A table showing total list of taxa with absence/presence marked for every region is available as a

Number of species in regions

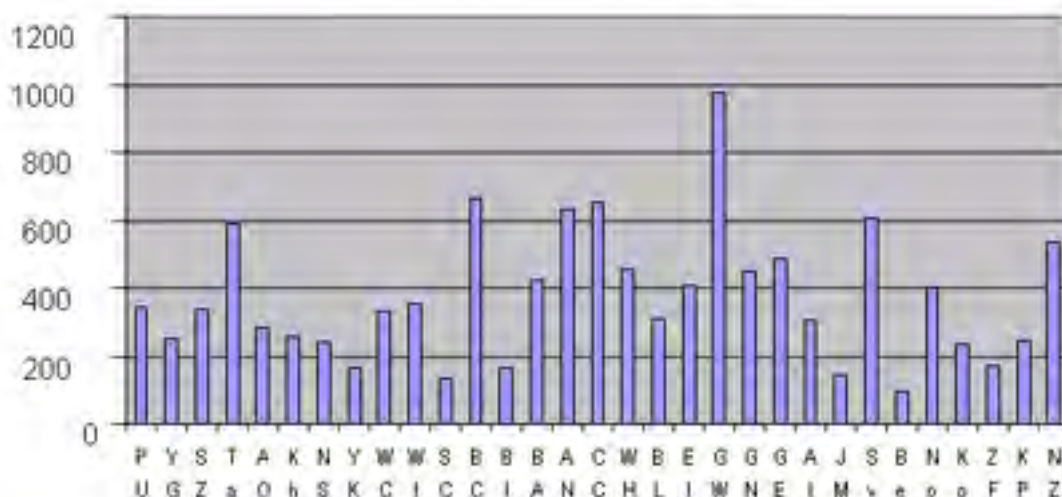


Fig. 1. Number of species recorded in each of the Panarctic regions (PU = Polar Ural-Vaigach Island; YG = Yamal-Gydan; SZ = Severnaya Zemlya; Ta = Taimyr Peninsula; AO = Anabar-Olenyok, Kh = Kharaulakh; NS = Novosibirskie Islands; YK = Yana-Kolyma; WC = Chukotka West; WI = Wrangel Island; SC = Chukotka South; BC = Chukotka East; BI = Beringian Islands; BA = Beringian Alaska; AN = Alaska North; CC = Central Canadian Arctic; WH = West Hudsonian; BL = Baffin Island, Labrador; El = Ellesmere; GW = Greenland West; GN = Greenland North; GE = Greenland East; AI = Arctic Iceland; JM = Jan Mayen; Sv = Svalbard; Be = Bear Island; No = Arctic Norway; Ko = Kola Peninsula; ZF = Franz-Josef Land; KP = Kanin-Pechora; NZ = Novaya Zemlya).

PDF file. Cooperation has been established with Eric Steen Hansen, Botanical Museum, Copenhagen, for information on Greenland and Mikhail Zhurbenko, Komarov Botanical Institute, St. Petersburg, for Russian language publications and lichenicolous fungi. In May 2007, the *Panarctic Lichen Checklist* contained 1,890 species of lichens and lichenicolous fungi (true lichens—1,679). The number of species recorded from each region varies from 100 to 200 in poorly recorded areas to more than 600 in well-recorded areas (Fig. 1), and species numbers are the greatest in West Greenland with nearly 1,000 species.

A list of about 200 recent synonyms has also been entered into the database. Problems have been with correlating the nomenclature of the different lichen lists. For example, in some regions different taxa at the subspecific level are listed for some of the collective species, and in other regions, species are listed in a wider sense. This means that the list of subspecies in these cases is very imperfect, even though the collective species is present in all regions. We have tried to eliminate double records of species under different names, but such cases may still be found. In certain areas like Novaya Zemlya, Russia, 16 of the recorded species have only been recorded once from the type locality, and these species have not been seen since a first recording.

The last addition to the lichen checklist has been a rough quantitative estimate of how common or rare a species is within and outside the Arctic. Inside the Arctic the numbers 1 to 5 were used as a rating scale, with 1 being very rare and 5 being widely distributed and common. Outside the Arctic the rating scale used the terms "absent," "rare," "scattered," and "common." The term, "common outside the Arctic" is used in a very broad sense and may be used for species that are common outside the Arctic but only in a very limited area.

At present (May 2007), 103 of the 1,679 lichenized species are still unrated. Of the 1,576 species that have been rated, 112 are probably endemic to the Arctic, and 185 have been rated as rare outside the Arctic. Many of the endemic species are known only from the type locality and have never been seen again after their first discovery. These cases should

be studied further before we can accept them as valid species.

The next steps for the *Panarctic Lichen Checklist* will be to complete the rating of the last 100 species still unrated and then concentrate on collecting better information on the distribution of the rare and endangered species.

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Floristic Subregions of the Canadian Arctic Archipelago

Stephen S. Talbot, Michelle C. LeBlanc, & Susan G. Aiken

Phytogeographers have long been aware of plant species range restrictions and recognized that plant species can be grouped on the basis of similarities among their geographic distributions (Hagen 1986). A long-established method of examining floristic affinities among geographical areas is the detection of what are termed “floristic units” or “floristic regions” (Stott 1981). These floristic units can be differentiated on the basis of their distinctive taxa. The Canadian Arctic Archipelago is one area in the Arctic that despite the availability of good regional floras, floristic variation has not been fully assessed. The recent examination of the database that was used in support of the *Flora of the Canadian Arctic Archipelago* (Aiken et al. 2007) has provided an opportunity to review the prospect of floristic subdivisions within the Canadian Arctic Archipelago. By updating and analyzing the database and constructing a model of floristic subregions, our current work in progress hopes to identify floristic variation in relation to defined geographical areas or subregions within this part of the Arctic.

The Canadian Arctic Archipelago occurs fully within a floristic region termed the “Arctic Province” by Takhtajan (1986). Although the area of the Canadian Arctic Archipelago is vast (1,424,500 km²), Takhtajan did not further subdivide it floristically. Earlier work by Porsild (1955) classified the North American Arctic into four major provinces: (1) arctic parts of Alaska and Yukon, (2) arctic parts of continental Northwest Territories and Ungava, (3) Arctic Archipelago, and (4) arctic parts of Greenland. Porsild noted that these provinces might be further subdivided, but because of the uniformity of their climate and topography, he thought such a subdivision would be difficult.

Origin of the Database

Possible subdivision of the Canadian Arctic Archipelago floristic provinces was brought to light while preparing the *Flora of the Canadian Arctic Archipelago* (Aiken et al. 2007) and in examining and updating the plant distribution database used to create the flora. By pooling updated collection data, a wealth of information was developed for specific sites. First, database errors and unconfirmed specimens were resolved. It was recognized that some areas were visited many times by different botanists with different taxonomic interests. Doubtful records were confirmed by re-examining specimens and by discussing and resolving controversial nomenclature with a North American authority on the taxon. Database errors resulting from compilation of information by different people over many years were corrected, and in some cases, records were eliminated altogether. The high number of species recorded at specific sites indicated

sites that could be considered relatively well-known with few additional species added. Criteria for inclusion in the database were: (1) the site flora must contain approximately 100 or more species, and (2) the sites must be representative of the spectrum of geographic variation within the Canadian Arctic Archipelago. Twenty-five sites met these criteria, and species lists were compiled from each site. Figure 1 indicates the names and locations of these sites.

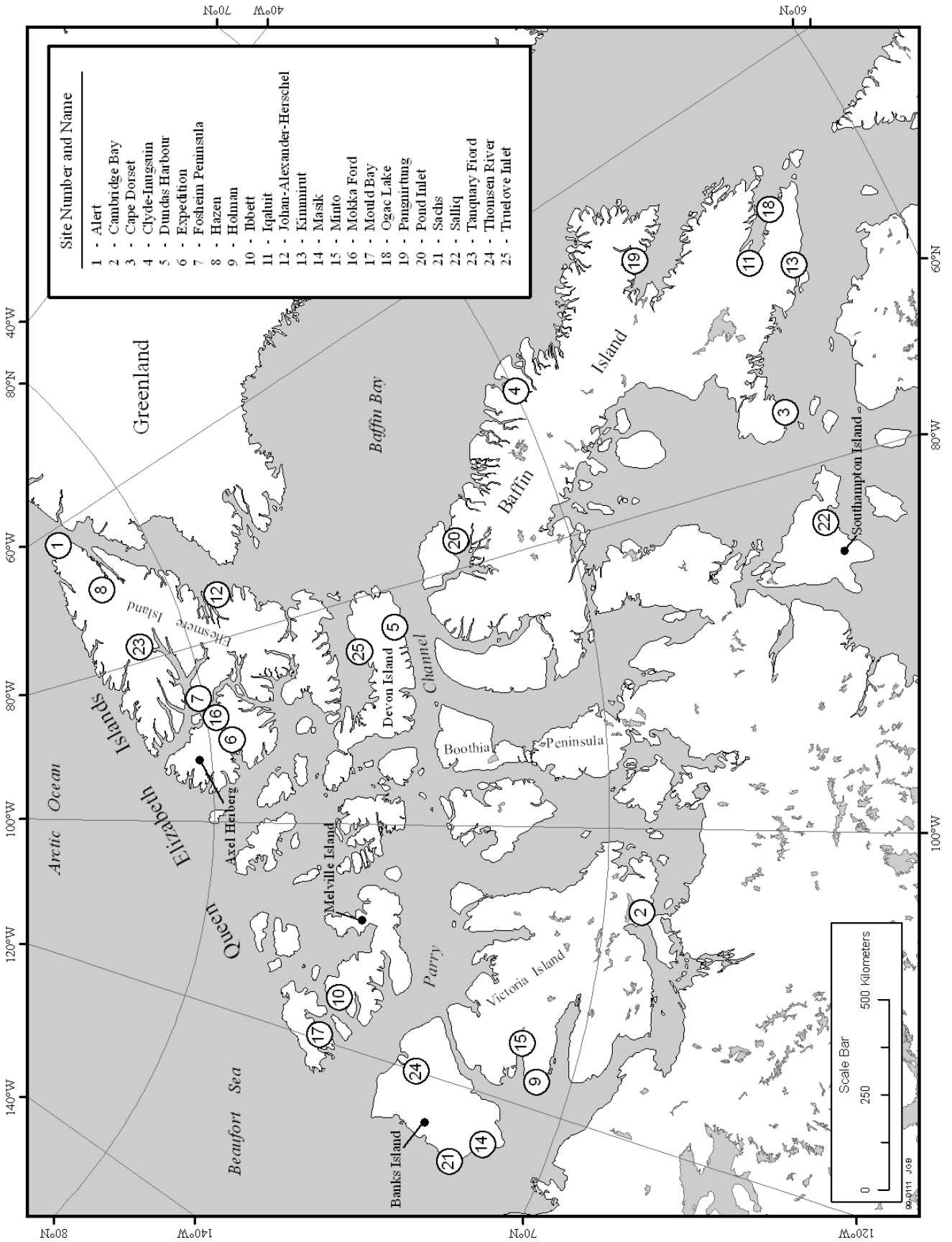
Study Objectives

One of the principal objectives of phytogeography is the identification and classification of floristic elements and their corresponding geographic areas (Weber 1965). Our study is designed to explore floristic variation within the Canadian Arctic Archipelago, from south to north and from east to west. We intend to develop a model of floristic subregions based on the 25 sites within the Canadian Arctic Archipelago and define floristic subregions with greater precision than was previously available. The objectives of the study are to: (1) establish a floristic database of vascular plant species recorded from these relatively few, well-botanized sites; (2) determine if floristic subgroups can be distinguished among the sites and species of the Canadian Arctic Archipelago by examining (a) which sites have similar floristic composition, and (b) which species have similar occurrence in the context of the sites investigated; (3) compare the results with previous floristic studies and concepts; (4) identify the main floristic types using numerical classification and ordination; and (5) interpret the floristic types in relation to selected site and geographic factors such as climate and latitude.

Methods

The data to be analyzed will be based on comprehensive species lists from 25 sites in the Canadian Arctic Archipelago. The sites to be included were selected from a north-south gradient (Southampton Island in the south and the northern tip of Ellesmere Island in the north) and from an east-west gradient (Baffin Island in the east and Banks Island in the west) (Fig 1). Taxonomy and nomenclature follow Aiken et al. (2007). Multivariate analysis will use presence and/or absence data for clustering and ordination in a number of software packages: Mulva-5 (Wildi & Orloci 1990), Juice (Tichý 2002), ClustanGraphics-7, Canoco 4.5 (Ter Braak & Smilauer 2002), and WinKyst 1.0 (Smilauer 2003). A resemblance matrix of sites will be measured by using the similarity ratio (van der Maarel's coefficient), clustering proximities will be assessed by using increase in sum of squares, and ordination will employ nonmetric multidimensional scaling.

Fig. 1. Location of the Canadian Arctic Archipelago study area and map of the study sites.



Preliminary Results

Our initial results indicate that there are four well differentiated floristic units that show close correspondence to geographic subregions within the Canadian Arctic Archipelago: southeastern, southwestern, northwestern and northeastern. These subregions will be more clearly defined in later studies; the subregions can be recognized by characteristic taxa. Some examples of these characteristic taxa organized by subregion follow: southeastern subregion (*Carex norvegica*, *Diapensia lapponica* subsp. *lapponica*, *Dryopteris fragrans*, *Empetrum nigrum* ssp. *hermaphroditum*, and *Ledum palustre* subsp. *decumbens*); southwestern subregion (*Androsace chamaejasme* subsp. *arctisibirica*, *Anemone parviflora*, *Artemisia borealis* subsp. *richardsoniana*, *Artemisia hyperborea*, and *Arctophila fulva*); northwestern subregion (*Braya thorild-wulfii*, *Deschampsia brevifolia*, *Draba arctogena*, *Draba* aff. *micropetala*, and *Festuca hyperborea*); and northeastern subregion (defined by the absence of characteristic taxa).

Conclusion

Our study has similarities to the Russian "local floras" methodology, as summarized by Balandin (2008). Up until now, this Russian methodology was not used in the English-speaking world ostensibly because of language difficulties. Russian studies of comparative floristics use the term "local flora" for the flora of a landscape, or full territorial set of plant species of an area that reveals the floristic situation at a given geographical site (Yurtsev 1974, 1975). The followers of this approach assumed that "the species listing around a locality is not a mechanical composition of species occurring there by chance, but a natural phenomenon, despite being less integrated than populations or phytocoenoses" (Penev 1997: 91). In discussing the size of floristic "plots," Tolmachev (1931) suggested area of a local flora to be 100 km² for the Arctic, preferably in the form of a circle with a radius more than 6 km. However, according to Yurtsev (1987) the size of the local floras area is not of crucial importance for resolving the basic tasks of comparative floristics. In this respect the landscape approach of the 25 sites from the Canadian Arctic Archipelago and their size are roughly compatible with the Russian approach. In Russia the local floras method is used to monitor changes in biodiversity (Yurtsev et al. 2001). Our Canadian data could similarly serve as a North American starting point for monitoring change over a wide latitudinal gradient in the Canadian Arctic Archipelago.

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Monitoring Vegetation Change in the Coastal, Low-Arctic Tundra of Ammassalik, Southeast Greenland

Fred J.A. Daniëls & Johannes G. de Molenaar

The knowledge of the low-arctic vegetation of the Ammassalik district, southeast Greenland, is mainly from phytosociological studies recorded from 1968 and 1969 (de Molenaar 1974, 1976; Daniëls 1975, 1982). These monographs present a detailed account of the flora, plant community types, and landscape at a time when there was little human impact or global warming effect. However, during the last 40 years, significant changes have occurred. Two major examples of these changes include increases in both the human population and temperature. The population of the small town of Ammassalik has grown from nearly 800 to more than 1,800 residents; and now over 5,000 tourists visit the district annually. Climatic changes during the periods from 1961 to 1965 and from 2001 to 2005 included a mean temperature increase for July from 7.1 °C to 7.5 °C, mean temperature rise for January from -8.6 °C to -5.2 °C, and a distinctly longer period of summer warmth (= months with mean temperature above 0 °C). In general, mean annual temperature rose 1 °C during the last 40 years, mainly due to the shorter and warmer winters (derived from Capellen et al. 2006, Capellen 2006).

The objectives of our research project, Monitoring Ammassalik Vegetation Change (MAVC), are to assess and evaluate the status of plant community types of the oceanic, low-arctic tundra in the Ammassalik district near Ammassalik. Our 1968 and 1969 data (de Molenaar 1974, 1976, Daniëls 1975, 1982) will be used as a baseline for fieldwork carried out in the MAVC study from mid July until mid August 2007. This is the first comprehensive examination of changes in low-arctic plant community types from a four-decade time scale.

Using the same methodology as our previous study from 1968 and 1969, we will describe and analyze 179 stands of key plant community types that are highly representative and characteristic of this regional landscape. Key plant community types include vegetation types of salt marshes (*Caricetum glareosae*), aquatic and littoral vegetation (*Potamion*, *Subularion aquatica*) (Fig. 1), mires (*Caricetum rariflorae*), snow beds (*Salicion herbaceae*), dry grasslands (*Caricetum bigelowii*, *Cladonio-Viscarietum*), dwarf shrub vegetation (*Phyllodoco-Vaccinion* and *Loiseleurio-Diapension* communities), and low shrub vegetation (*Festuco-Salicetum callicarpaeae*).

The current distribution of the 81 plant community types recognized in the 1960s will be determined, and the vegetation pattern of two wetlands will be remapped. Moreover, 12 permanent plots from 1981

along a typical zonation pattern on south-exposed slopes will be monitored and restudied. These plots include *Festuco-Salicetum callicarpaeae* (two plots), *Cladonio-Viscarietum* (six plots), *Alchemilletum alpinae* (one plot) and *Festuco-Salicetum callicarpaeae* (three plots) (Fig. 2). All datasets will be treated and evaluated with identical multivariate and statistical methods. Special attention will be paid to the relationship between changes in the floristics and structure of plant communities in this area and the impacts of humans and climate change in the last 40 years.



Fig. 1. Vegetation in and around Sparganiumdam, Blomsterdalen, near Ammassalik (Fred J.A. Daniëls, 1995).



Fig. 2. Vegetation complex with Cladonio-Viscarietum, Caricetum bigelowii, and Festuco-Salicetum glaucae on dry, sandy soil on the east-southeast slope of the Praestefjeld northeast of Ammassalik (F.J.A. Daniëls, 1995).

We expect the results of this study to substantially contribute to the knowledge of plant community dynamics and to the knowledge about the effects of global warming and human impacts on low-arctic tundra vegetation types.

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The GLORIA Multi-Summit Methods and Their Application

L. Nagy, M. Gottfried, G. Grabherr, C. Klettner & H. Pauli

Introduction

The historical roots of the Global Research Initiative in Alpine Environments (GLORIA) are in fieldwork that was carried out in the European Alps in 1992, during which 26 high alpine summits (above the elevation of closed sedge heaths) were enumerated for their vascular plant species. Each of these summits had been visited approximately 40 to 100 years before by botanists who provided a full species list. Resulting from this fieldwork was a publication by Grabherr et al. (1994) that focused on changes in vascular plant species numbers, with the underlying assumption that the change in species richness is related to the rise in mean temperature of about 1 °C during the 20th century. This rationale and the calculated maximum rates of altitude advance by vascular species are reflected in the sampling design of the GLORIA multi-summit approach (Pauli et al. 2004).

The multi-summit methodology was conceived as a simple and cost effective way to collect floristic and vegetation data from permanent plots along a virtual elevation gradient. In addition, temperature (the presumed main driving force of potential change) is being continuously recorded in the rooting zone. The null hypothesis for this methodology is that changes in rooting zone temperature (and in the length of the growing season) will not have an appreciable impact on floristic richness and on the relative cover of species. The valid hypothesis is that if changes in temperature occur, they will be reflected by changes in the flora and vegetation.

During the development of the methodology (Pauli et al. 2004) a considerable amount of time was devoted to designing a system that was readily applicable in remote and harsh mountain environments. The methods used are standard with botanists and do not necessitate high levels of technical skill other than the ability to identify local flora. Soil temperature is the single variable that is measured by automatic loggers, which require a triennial maintenance. This simplicity makes the multi-summit method a universally applicable tool across the world for collecting floristic and vegetation data. The simplicity of the method does not mean rigidity; on the contrary, the potential for measuring optional extra variables is unlimited.

Methodology

The Field Manual

The GLORIA Field Manual by Pauli et al. (2004) provides an introduction to and a detailed description of the rationale and methods (including the construction

of field equipment, establishment and documentation of field plots, and data logging). It also describes data archiving and maintenance in a central database (see www.gloria.ac.at for updates).

Sampling Design

The sampling design of the method aims at capturing immigrant vascular plant species of lower elevation origin on the top of alpine summit features. In addition, it documents changes in species presence at both the whole summit level and in small, permanently marked plots. Relative vascular plant species cover is visually estimated for the whole summit and in the permanent plots. In addition, temperature loggers provide a record of 1-hourly readings of soil temperature. Visual estimation and temperature logging is repeated on four nearby summits, which form a virtual elevation gradient from the treeline ecotone to the upper limit of vascular plant life, or the highest available summit.

The Summit Areas

Summit areas are delineated by connecting four points 10 m below the peak (highest summit point) that are set in each of the four main compass directions (Fig. 1). Within each summit area, further vertical and horizontal subdivisions are made. There is a smaller upper summit area delineated at 5 m below the peak. Such a subdivision is made based on the calculated maximum altitude advance by nival species by Grabherr et al. (1994), which is about 4 m per decade.

The summit areas are divided into four quadrants by lines running 45° to each side of the main compass direction. The four quadrants represent north, east, south, and west—for example, the north quadrant lies between 315° and 45°. The summits are therefore divided into eight sections altogether: four upper quadrants (from the peak to 5 m) and four lower quadrants (from 5m to 10 m below the peak).

Permanent Quadrats

There are 16, 1 square-meter permanent quadrats on each summit. They are arranged in four clusters of four, on the 1 m x 1 m corner cells of four 3 m x 3 m grids. Each of the four grids is positioned on the line facing one of the main compass directions, at 5 m altitude from the peak (Fig. 1).

Permanent Marking and Documentation

The peak or highest summit point is the permanent reference point for all distance and angle

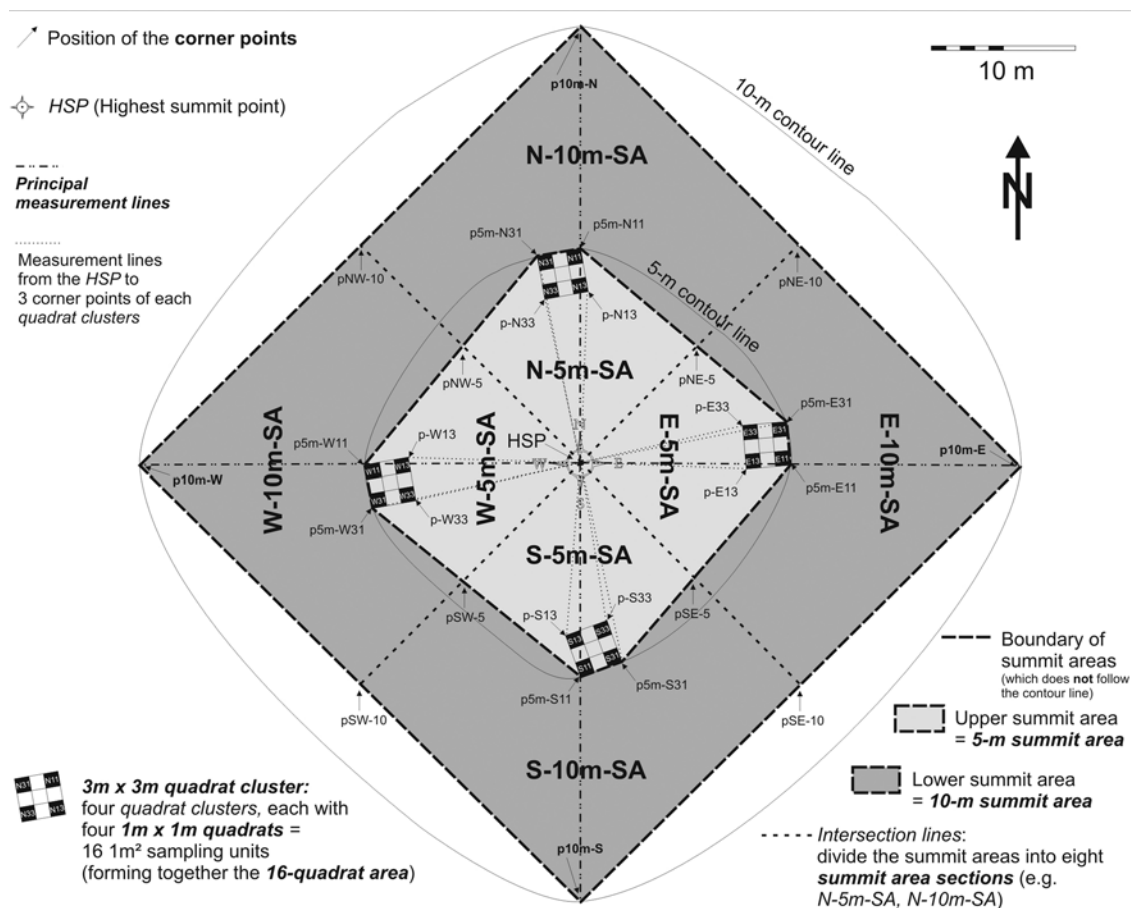


Fig. 1. The sampling layout for summits (source Pauli et al. 2004).

measurements; it is marked permanently, where possible by rock chisels. Each intersection of summit areas and the corner points of permanent quadrats are marked by pins (metal or plastic) driven into the ground. The distance and angle of each pin is measured relative to the principal peak marker. Temperature loggers are the only exception, with their placement measured from the bottom corner points of the quadrat clusters. Additional marking such as small cairns or paint may be used. All measurements are logged, together with accompanying photographs.

Data Collection

Summit Sections

All eight sections are recorded individually for the presence and estimated percent cover of vascular plant species.

Permanent Quadrats

Each quadrat is recorded in two phases. First, the top cover of surface types (sum = 100 %), such as exposed rock, gravel, soil, and vegetation, is estimated visually. Bryophytes and lichens are recorded separately with cryptogams noted according to the substratum they are found on. The main aspect of estimating visual cover is recording the percentage cover of every vascular plant species (sum may be > 100 %). In the second

phase, a grid of 10 cm x 10 cm cells is placed over the quadrat to record the presence of species within each cell. The data from this recording are used to obtain frequency counts per 100 cells.

In the center of the 3 m x 3 m grid, a miniature sealed temperature logger (with an estimated lifetime of three years) is buried to continuously log soil temperature 10 cm below the surface at hourly intervals.

Data Management

The University of Vienna hosts the GLORIA co-ordination team, which maintains a central database of all contributed data. Contributors have password-protected access to managing their own data.

Data are stored in a database in Microsoft Access and Oracle. When contributors submit a recording of a full species list, they are supplied with species codes for data input by the GLORIA co-ordination team. This is in effect part of the registration process of a new GLORIA site. Data input tools are supplied to contributors so they can enter and upload species data, documentation logs, and photographs. A metadata database is available to the public.

The maintenance of field sites is undertaken by the contributors. The use of data is regulated by an agreement, originally signed by the participants of a

European Union Framework Program 5 (EU FP-5) project, GLORIA-Europe, in 2001. Each contributor is encouraged to publish an account of his or her data. Contributors retain ownership of their contributed data; the use of data in joint publications requires agreement by all parties.

Application

The multi-summit method was developed in the Austrian Alps from 1997 to 1998 and was subsequently tested in the Sierra Nevada of Spain (1999). These two mountain ranges provided contrasting environments for comparison: the humid temperate eastern Austrian Alps, with their closed vegetation over calcareous bedrock, and the open siliceous scree-dominated Mediterranean Sierra Nevada. The GLORIA Program was launched at the first conference organized by the Global Mountain Biodiversity Assessment (<http://gmba.unibas.ch/index/index.htm>) in Rigi, Switzerland in 2000. The first systematic application was that carried out across 18 sites in Europe from 2001 to 2003 (see: http://www.gloria.ac.at/res/gloria_europe/target_regions/tr_europe1.jpg). During this time, a baseline was established against which future datasets can be compared. GLORIA-Europe is now preparing for a re-recording of the original plots in 2008.

The multi-summit methods were further promoted in a EU FP-6 Specific Support Action, the Global Change and Mountain Regions Research Strategy (GLOCHAMORE), sponsored by the United Nations Educational, Scientific and Cultural Organization (UNESCO). The latter provided financial backing for piloting the method in Biosphere Reserves in Chile (Araucarias), Peru (Huascarán), and Russia (Altai). An EU top-up fund allowed the inclusion of South American partners in the EU-FP6 integrated project, Assessing Large-Scale Risks for Biodiversity Threats with Tested Methods (ALARM), with the aim of establishing four sites in Colombia, Peru, Bolivia, and Argentina. An informal collaboration with Conservation of Arctic Flora and Fauna (CAFF) was established in 2006-2007, and the GLORIA methods were recommended for inclusion in the Circumpolar Biodiversity Monitoring Program (CBMP) of the Arctic Council. The first site within the CBMP was established in the Selawik National Wildlife Refuge, Alaska, in July 2007. Other initiatives in North America, southwest China, Australia, and New Zealand (Mark et al. 2006) have led to the establishment of numerous sites (see http://www.gloria.ac.at/maps/HiRes/world_600dpi.jpg).

Data Interpretation

Use of Data

The GLORIA-Europe dataset has been extensively explored, both at the regional (Coldea & Pop 2004,

Stanisci et al. 2005, Erschbamer 2006, Erschbamer et al. 2006, Kazakis et al. 2007) and at the continentwide levels (Dullinger et al. 2007) (Table 1).

The regional studies reported species richness and temperature patterns as were recorded in 2001-2002. Erschbamer et al. (2006), additionally, presented a comparison of two Alpine regions that her team had established.

An all-European analysis, based on the 2001-2002 dataset was carried out by Dullinger et al. (2007), who explored the potential impact on species interactions of an increasing environmental severity gradient (Table 2). Their work concluded that the small-scale co-occurrence of species was connected with environmental severity, although weakly and in a variable fashion. Further work is being undertaken on the full European dataset with regard to discerning species richness and temperature patterns and for using the dataset for predictive modeling.

Design Constraints

The design is simple and can feasibly be applied in most parts of the world. Simplicity in terms of design and technical aspect entails some restrictions with regard to data analysis and interpretation. However, these restrictions are rectifiable with specific objectives of an investigation.

Statistical Considerations

Statisticians will no doubt level the charge against the multi-summit method that sampling units are not independent of each other in a statistical sense. A straightforward comparison of means of sampling units within a site is biased because the summit areas within each summit are unreplicated and the four quadrats arranged in a regular manner are not independent of each other. One could overcome this bias by using additional random permanent samples; statisticians would recommend a minimum of 20 or more of such plots (e.g., Manly 2001). This is usually not feasible because of the time, labor, and additional data loggers involved and, most importantly, because of the collateral damage it causes to plots from trampling by recorders. Trampling causes perturbation and defeats the purpose of monitoring.

A possible way of analyzing data from a single site is by nonparametric multidimensional or multivariate analysis methods that make no underlying assumptions about data distribution and of the independence in time or space of the samples (Clarke 1993, Legendre & Legendre 1998). However, the use of permutation-based significance testing should be avoided (Clarke 1993).

Region	Reported Results	Nature of Presentation	Reference
Northern Apennines, Italy	Summing of species versus elevation/aspect	Descriptive, graphical	(Bertin et al. 2001)
Southeast Carpathians, Romania	Summing of species versus elevation/summits; life forms; biogeographical flora elements	Descriptive	Coldea & Pop (2004)
Lefka Ori, Crete, Greece	Summing of species; diversity index; beta diversity or species turnover with altitude; Sorensen's similarity index for floristic similarity between summits; biogeographical flora elements	Descriptive, graphical	Kazakis et al. (2006)
Central Apennines, Italy	Summing of species; Sorensen's similarity index for floristic similarity between summits; biogeographical flora elements; life form spectrum; mean annual soil temperature	Descriptive, graphical	Stanisci et al. (2005)
Dolomites, Southern Alps, Italy; Texel Complex, Central Alps, Austria	Species totals; endemics; Jaccard similarity index; altitude range classes; ordination (detrended correspondence analysis)	Descriptive; graphical; analytical: biplots from multivariate analyses	Erschbamer et al. (2006)
Burns Range & Pisa Range; South Island, New Zealand	Species totals; monthly temperature means/ranges	Descriptive, graphical	Mark et al. (2006)

Table 1. Examples of reporting the baseline data from individual regions where GLORIA sites have been established.

Region	Reported Results	Nature of Presentation	Statistics	Reference
Europe (18 sites)	Vascular plant species co-occurrences in relation to coldest month mean, altitude above treeline, temperature sum of growing season, and percent plant cover (corrected for unavailable area represented by rock)	Analytical	Null model analysis with co-occurrence index at different grain size and using different growth forms; linear mixed models for testing standardized effect sizes vs. environmental predictors	Dullinger et al. (2007)

Table 2. Analytical methods and reported results from a combined dataset of 18 regions in Europe.

Statistically Independent Samples are Produced by Replicating the Virtual Elevation Gradient Across Regions

The strength of the multi-summit methodology is in the number of sites that are established. By replicating the virtual elevation gradients across regions, statistically independent samples are produced. Such a dataset allows for the detection of statistically significant changes at given probabilities over a given time. It is worth noting that the field design results in a hierarchical nesting structure that needs to be taken into consideration at analysis.

Statistically Versus Ecologically Significant Change

The minimum number of samples that are required in accordance with the aims of the monitoring activity implicitly takes into account differences, for example,

differences between recorders and samples. The GLORIA is currently undertaking an inter-observer study to evaluate the minimum statistically detectable difference for the GLORIA-Europe dataset.

However, the minimum statistically detectable significant difference is only a number derived from (and determined by) the available data. Whether such statistically significant differences have an ecological meaning or not has to be interpreted in the light of a *priori* hypotheses. These hypotheses can be based on the rates of species increase from the literature (e.g., Grabherr et al. 1994, Grabherr et al. 1995), or measured temperature lapse rates, and climate change projections.

The Importance of Optional Extra Activities

In addition to the minimum prescriptions of the multi-summit methodology, optional activities can contribute

to the underlying design. For example, optional activities can contribute additional information on drivers of ecological change, such as atmospheric N input, soil P (a potential indicator of grazing history), or on reproduction, such as pollinators, phenology, and demography. Plant-herbivore interactions, both aboveground and at ground level, and nutrient fluxes would be potential additional areas of study, as well as soil biology. The list of potential additional activities is endless and may be decided upon by the availability of local resources and expertise. Activities that involve local expertise, such as the traditional uses of alpine land and plants, are especially encouraged.

An example of research linked to a GLORIA site is that of Hoschitz & Kaufmann (2004), who sampled soil nematodes following the multi-summit layout in the Hochschwab region of Austria. Hoschitz & Kaufmann (2004) found that across all summits, nematode diversity and family composition were correlated with winter temperature minima. Total nematode abundance within summits, however, co-varied with annual mean temperature and growing season duration. Most notably, nematode abundances were four-fold higher on the south or east facing sides than on the northern and western sides.

Conclusions

The GLORIA multi-summit approach provides a network for flexible and wide-ranging work on climate change and alpine biota. The multi-summit approach can be incorporated into a set of tools for monitoring or research initiatives, in its original, or extended forms. The worldwide use of the methodology thus far is encouraging for the prospect of developing a field-based system on detecting signs of climate change in the alpine regions of the world and for providing data for testing models.

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Defining the Boreal in the Ecological Land Classification for Québec (Canada)

Jean-Pierre Saucier

Ecological Land Classification for Québec

The territory of Québec covers a vast area of 1,514,100 km², and very strong ecological gradients occur over the landscape. For example, mean annual temperature declines from 7 °C at its southern border, at latitude 45°N, to -11 °C at its northern extent, latitude 62°30'N. Other gradients affecting precipitation or growth season length can be seen along a south-west–north-east axis or with altitude variations. Accordingly, vegetation formations change from south to north. To express the links between climate or other abiotic factors and the vegetation, Québec's Ministère des Ressources naturelles et de la Faune (MRNFQ) designed an Ecological Land Classification, or ELC (Saucier et al. 1998, Robitaille & Saucier 1996). The purpose of this hierarchical system of ecological land and ecosystem classification is to (1) summarize ecological information on composition and natural dynamics of vegetation; (2) analyze distribution of the ecosystems in the landscape; (3) map ecosystems at various resolutions, and (4) make the results available to the people responsible for managing the forests and their resources (Saucier & Robert 1995).

The hierarchy of the Québec ELC has 11 levels, from a local to a continental scale (Table 1). Each level is defined by key ecological factors and is better expressed at a specific scale of resolution. The system was derived from bottom to top, using detailed information from lower levels to define the levels above.

The two lowest levels of the hierarchy, forest type and ecological type, are expressed at local scale. Forest type, or vegetation type, describes the actual composition and physiognomy of vegetation on a particular site type. As a classification unit, it describes current vegetation in terms of dominant tree species and understory indicator species. Those indicator species reflect local conditions, soil fertility, or the dynamic status of the forest type. Ecological type represents an area that exhibits a permanent combination of the site's potential vegetation and physical features. It is a classification unit that integrates both the dynamics of the vegetation and the soil and site characteristics such as soil texture, moisture regime, or aspect. The concept is similar to the one defined by Jurdant et al. (1977), or to Hill's "site type" (Hill 1959), or to British Columbia's "site series" (Pojar et al. 1987). Ecological types are defined, for each ecological region, by analyzing potential vegetation and the surficial deposits on which it grows. Ecological types occupy sites that have specific textural characteristics and moisture regime, and which are found at particular locations in the landscape. The distribution of ecological types in the

landscape is expressed by means of a toposequence characteristic of a given subregion.

At a smaller scale, there are three hierarchical levels expressing the landscape structure: altitudinal vegetation level, ecological district, and regional landscape unit. The ecological district is an area characterized by its own relief pattern, as well as its geology, hydrography, geomorphology, and regional vegetation. This definition is consistent with that given by Jurdant et al. (1977). Ecological districts are delineated on the basis of the spatial arrangement of relief forms, surficial deposits, and bedrock geology. Vegetation is conditioned by those site factors and by the climate, which is considered homogeneous throughout an ecological district. Some ecological districts with high altitudinal gradients are subdivided in altitudinal vegetation levels when altitude has such an impact on climate that it changes the physiognomy and often the nature of the vegetation. This latter hierarchical level is used to distinguish the sites within a given ecological region where significant variations in altitude result in vegetation that differs from the vegetation that is typically present in the region, creating a montane, subalpine, or alpine level. The regional landscape unit groups ecological districts with a recurrent arrangement of the main permanent factors of the environment and the vegetation. The main ecological factors considered at this level are type of relief, average altitude, the nature and proportion of the main surficial deposits, hydrography, the nature and distribution of the ecological types (combining potential vegetation and physical environment), and the distribution of certain species indicative of the climate. The physical environment and vegetation features are considered simultaneously, and none is given a predetermined dominant role. The method used to delimit and map regional landscape units has been described in previous publications by Robitaille and Saucier (1996 and 1998). This is the level making the link with the regional scale.

At a regional scale, ecological regions, or land regions, are characterized by the distribution of ecological types in the landscape, and particularly by forest composition and vegetation dynamics on the mesic sites, those sites with no severe limitations, or especially rich conditions for plant growth. A detailed analysis of the vegetation on the mesic sites is required. Both potential vegetation and the different transitional forest types are studied, as are the links between the vegetation and the main physical features of the environment, such as relief, altitude, and surficial deposits, in order to identify any changes in toposequences. Ecological regions are sometimes divided into subregions, described as typical, southern, or northern, if they exhibit departure from

the general characteristics of the region, showing a transition between average bioclimatic conditions and warmer or colder adjacent ecological regions. Limits of ecological regions regularly fit with some species or ecosystems distributions when the combination of climatic conditions, soil richness, and relief or altitude induces a significant change in their abundance or presence.

The next higher level of the hierarchy, bioclimatic domain, is expressed at national scale. A bioclimatic domain is a large area characterized by the nature of the potential vegetation on the mesic sites, expressing the effects of the climate. In fact, the expression of the climate through the vegetation nature and structure is the main general criterion used to separate the domains. For example, Québec has ten bioclimatic domains. There are six bioclimatic domains in southern Québec: the sugar maple-bitternut hickory (*Acer saccharum-Acer saccharum*), the sugar maple-basswood (*Acer saccharum-Tilia americana*), the sugar maple-yellow birch (*Acer saccharum-Betula alleghaniensis*), the balsam fir-yellow birch (*Abies balsamea-Betula alleghaniensis*), the balsam fir-white birch (*Abies balsamea-Betula papyrifera*), and the black spruce-moss domains (*Picea mariana-Pleurozium schreberi*). Four more bioclimatic domains are located in northern Québec: the black spruce-lichen (*Picea mariana-Cladina* sp.), forest tundra, shrub tundra, and herbaceous tundra domains. Figure 1 shows the boundaries of the bioclimatic domains in Québec. Some of the bioclimatic domains in southern Québec are divided into subdomains according to variations in vegetation or in natural disturbance regime mainly caused by differences in precipitation patterns.

At the top of the hierarchy, are the vegetation zone and subzone levels. A vegetation zone is a huge, continental-scale area characterized by the physiognomy of the plant formations found there. There are three vegetation zones in Québec: (1) the northern temperate zone dominated by hardwood or mixedwood formations; (2) the boreal zone, characterized by evergreen coniferous formations; and (3) the arctic zone, dominated by shrubs and herbaceous formations (see Fig. 1). These three zones situate Québec in the world biomes classification system. These zones correspond to specific flora and distinct plant formations, and reflect the major bioclimatic subdivisions. When needed, vegetation zones are divided into subzones according to the physiognomy of the dominant late-succession vegetation in the landscape.

The limits of the various hierarchical levels have been mapped at relevant scales for southern Québec, under latitude 52°N, using a bottom up approach from the ecological district to the vegetation zone (Saucier et al. 1998). Ecological types are also delineated over very large areas for forest management units and

expressed in digital integrated eco-forest maps at the scale of 1:20,000. For northern Québec, only the bioclimatic domain level and above levels have been mapped by using works borrowed from other authors (Grondin & coll. 1996, Lavoie & Payette 1994, Richard 1987, Gérardin 1980). The Québec ELC three upper levels are shown on Fig. 1. The area covered by the different vegetation zones and subzones appear on Table 2.

Limits of the Boreal Zone in Québec, or How To Assess Boreality?

While looking at the higher levels of Québec's ELC, a set of criteria were needed to determine whether a particular landscape unit or ecological region belonged to the temperate, boreal, or arctic zone. Should a limit between two zones be defined climatically or by using vegetation structure and composition?

Using climatic data is appealing and there are maps available for many climate variables such as mean annual temperature, precipitation, and growth season length. Also, climatic data have to be related to plant species distribution in order to select meaningful thresholds. For southern latitudes, where weather stations are more numerous and where survey data is available over large areas, climatic data can be used. However, for the northern part of Québec, the number of weather stations with interpretive map data is very low and records don't date back many years. In many cases, weather stations are located along the coast of James Bay or along the shoreline of Ungava, making the forecast precision of average values quite low for inland territories at greater elevation. In these northern regions, vegetation surveys are scarce. Information usually exists as detailed floristic surveys for small areas. Morisset et al. (1983) used some 19 local floristic surveys from different locations to study the number and diversity of plant species along a climatic and geographic gradient. They studied both the total number of species classified as boreal because they were frequent in southern locations and the boreal species associated with the genus *Picea*. They found the total number of boreal species to fall dramatically when a certain threshold was reached and decided to use this inflexion point as an indicator of the limit between the subarctic floras and the arctic floras. This limit matched closely with the tree line and, therefore, could be mapped as the limit between the boreal and the arctic zone.

A similar method was used in southern Québec by Québec's ELC team to seek the limit between the boreal and the temperate zones. There is an ecotone between these two zones that is generally recognized as mixed forest. In this ecotone, mixed forest stands, where coniferous species such as balsam fir (*Abies balsamea* (L.) Mill) and broadleaf species such as yellow birch (*Betula alleghaniensis* Britton) coexist,

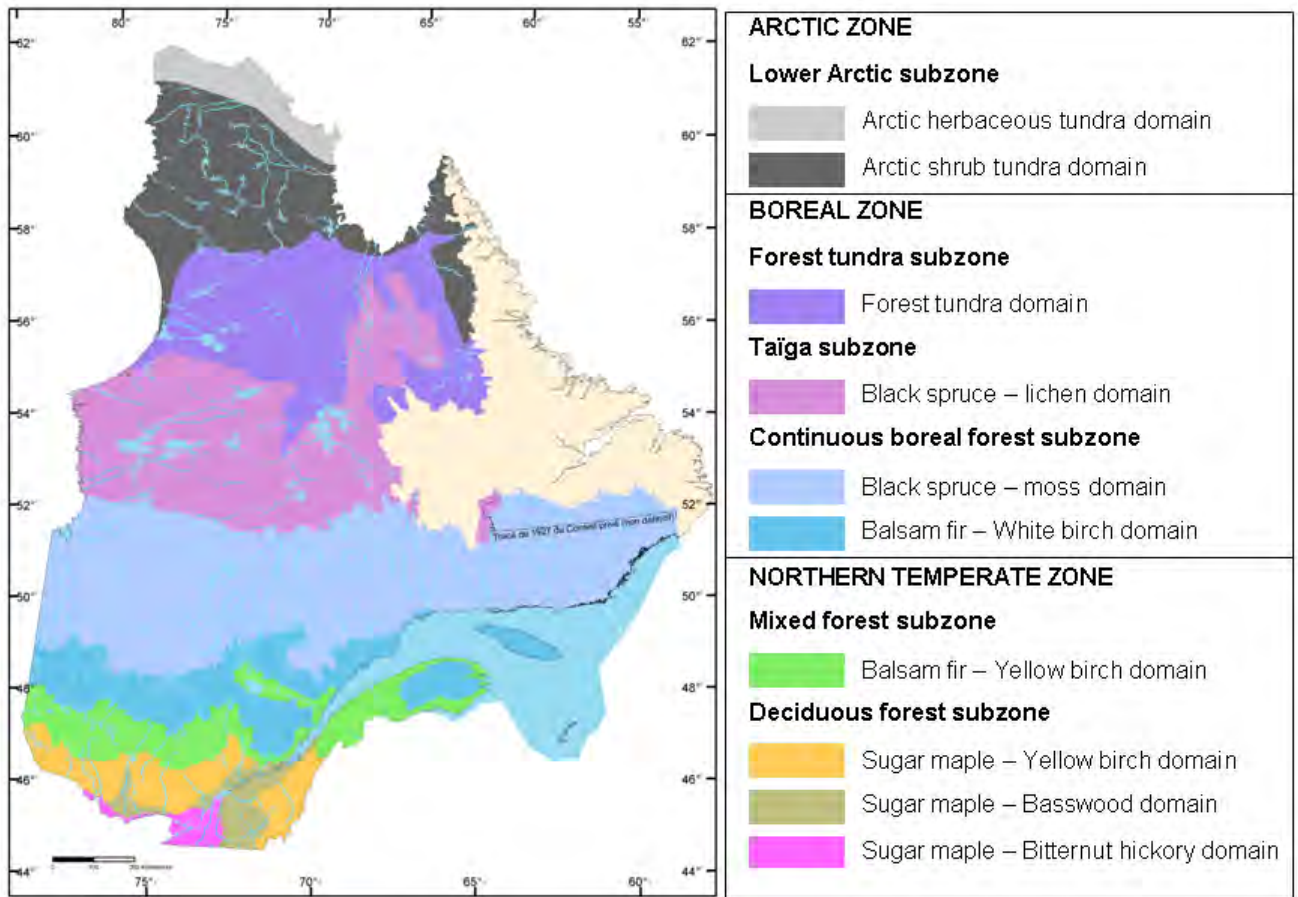


Fig. 1. Québec's vegetation zones, subzones, and bioclimatic domains.

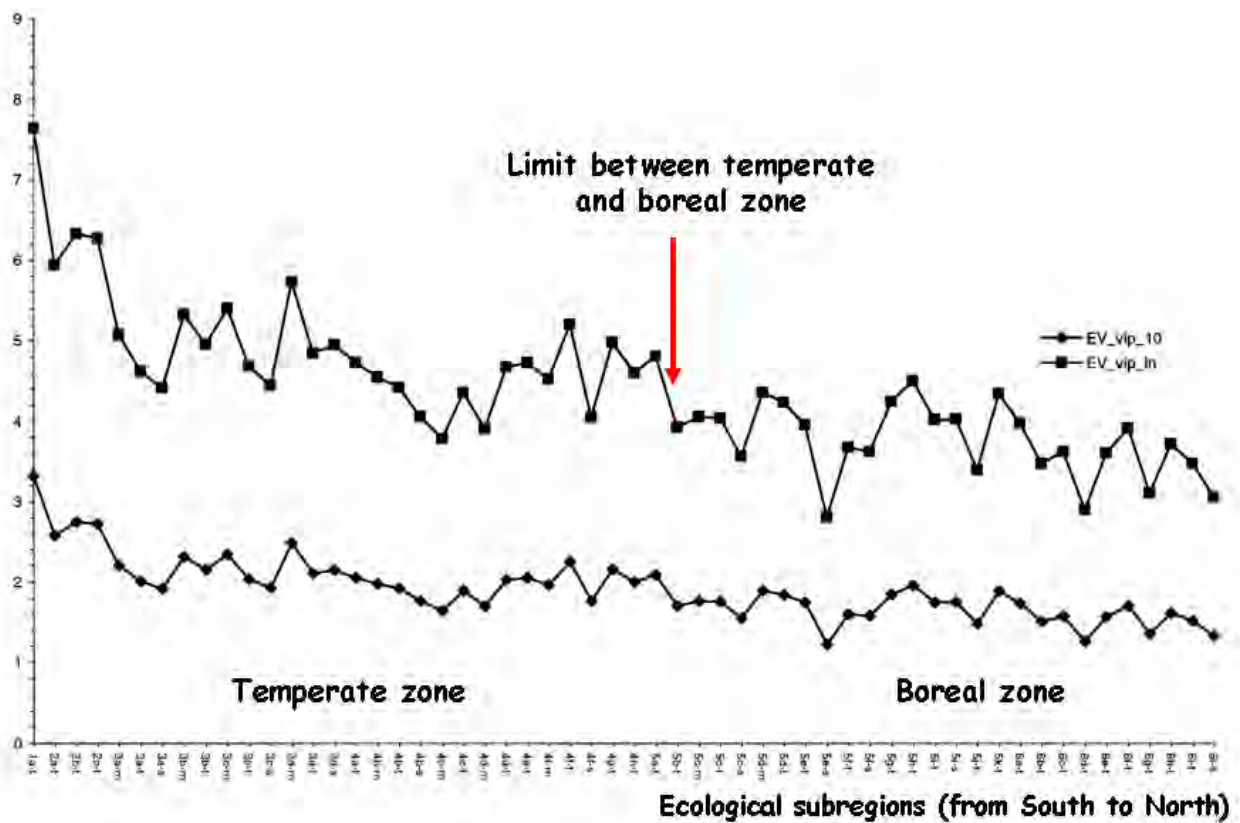


Fig. 2. Evenness index on importance value of forest species in Southern Québec (adapted from Guay & Saucier 2001).

often colonize zonal sites. This mixed forest subzone has been considered as boreal by some authors, while others have considered it the northernmost expression of the temperate zone. Guay and Saucier (2001) conducted an analysis of the evenness index on importance value of the forest species for all subregions and regional landscape units of southern Québec (south of latitude 52°N). The results showed a general decline of the species diversity from south to north, or with increasing elevation (Fig. 2). Some subregions located in the south also showed a low diversity but they were either areas with higher elevation and therefore colder climate, or areas disturbed by humans for many decades. Finding a

clear threshold in the evenness index was difficult, but those values were compared to a set of species distribution maps, for trees and understory species, derived from a wide ecological survey conducted by MRNFQ (28,400 relevés), as well from inventory data (more than 100,000 plots). It was verified that the decline of the evenness index was correlated to the rarity or absence of sugar maple (*Acer saccharum* Marsh.) and yellow birch ecosystems with their associated characteristic flora. Considering that the ubiquitous boreal flora is also widely distributed from southerly regions to the north, the drop in the evenness index can be attributed to the loss of species associated with sugar maple or yellow birch

Hierarchical level	Key ecological factors	Average size	Scale
Vegetation zone	Major plant formation	≥10 ⁶ km ²	
Vegetation subzone	Plant formation dominant in the landscape		
Bioclimatic domain	Potential vegetation on zonal sites	10 ⁵ km ²	National
Bioclimatic subdomain	Difference in climate inducing change in disturbance regime, thus in succession scheme		
Ecological region	Distribution of potential vegetations along the landscape, on zonal sites and azonal sites	10 ⁴ km ²	Regional
Ecological subregion	Differences in distribution of potential vegetations along the landscape expressing transitional climatic characteristics		
Regional landscape	Nature, abundance and recurrence of the main permanent ecological features of the physical environment and of the vegetation	10 ³ km ²	
Ecological district	Nature and distribution pattern of the physical features of the environment		
Altitudinal vegetation level	Vegetation structure modified by altitude variations		
Ecological type	Permanent combination of potential vegetation and environmental features	0.2 km ²	Local
Forest type	Present composition and structure of the vegetation	0.1 km ²	

Table 1. Québec's ecological land classification hierarchy and key ecological factors.

Vegetation zone	Vegetation subzone	Area (km ²)	Area (% of Québec)
Arctic Zone	Lower arctic (tundra)	236,000	16 %
Boreal zone	Forest-tundra	217,100	14 %
	Taiga (open forest)	299,900	20 %
	Continuous boreal forest (closed forest)	551,400	36 %
Northern temperate zone	Mixed forest	98,600	7 %
	Deciduous forest	111,100	7 %
Total Québec's territory		1,514,100	100 %

Table 2. Area of Québec's vegetation zones and subzones.

ecosystems. Sugar maple and yellow birch ecosystems have a wide distribution in the United States and Canada and reach their northern limit, in Québec, into the mixed subzone. Therefore, it was decided that this transitional subzone, the mixed forest, belonged to the temperate zone, thus defining the southern limit of the boreal zone in Québec (Saucier et al. 1998).

Circumboreal Vegetation Mapping Project

The players from the many different Nordic countries that will certainly be involved in the Circumboreal Vegetation Mapping Project should agree on the objects to be mapped, the methods to draw the limits on the map, and the variables used to describe the mapping units derived along the process. Examining the two examples from Québec's ELC, we can retain some factors and conditions that can lead to a successful circumboreal mapping project. The scientific committee should adopt first, a clear definition of the concept of "boreality" and ways to demonstrate it. Then, a common set of ecological factors to be integrated should be assessed for an area larger than the supposed area of the boreal zone. At this stage, it will probably be necessary to generate some standardized mapping products, such as a vegetation cover map from satellite imagery, but data from existing vegetation or ecosystem classifications should not be ignored. Finally, mapping decisions should be documented, so that a community larger than the group who participated in the project can understand the end product. Mapping the boreal is more than matching existing lines from different products made by using concepts that are not equivalent. The Circumboreal Vegetation Mapping Project is a challenging one.

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The Circumpolar Biodiversity Monitoring Program (CBMP)

Michael Svoboda



The Biodiversity Monitoring Program (CBMP) provides an opportunity, for Arctic botanists and ecologists alike, to expand and harmonize monitoring research programs and increase project value. A summary of the history and context, purpose, scope, approach, and priorities are presented here. For a more detailed description of the program and workplan please visit the CBMP's website and or read the CBMP implementation plan at www.cbmp.is.

History and Context

In response to the global importance of the Arctic's biodiversity, the increasing pressures on Arctic biodiversity and human communities, and our limited capacity to monitor and understand these changes, the Arctic Climate Impact Assessment (ACIA) recommended in 2004 (see <http://www.acia.uaf.edu/pages/overview.html>) that long-term Arctic biodiversity monitoring be expanded and enhanced. In its acceptance of the findings and projections from the ACIA, the Arctic Council directed the Conservation of Arctic Flora and Fauna Working Group (CAFF) to examine the ACIA findings related to biodiversity conservation and develop follow-up programs and activities to address key projections for the future of the Arctic. A primary response has been the implementation of the Circumpolar Biodiversity Monitoring Program (CBMP).

Arctic biodiversity is globally significant and under increasing pressure. Despite this, our current monitoring capacity is limited and lacks coordination, resulting in an inability to detect trends on a reasonable time frame, understand the mechanisms driving these trends, and communicate the information to decision-makers.

With the lack of coordination between existing programs, CBMP works in a manner to create linkages between monitoring programs to enhance monitoring power and increase overall scope. Therefore, rather than creating a new spectrum of Arctic monitoring programs, CBMP is a mechanism for harmonizing existing programs and for enhancing long-term biodiversity monitoring efforts across the Arctic in order to improve our ability to detect and report on significant trends and pressures. If gaps exist, appropriate and coordinated monitoring initiatives will be encouraged to address such deficiencies. Coordination of independent monitoring programs will provide immediate benefits to northern research.

While the historic backlog of information collected in the Arctic will never be fully accessible, CBMP aims to promote project partners to contribute to standardized data platforms that ensure long-term data interoperability and access by researchers around the world. Using technologies such as data

web-portal are examples of reaching these objectives while keeping individual researchers involved and credited. This strategy will also increase the scope of individual monitoring programs and increase power of detectable trends for all interested parties.

The demands to ensure Arctic research applicability for local people who live in the north are growing. With global warming and climate changes in Arctic regions, the need to detect change in order to mitigate or adapt are paramount to those who depend on the region for daily well-being. Special attention will be paid to community-based observations and citizen science, recognizing the valuable and significant contributions that people living in this environment can make to monitoring Arctic biodiversity.

Achieving significant gains towards Arctic monitoring coordination, information access, and enhanced local involvement will greatly contribute towards our long-term ability to detect change and effectively inform those making decisions from policy to individual ways of life.

Purpose

The stated purpose of the CBMP is to strive for the conservation of biological diversity in the Arctic, to halt or significantly reduce the loss of this biodiversity, and to provide information to the indigenous peoples of the Arctic, other Arctic residents, and stakeholders inside and outside the region on the sustainable use of the region's living resources.

The CBMP is, first and foremost, a coordinating entity for:

- Existing Arctic biodiversity monitoring programs
- Identifying new programs to address gaps in knowledge
- Gathering, integrating, and analyzing data
- Communicating results

The CBMP will serve as a mechanism for harmonizing and enhancing monitoring efforts across the Arctic in order to improve our ability to detect significant trends within a reasonable time frame and report on them effectively.

Approach

The circumpolar Arctic, as defined by CAFF, covers 14.8 million km² of land and 13 million km² of ocean. It encompasses highly complex ecosystems, due in part to the interplay between terrestrial and marine species, habitats, and ecosystems both inside and outside the region. Considering the size and complexity of the circumpolar Arctic, it is essential that the CBMP promote and develop an integrated ecosystem-based approach to monitoring.

The delivery of an ecosystem-based approach involves monitoring that targets ecosystems, habitats, and species. It demands information not only on the status and trends in Arctic biodiversity, but also on their underlying causes. It is critical that this information be collected and made available to generate effective strategies for adapting to the changes now taking place in the Arctic—a process that ultimately depends on rigorous, integrated, and efficient monitoring programs that have the power to detect change within a reasonable time frame.

The CBMP's goal to enhance Arctic monitoring depends greatly on the coordination of existing expertise. Thus, the CBMP will facilitate the integration and coordination of a multidisciplinary, integrated ecosystem-based approach through the development of five integrated Expert Monitoring Groups (Marine, Coastal, Freshwater, Terrestrial Vegetation, and Terrestrial Fauna). Each group will be made up of existing site-based and network-based research and monitoring programs, representing a diversity of expertise, including both community-based monitoring and scientific-based monitoring capabilities.

Next Steps

Over the next five years, the CBMP will focus its efforts on the following key areas:

- Developing a strategy for building and maintaining a comprehensive and cost-effective circumpolar monitoring program that addresses current deficiencies
- Coordinating and integrating biodiversity

monitoring programs and promoting standardized measures and harmonized data protocols

- Assessing current monitoring capacity and design to identify elemental, geographic, and statistical design deficiencies and inefficiencies
- Interpreting, integrating, and communicating existing biodiversity information (establishing statistical baselines and retrospective assessments)
- Developing data-management structures and a Web-based data portal for the synthesis, analysis, and dissemination of biodiversity information
- Identifying and initiating pilot monitoring projects, where clear gaps exist
- Reporting on the status of Arctic biodiversity and the issues facing it, using diverse formats for communication, education, and outreach at the global, national, regional, and local levels

Conclusions

The CBMP is a strategic Arctic program that aims to coordinate and support monitoring research to increase the value of current and future monitoring results. Opportunities for researchers to enhance current and planned Arctic monitoring programs will lead to more efficient research, enhanced accessibility to research data and analysis, and improved involvement of local populations in research programs as well as receiving research findings. With the growing concerns for Arctic biodiversity throughout the world, the CBMP is well positioned to contribute towards improved circumpolar biodiversity monitoring for all.

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The Circumpolar Arctic Vegetation Map, the Alaska Arctic Tundra Vegetation Map, and the Arctic Geobotanical Atlas

D.A. Walker

This paper gives overviews of the *Circumpolar Arctic Vegetation Map* (CAVM), published in 2003 as Conservation of Arctic Flora and Fauna (CAFF) Map No. 1 (CAVM Team 2003, Walker et al. 2005) and the *Alaska Arctic Tundra Vegetation Map*, published in 2006 as CAFF Map No. 2 (Raynolds et al. 2006). Also provided is an overview of an ongoing project that uses the two maps as core datasets for a web-based, hierarchical Arctic Geobotanical Atlas.

The Circumpolar Arctic Vegetation Map (CAVM)

The CAVM, scale 1:7,500,000, is the first map of a complete global biome at a comparable level of detail. The map covers the Arctic Bioclimate Zone, which lies north of the treeline and is characterized by an arctic climate, arctic flora, and tundra vegetation. According to this definition of the Arctic, six nations have arctic lands within their boundaries: Canada, Greenland, Iceland, Norway, Russia, and the United States. Fifteen vegetation-type names based on the dominant plant functional types are grouped into five broad physiognomic units:

Barrens

- B1. Cryptogam, cushion-forb barrens
- B2. Cryptogam barrens (bedrock)
- B3. Noncarbonate mountain complexes
- B4. Carbonate mountain complexes

Graminoid Tundras

- G1. Rush/grass, forb, cryptogam tundra
- G2. Graminoid, prostrate dwarf-shrub, forb tundra
- G3. Nontussock-sedge, dwarf-shrub, moss tundra
- G4. Tussock-sedge, dwarf-shrub, moss tundra

Prostrate-Shrub Tundras

- P1. Prostrate-shrub, herb tundras
- P2. Prostrate/hemiprostrate dwarf-shrub tundra

Erect-Shrub Tundras

- S1. Erect dwarf-shrub tundra
- S2. Low-shrub tundra

Wetlands

- W1. Sedge/grass, moss wetland
- W2. Sedge, moss, dwarf-shrub wetland
- W3. Sedge, moss, low-shrub wetland

By placing physiognomy at the highest level in the legend, the vegetation is ordered according to structure rather than bioclimate subzone, which is a more traditional Russian approach. This was actually a necessary step in order to unite the previously disparate mapping approaches that had been used to describe Arctic vegetation in North America and Eurasia. A renaming of the bioclimate subzones with simple letter designations (Subzone A thru Subzone E) was also necessary because of difficult nomenclatural conflicts between the many different approaches to naming the subzones.

An integrated mapping approach was used, whereby all map polygons were mapped with the following attributes: bioclimate subzones, floristic province, landscape types, lake cover, and substrate chemistry. The information is in a geographic information system (GIS) database. Elevation and the maximum normalized difference vegetation index (NDVI) are in separate coverages of the GIS database at 1-km pixel resolution. Information from previous vegetation maps was used when available. Most of the Arctic, however, required interpreting the vegetation from small-scale satellite images and expert knowledge. Tables of detailed plant-community level information were used to construct the map. Future maps at larger scales can use this information to portray the dominant plant communities in each of the major floristic regions of the Arctic. The map is useful for global and regional computer models of climate change, land-use planning, conservation studies, resource development, and education. Some results from the area analysis include:

1. The area of the Arctic is 7.1 million km² (5.1 million km² are ice free).
2. The Arctic is divided into five bioclimate subzones, A-E, with Subzone A being the coldest, and Subzone E, the warmest. Excluding glaciers, Subzone A covers 0.1 million km² (2%), Subzone B covers 0.5 million km² (9%), Subzone C covers 1.2 million km² (23%), Subzone D covers 1.6 million km² (30%), and Subzone E covers 1.8 million km² (36%).
3. Canada has the most terrain in the Arctic (36% of the total) and by far the most in the High Arctic (Subzones A, B, and C: 63% of the total), whereas Russia has the most terrain in the Low Arctic (Subzones D and E: 42% of the total). Alaska has 7% of the Arctic, much of which is mountainous.
4. Erect-shrub tundras cover the largest area (25.8% of the map), followed by peaty graminoid

tundras (18%), mountain complexes (13.3%), barrens (11.9%), mineral graminoid tundras (11.3%), prostrate-shrub tundra (10.7%), wetlands (7.9%), and lakes (1.3%).

5. Total aboveground plant biomass for the Arctic is estimated at 2.5×10^{15} g. Phytomass is exponentially related to summer temperature along both latitude and elevation gradients. Subzone A phytomass averages 39 g m^{-2} , and Subzone E phytomass averages 818 g m^{-2} . Phytomass areas above 2,000 m in elevation average 21 g m^{-2} , whereas areas below 333 m average 522 g m^{-2} . Phytomass is also affected by substrate, glacial history, and proximity to warm ocean currents.
6. Canada has relatively low biomass in all bioclimate subzones because of the abundance of its glaciated and carbonate terrain (the latter especially in subzones A, B, and C). Greenland has the lowest biomass per unit area in all subzones, which is due mostly to its mountainous terrain. Russia has the highest biomass in subzones B, C, and D, and Alaska in subzone E.
7. The majority of the Arctic is acidic tundra, which on average has higher biomass per unit area, 579 g m^{-2} , compared to 381 g m^{-2} in nonacidic tundra areas and 156 g m^{-2} on limestone areas.
8. The zonal vegetation of Subzone A, cryptogam, herb, barren, has the lowest NDVI of any cover type and is predominantly (> 90 %) located on the Canadian Arctic Islands. It covers a relatively small area (225,000 km²) and is the subzone most at risk due to climate warming.

Alaska Arctic Tundra Vegetation Map (AATVM)

The AATVM, scale 1:400,000, was directly derived from the CAVM and uses the tables of plant communities to derive a total of 33 map units. The coding for the map units is very similar to that on the CAVM, except that a numerical suffix is added to codes and generally designates a floristically unique region in Alaska where the map unit occurs. As an example, the CAVM G3 unit (non-tussock, graminoid tundras) is divided into three subunits:

- *G3.1. Non-tussock sedge, dwarf shrub, moss communities* (comm. 27) on mesic non-acidic loess. Northern Arctic Coastal Plain, Subzone D.
- *G3.2. Graminoid, prostrate dwarf-shrub, forb communities* (comm. 18) on mesic areas. St. Lawrence Island, Subzone D.
- *G3.3. Non-tussock sedge, dwarf-shrub forb, moss communities* (comm. 75) on mesic non-acidic loess Arctic foothills of the Brooks Range and the Seward Peninsula, Subzone E.

Three additional physiognomic units were also distinguished. Tussock-graminoid tundra was divided into “tussock graminoid tundra on sandy substrates” and “tussock graminoid tundra on non-sandy substrates,” in order to distinguish the tundra of the large sand sea in northern Alaska. The unit of saline wetlands was also added to delineate the large brackish wetlands in the delta of Yukon and Kuskokwim Rivers.

A unique feature of the map is that full descriptions of the plant communities, designated by numeric codes (e.g., comm. 27) and their literature sources, are listed on the reverse side of the map. Also on the reverse side, communities are arranged in tables according to bioclimate subzone, floristic province, substrate pH, and position along the meso-topographic gradient (dry exposed sites, moist sites, wet sites, snowbeds, riparian areas). Each community is accompanied by a list of the dominant plant functional types (with species in parentheses), literature sources where units are described more fully, and the names of units as they are described in the literature.

Arctic Geobotanical Atlas (AGA)

The AGA is a web-based, multi-scale GIS database that uses the CAVM as a framework for a hierarchy of maps focused on the Arctic Long-Term Ecological Research site at Toolik Lake, Alaska. In the Atlas are maps at eight different scales, with map themes, legends, and colors consistent across all map scales. The geobotanical themes include vegetation, soils, landforms, surface geomorphology, geology, hydrology, and topography. The maps can be viewed by a variety of tools to enhance downloading and use of the maps, including PDF versions, downloads of the GIS databases, and with various viewing options, including the GINA SwathViewer, GINA Map Server, and EarthSLOT software. The AGA is part of a regional GIS node at the University of Alaska Fairbanks (UAF) and an envisioned circum-Arctic GIS network.

The Atlas is a key International Polar Year (IPY) legacy dataset for future research and monitoring of the Toolik Lake region. The maps were made during a period of approximately 20 years starting in the 1980s with the U.S. Department of Energy’s R4D project at Imnavait Creek and have resulted in many publications. Before the AGA the bulk of the maps in the Atlas were only available as hard copy maps or by FTP of data files. Future use of the maps and data products are key to several ongoing and proposed IPY projects, including the International Tundra Experiment (ITEX), the Circumpolar Active Layer Monitoring (CALM) project, two arctic Biocomplexity in Environment (BE) projects, the Arctic Long-Term Ecological Research (LTER) project, and the Study of Environmental Arctic Change (SEARCH). The AGA is one of the primary outreach and education components for the Greening of the Arctic (GOA) project, which is examining the spatial

and temporal trends of greening in the Arctic and how these trends are affecting the indigenous people of the Arctic. A major effort is being made to make the information accessible to nontechnical users, including students at high schools and universities and the general public. It is anticipated that many government and private agencies working within the Kuparuk River region and the Dalton Highway corridor will use the information in the Atlas.

The maps and website are being developed at the Alaska Geobotany Center in collaboration with other groups at the University of Alaska Fairbanks, including the Toolik Field Station, the Geographic Information Network of Alaska (GINA), and the Water and Environmental Research Center (WERC). Funding was provided by the National Science Foundation (ARC-0425517). The Alaska Geobotany Center is located within the Institute of Arctic Biology, University of Alaska Fairbanks (see <http://www.iab.uaf.edu>).

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Project for Interlinked Arctic Flora and Vegetation Databases

Patrick Kuss & D.A. Walker

Summary

Of all the global biomes, the circumpolar Arctic tundra biome is the only biome that has its entire known set of plants, including vascular plants, mosses, and lichens (soon to be documented in up-to-date flora checklists). These checklists are an essential first step in understanding the relationship of the flora and plant communities to climate and other geographical variables and how these communities might change under altered climate regimes. Our proposed project will use these Panarctic checklists to make two databases that are needed for circumpolar studies of vegetation: (1) the Flora Arctica database and (2) the Arctic Vegetation Database. We will make these databases accessible through the World Wide Web and will provide a number of products, such as species and community pages, as well as summary statistics on gaps in knowledge and trends in Arctic biodiversity.

Introduction

The Arctic has attracted and fascinated botanists for over a century. Our current knowledge about this northernmost biome is based on a wealth of literature, such as literature on taxonomy, biology, and vegetation composition, but no single modern circumscription of the Arctic flora and vegetation has emerged so far. This is partly because of the different scientific traditions in Arctic taxonomy and vegetation classification, and partly because of the independent treatment of organismic groups (i.e., vascular plants, bryophytes, and lichens). In the last few years the Arctic has received considerable attention because the most rapid change in temperature is predicted to occur at northern latitudes (ACIA 2004). In this context, climate change will likely influence the diversity, distribution, and performance of species in the Arctic, and solid models are needed to assess the impact of change on ecosystems and human well-being. However, in order to quantify biodiversity, assess the current status quo, and model biodiversity trends in the Arctic, it is of paramount importance to have a list of accepted names for the different organisms and to know their synonyms as well as basic biological properties, ecological behavior, and distribution. A large set of this information is already available in print or digital format as checklists (Afonina & Czernyadjeva 1995, Elvebakk & Prestrud 1996, Sekretareva 1999, Afonina 2004, Kristinsson et al. 2006, Elven et al. 2007), regional floras (e.g., Hultén 1968, Böcher et al. 1968, Porsild & Cody 1980, Rebristaya et al. 1995, Cody 2000, Petrovskiy et al. 1996, Aiken et al. 1999 onwards, Talbot et al. 1999, Brodo 2001, Kristinsson 2001, Alsos et al. 2005-2007, Lid 2005), community

descriptions (e.g., Dierssen 1992, Elvebakk 1994, Walker et al. 1994, Matveyeva 2006), or herbarium vouchers (e.g., University of Alaska Museum of the North 2001-2007). However, a database that combines and standardizes all this relevant information and makes it available to taxonomists, field botanists, and modelers is currently missing. Therefore, we propose to create interlinked Panarctic floristic and vegetation databases that synthesize existing knowledge and provide a reference base for research and education.

Interlinked Databases for Arctic Vegetation

Flora Arctica Database: The Flora Arctica database will contain the combined taxonomic checklists of vascular plants, mosses, and lichens of the Arctic (Fig. 1). This list will have the latest, consistent nomenclatorial information for all known species in the Arctic. The core information will consist of a list of accepted taxonomic names and synonyms. The database will also include information about geographic occurrence within floristic provinces and bioclimatic subzones of the Arctic (Yurtsev 1994, CAVM Team 2003), as well as global distribution. We will enter additional ecological baseline information such as habitat requirements and plant functional type for each species (e.g., Sekretareva 1999) and provide a reference bibliography of consulted works. We further plan to interlink the Flora Arctica database with existing herbarium collection databases in order to improve data quality and facilitate future nomenclatorial research.

Arctic Vegetation Database: The vegetation database will contain the detailed species-cover information from all the published studies of plant-communities in the Arctic. The database will be created using the software Turboveg (Hennekens & Schaminee 2001), which is the international standard database application for large vegetation data sets. With the species checklist at hand, existing vegetation relevés from published and unpublished works throughout the Arctic will be combined and compared in a taxonomically standardized framework. A bibliography of vegetation surveys in the Arctic will accompany the database. The species checklist will be distributed to vegetation scientists working in the Arctic to facilitate data interchange and storage in the future.

World Wide Web-Based Products: The Flora Arctica and the Arctic Vegetation databases will be accessible through the World Wide Web. Species and community pages will contain images, line drawings, maps, and a language independent, iconographic description of the biology and ecology of a given species or

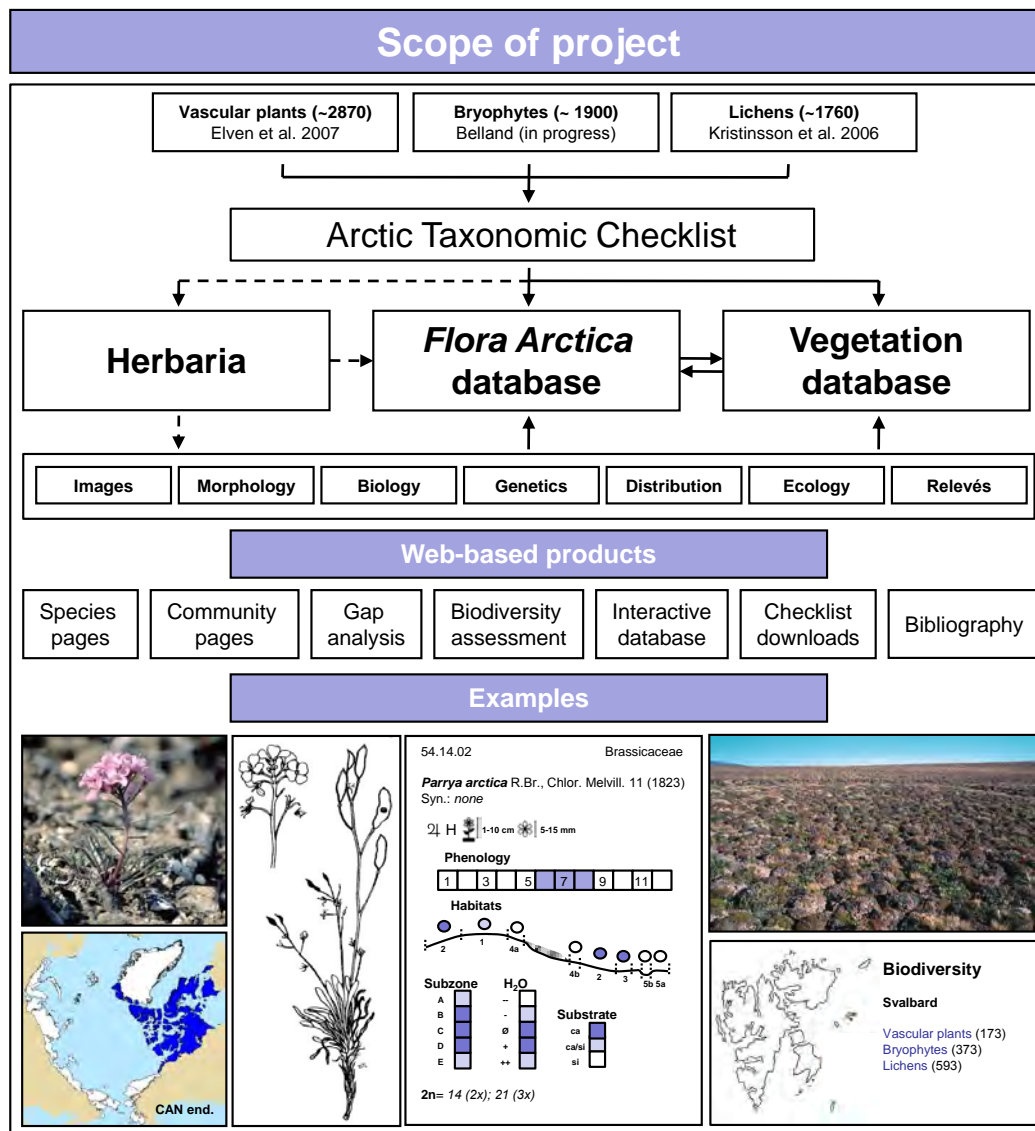


Fig. 1. Scope of the project for interlinked Arctic flora and vegetation databases. Images: P. Kuss, D.A. Walker; line drawing: Cody (2000); map: Circumpolar Arctic Vegetation Map (CAVM) Team (2003), modified.

community type (for examples see Aeschmann et al. 2004, Vust 1998). The databases will further lay the foundation for an annotated list of all described plant communities in the Arctic (an Arctic Prodrum), which will be compiled by an international group of collaborators from the Conservation of Arctic Flora and Fauna (CAFF) Flora Group. We will create download options for checklists and species information that can be customized and retrieved (e.g., for specified geographic areas). Apart from the above-mentioned products, we will provide a range of summary statistics that aim to identify gaps in knowledge and provide up-to-date biodiversity assessments of the Arctic.

Call for Participation

We invite scientists with an interest or focus on Arctic botany (systematics, vegetation description and analysis, phylogeography, biodiversity, ethnobotany, global change modeling, education, and/or species databases) to contribute and comment on this collaborative circumarctic project.

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Canadian National Vegetation Classification

Kenneth A. Baldwin & William J. Meades

The Canadian National Vegetation Classification (CNVC) defines and describes the vegetation of Canada at various levels of taxonomic generalization, using standardized criteria and terminology. The CNVC provides a consistent framework for applying ecological knowledge of Canadian forests, woodlands, grasslands, wetlands, alpine, tundra, and other vegetation to land management, research, monitoring, and reporting activities. The classification system not only enhances the interpretive value of spatial information products (e.g., the National Forest Inventory) by linking them to ground-derived ecological attributes, but it is also essential for extrapolating ecological information from local to global scales.

The CNVC can be thought of as an “encyclopedia” of Canadian vegetation types. By integrating knowledge of vegetation communities in relation to environmental gradients, such as regional climate and site-specific moisture and nutrients, the CNVC can be effective for a broad range of applications within Canada, from exchanging resource management information across provincial/territorial boundaries to identifying ecosystems with high potential for biodiversity conservation.

Currently, provincial and territorial vegetation/ecosystem classifications identify and describe many vegetation types (primarily forests, woodlands, and grasslands) across Canada, but because each classification is only consistent within its provincial/territorial boundaries, direct comparisons between the classification systems are not possible (Ponomarenko & Alvo 2001). Presently, the CNVC correlates existing provincial, territorial, and regional classifications in a common national system derived by compilation of plot data and comparison of vegetation descriptions. Over time, additional data from multiple sources will be brought together to further develop the CNVC.

The CNVC is separate from, but linked to, existing provincial, territorial, regional, and international classifications. It is intended to suit Canadian national needs and to be acceptable as a Canadian vegetation classification standard. When possible, definitional standards of the United States National Vegetation Classification (USNVC) (Federal Geographic Data Committee 2006) and the International Vegetation Classification (IVC) (NatureServe 2006) are applied in the CNVC. As the CNVC units are constructed and integrated with international classifications, multiple benefits are possible (e.g., global ranking of rarity; see British Columbia Conservation Data Centre 2004, unpubl. rpt.: Global Ranking of Plant Associations in British Columbia and Adjacent Jurisdictions, Progress Report, March 31, 2004).

The CNVC partnership comprises approximately 20 international, federal, provincial, and territorial governmental and nongovernmental agencies, including provincial forest ecology programs, provincial and territorial conservation data centres, NatureServe and NatureServe Canada, Parks Canada, Natural Resources Canada - Canadian Forest Service, and Environment Canada.

The mandate of the CNVC is:

To comprehensively classify and describe natural and seminatural Canadian vegetation in an ecologically meaningful manner.

The goals of the CNVC are to:

1. Develop standardized vegetation classification units.
2. Classify vegetation at various taxonomic levels of generalization.
3. Provide a standardized taxonomic nomenclature for vegetation units.
4. Provide descriptions of the vegetation units in a publicly accessible manner.
5. Engage partners with relevant expertise, data, and jurisdictional authority in order to complete the classification with the greatest degree of consensus.
6. Coordinate classification standards and correlate CNVC classification units with Canadian provincial, territorial, and regional classifications, as well as with international classifications such as the United States National Vegetation Classification (USNVC) and the International Vegetation Classification (IVC).
7. Communicate to a wide audience of potential users the need for, and utility of, a standardized national/international classification of vegetation types, and promote the application of ecosystem-based land management approaches across all jurisdictions in Canada.

The CNVC comprises:

1. A list of nationally standardized vegetation units (e.g., associations, alliances) that are defined and described in terms of vegetation characteristics in relation to climate, site, and ecological process factors.
2. A classification database containing summaries of vegetation and site/soil data.
3. A description of each unit that includes location, vegetation, site/soil factors, provincial/territorial/

international correlations, regional and national ecoregions/zones of occurrence, ecological process relationships, references to plot data sources, etc.

Classification principles of the CNVC include:

1. Units must define and describe vegetation using standardized criteria and nomenclature.
2. The classification consists of a full taxonomic vegetation hierarchy to permit descriptions of vegetation at various levels of generality. The classification is based on floristic, ecological, and physiognomic criteria, with the association as the basic classification unit (CNVC Technical Committee 2004) and the alliance as a first-order grouping of associations (CNVC Technical Committee 2007, in prep.: Alliance Concept for the Canadian National Vegetation Classification). Provisionally, the 6-level upper hierarchy (i.e., above alliance) proposed for the USNVC (Federal Geographic Data Committee 2006) is accepted for the CNVC, pending confirmation in Canadian vegetation conditions (Fig. 1).

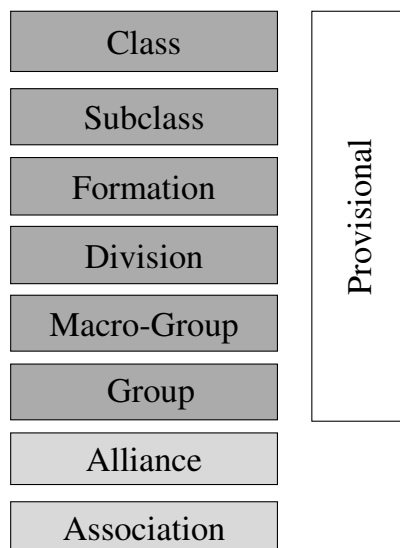


Fig. 1. Proposed Canadian National Vegetation Classification (CNVC) taxonomic hierarchy.

3. The classification will be integrated with spatial, or ecological land, classifications, using the association as the basic unit of integration.
4. Diagnostic features among the units are based upon vegetation characteristics that can be observed and measured objectively in the field, preferably using plot-based sampling methods. Wherever possible, units are developed from plot data adhering to the standards outlined in Chapter 5 of the guidelines document developed by the Ecological Society of America (ESA) Vegetation Classification Panel (2004). In the absence of high quality plot data, other information sources (e.g., incomplete plot data, literature sources, etc.) are used.

5. The units are concepts based upon characteristics of existing vegetation conditions. As much as possible, data are obtained from across the distribution range of the classification units in Canada, supplemented as necessary by additional range-wide information. Diagnostic and conceptual criteria are clearly stated, and the ranges of variability of important attributes are clearly described. The quality of each classification unit is expressed by a confidence level designation, based on the relative rigor of analysis used to define it.
6. The classification is designed to be updated and revised through a structured peer review process, as new information and type concepts become available. Periodic evaluation of the entire classification structure is encouraged.

Canadian National Vegetation Classification Association Development

The CNVC has adopted the definition of plant association proposed by the Ecological Society of America (ESA) Vegetation Classification Panel (2004): "A recurring plant community with a characteristic range in species composition, specific diagnostic species, and a defined range in habitat conditions and physiognomy or structure." The CNVC Technical Committee (2004) has developed a document further outlining the association concept for the CNVC. In practice, CNVC associations are defined according to a combination of criteria, including:

1. Species dominance
2. Diagnostic species that are indicators of:
 - a. ecological gradients (e.g., site moisture/nutrients, climate)
 - b. ecological processes (e.g., flooding, succession)
3. Physiognomy (e.g., closed forest versus ecological woodland)

Wherever units that approximate CNVC association standards are present within existing provincial/territorial classification systems, they are used as antecedents for development of national associations. When such units do not exist, they are developed in conjunction with provincial/territorial ecologists prior to proceeding to inter-jurisdictional correlation and the development of national (CNVC) associations. The idealized protocol is outlined in Fig. 2.

Correlation of provincial/territorial associations uses plot data collected by these jurisdictions during the development of their individual classifications. These antecedent units are compared analytically using multivariate and phytosociological methods, mediated by VPro software (British Columbia Ministry of Forests and Range 2007). Proposals for national associations are submitted to a panel of experts familiar with the

ecological conditions of the region in question. This process is iterated until the regional panel accepts both the concept and data content of the associations in question, at which point the units are confirmed as CNVC associations.

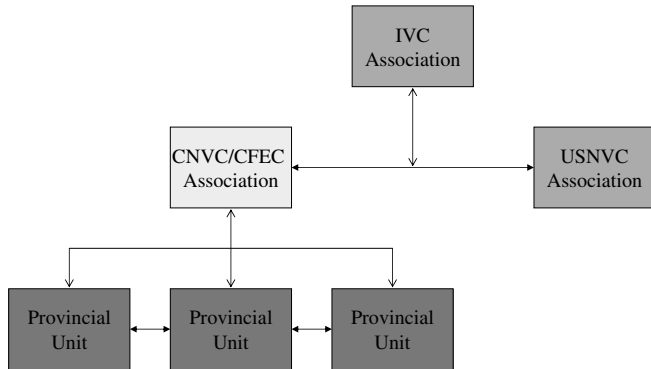


Fig. 2. Idealized developmental model for Canadian National Vegetation Classification associations.

Each CNVC association is described according to attributes such as vegetation condition, environmental context, dynamic regime, geographic distribution, soil and site characteristics, etc. in a standardized factsheet template (Fig. 3). Factsheets will be available in PDF format at <http://cnvc-cnvc.ca> (currently under development; anticipated date for public access is June, 2008).

Current Status

At present (May, 2007), CNVC units are being developed only at the association level. Ongoing work is concentrated on forest/woodland associations, employing provincial/territorial plot data and linking national associations to existing provincial/territorial units wherever possible. Canadian National Vegetation Classification data and conceptual standards, as well as analysis protocols, are being developed from the forest/woodland project. This component of the overall CNVC is being funded and coordinated by Natural Resources Canada–Canadian Forest Service.

Canadian National Vegetation Classification associations have been confirmed in the southern portion of the boreal forest in western Canada (46 associations), in Pacific coastal forests (76 associations), and in the Acadian forest region of eastern Canada (125 associations). New provincial/territorial associations are being developed in Ontario, Québec, Saskatchewan, British Columbia, and the Yukon Territory; these associations will be correlated across provincial/territorial borders to formulate new CNVC associations.

Development of arctic plant associations will commence in fall, 2008, with funding from the International Polar Year (IPY). This work will be

Canadian National Vegetation Classification (CNVC)
Classification nationale de la végétation du Canada (CNVC)
<http://cnvc-cnvc.ca>

Desc	Dist	Veg	Site	Refs
<p><i>Pseudotsuga menziesii</i> - <i>Pinus contorta</i> var. <i>latifolia</i> (<i>Tsuga heterophylla</i>) / <i>Vaccinium membranaceum</i> / <i>Arctostaphylos uva-ursi</i> Association Forest CNVC00002</p> <p>Douglas-fir - Lodgepole Pine (Western Hemlock) / Black Huckleberry / Kinnikinnick Forest</p> <p>French Name</p>				
<p>Subassociations: n/a CNVC Alliance: n/a CNVC Group: n/a</p>				
<p>Type Description</p> <p>Concept: This small-patch, late seral (mature and climax) association occurs at low elevations in the subarctic and subcontinental areas of coastal southwestern British Columbia on nutrient-deficient dry crests and upper slopes with shallow soils, or on coarse-textured glacial outwash. It has an open coniferous canopy dominated by moderate cover of Douglas-fir (<i>Pseudotsuga menziesii</i>) and lodgepole pine (<i>Pinus contorta</i> var. <i>latifolia</i>), often with low to moderate cover of western hemlock (<i>Tsuga heterophylla</i>). The understory is characterized by moderate cover of black huckleberry (<i>Vaccinium membranaceum</i>), kinnikinnick (<i>Arctostaphylos uva-ursi</i>) and western hemlock regeneration. The moss/lichen layer is diverse and well-developed, often with high cover of red-stemmed feathermoss (<i>Pleurozium schreberi</i>) and clad lichens (<i>Cladonia</i> spp.). Stands of this association typically originate from infrequent stand replacing fires (perhaps every few hundred years) or windthrow.</p> <p>Vegetation: This association has an open coniferous canopy dominated by moderate cover of <i>Pseudotsuga menziesii</i> and <i>Pinus contorta</i> var. <i>latifolia</i>, often with low to moderate cover of <i>Tsuga heterophylla</i>. Moderate cover of <i>Tsuga heterophylla</i> regeneration and <i>Vaccinium membranaceum</i> characterizes the shrub layer, together with low to moderate cover of regenerating <i>Pinus contorta</i> var. <i>latifolia</i> and <i>Thuja plicata</i>. Low to moderate covers of <i>Vaccinium parvifolium</i>, <i>Vaccinium alaskaense</i>, <i>Menziesii ferruginea</i></p>				



Courtesy of BC Forest Service

Fig. 3. Example portion of a Canadian National Vegetation Classification (CNVC) association factsheet.

coordinated by the Department of Environment, Government of Yukon. Additional CNVC-related work with IPY funds will be conducted by Parks Canada. International circumpolar collaborations are being established to support the arctic work.

Pilot projects to develop and test prototype units at various upper levels of the provisional CNVC hierarchy (Fig. 1) will be undertaken as resources become available.

Summary

The Canadian National Vegetation Classification will ultimately classify the natural and seminatural vegetation of Canada using a nationally standardized protocol. Canadian National Vegetation Classification units will be defined and described at multiple levels in a taxonomic hierarchy, facilitating development of applications at multiple spatial and conceptual scales. The work is being undertaken by a broad partnership of governmental and nongovernmental agencies. Currently, work is confined to the development of plant associations in forest and woodland ecosystems. Classification of arctic vegetation will commence in fall 2008.

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Classification and Distribution of Boreal Vegetation in Europe (in the Map of the Natural Vegetation of Europe)

Udo Bohn

This paper explains the classification and distribution of the boreal vegetation in Europe and is based on digital data from the Map of the Natural Vegetation of Europe, scale 1:2,500,000 (Bohn et al. 2000/2003, Bohn et al. 2004). All of the information in this paper was given in a Microsoft PowerPoint presentation (Bohn and Gollub 2007) at the Fourth International CAFF Flora Group Workshop. For the full PowerPoint presentation and references to slides herein, see <http://arcticportal.org/en/caff/caff-expert-groups/caff-flora-expert-group-cfg/4th-international-workshop>. Principal vegetation formations and their subgroups, along with structural and floristic features of boreal vegetation are illustrated in slides from the PowerPoint presentation (e.g. Slide # PP).

Introduction

In the *Map of the Natural Vegetation of Europe*, the boreal zone comprises 10 different principal vegetation formations. These consist of five zonal and five azonal formations. All formations are hierarchically subclassified according to zonal, altitudinal, geographical, and edaphical criteria. The boreal core formations are birch forests (formation C) and coniferous forests (formation D).

The *Map of the Natural Vegetation of Europe* includes altogether 700 mapping units that are linked into a hierarchically structured classification system within the framework of the overall legend. The main groups of this system form 19 physiognomic-structurally and ecologically characterized formations and formation complexes, of which 14 (A to O) represent the macroclimatic zones from the north to the south and southeast of Europe, as well as the corresponding altitudinal belts in the mountain ranges. Their differentiation and spatial sequence is determined primarily by the temperature gradient: from cold and humid to warm and dry climates. The last five formations (P to U) are listed as azonal vegetation types and complexes characterized by predominantly edaphic site factors, such as the presence of sandy, saline, or wet soils, and are modified only secondarily by macroclimatic factors. The individual formations are labelled (as a code for the vegetation map) with capital letters in alphabetical order.

The principal formations are divided into subgroups according to their species composition, finer climatic differences, and larger-scale site conditions. The subzones are arranged according to the temperature gradient from north to south, and further subdivided corresponding to oceanicity or continentality classes along the climatic gradient from west to east. These in turn are subdivided according to nutrient supply, altitudinal belts, water balance, and geographical location into mapping units (Bohn 1998).

For the phytogeographical classification in the *Map of the Natural Vegetation of Europe* we used the classification produced by Meusel and Jäger (1992)

and published in the *Atlas of the Central European Flora* (consisting of 6 volumes) (see Slide 2 PP presentation, Bohn and Gollub 2007). The map provides a system of global zones that are further divided into floristic regions, subregions, provinces, and subprovinces. The boundaries between the global zones are depicted by dotted lines. These zones are designated from north to south as circumarctic, circumboreal, temperate, submeridional, and meridional, with the latter including the Mediterranean region.

The boreal zone in Europe comprises Iceland, the Faroe Islands, northern Scotland, the main part of Fennoscandia, and the North European part of Russia. In Europe this zone is further divided into climatically and floristically characterised provinces, named boreo-Atlantic, Scandinavian, and boreo-Russian.

As illustrated on the *General Map of the Natural Vegetation of Europe* (Fig. 1; Slide 3 PP), the natural vegetation of the boreal zone is dominated by coniferous forests (violet and red-brown colors) in the eastern, climatically more continental part and birch forests (pink colors)—as well as Atlantic dwarf-shrub heaths—in the western part with oceanic climate. Adjoining the boreal zone to the north appears tundra vegetation of the Arctic zone (grey-brown colors). Adjacent to the south, the vegetation of the temperate zone is depicted in different green colours. The transition zone from boreal coniferous to temperate broad-leaved forests is designated as hemiboreal subzone of the temperate zone with mixed broad-leaved-coniferous forests. The Mediterranean sclerophyllous vegetation is characterized by orange and red colors. Continental steppes and desert vegetation, depicted by yellow and ochre colors, are belonging to the eastern submeridional zone (Bundesamt für Naturschutz 2002).

An overview map for Europe was constructed by combining all formations, subformations, and mapping units within the major zones in major classes (Fig. 2; Slide 4 PP). In this map the boreal zone is depicted by purple colors. Within the major zones, differentiation was made only in lowlands and mountain regions, which were distinguished by shading of the basic

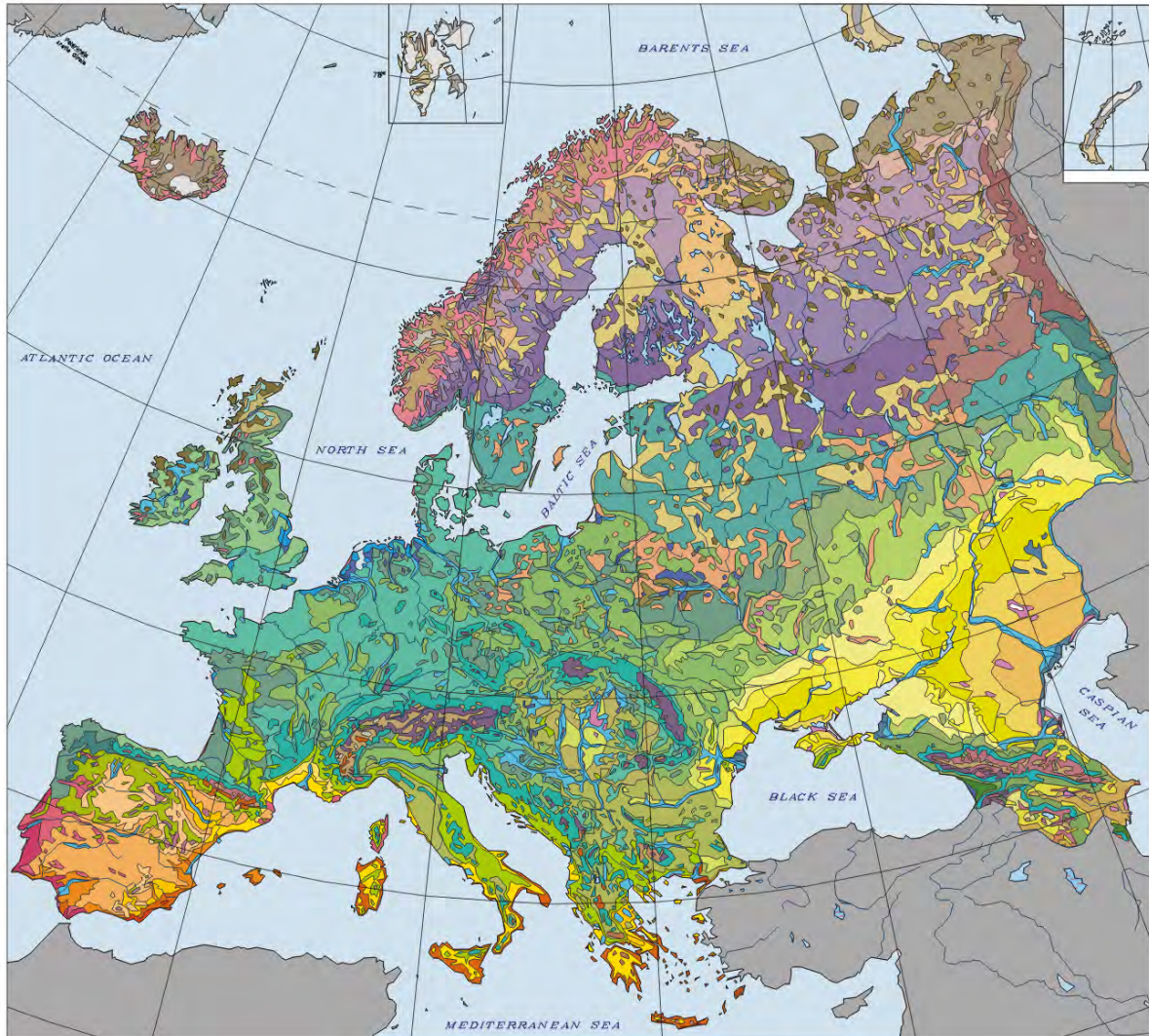


Fig. 1. General Map of the Natural Vegetation of Europe showing the distribution of the principal formations and their sub-formations. It consists of 77 aggregated mapping units (scaled-down version of the generalized vegetation map at a scale of 1:10,000,000; Bundesamt für Naturschutz 2002).

colors. Thus, the European natural vegetation was roughly classified into Arctic, boreal, temperate (including submeridional), and Mediterranean vegetation (Bohn and Gollub 2006).

Zonal Formations of the Boreal Zone and Their Classification

The boreal forest vegetation of Europe is composed of two main formations (Fig. 3; Slide 5 PP): Formation C (pink colors) represents subarctic and boreal open woodlands dominated, especially in the western part, by birch trees and shrubs (mostly *Betula pubescens* s.l.), and Formation D (purple, red-brown and light brown colors) represents coniferous forests with different dominating tree species, such as spruce, fir, and pine. Purple colors represent spruce forests (*Picea abies*, *P. obovata*), red-brown colors represent the predominance of Siberian conifer species such as *Picea obovata*, *Pinus sibirica*, *Abies sibirica*, and *Larix sibirica*. Light brown colors indicate prevailing pine forests with dominating *Pinus sylvestris*.

Subdivision of the Boreal Core Formations and Their Distribution

Formation C—subarctic, boreal, and nemoral-

montane open woodlands (see Slide 6 PP). This formation consists of two geographically differentiated subgroups:

- C.1 represents the eastern boreal open woodlands with different combinations of the main tree species *Betula pubescens* subsp. *czerepanovii*, *Picea obovata*, and *Pinus sylvestris*.
- C.2 represents the western boreal birch forests, partly in complex with pine forests, in the more oceanic influenced regions, especially western Scandinavia and Iceland.

These two subgroups consist altogether of 15 mapping units differentiated according to floristic criteria, depending on geographical, climatic, and edaphic factors.

Characteristic natural vegetation and landscapes within formation C:

- Eastern boreal open woodland with predominating Siberian spruce (*Picea obovata*), scattered birch trees (*Betula pubescens* subsp. *czerepanovii*), and juniper shrubs on Kola Peninsula, Russia, in contact to treeless mountain tundra (see Slide 7 PP).

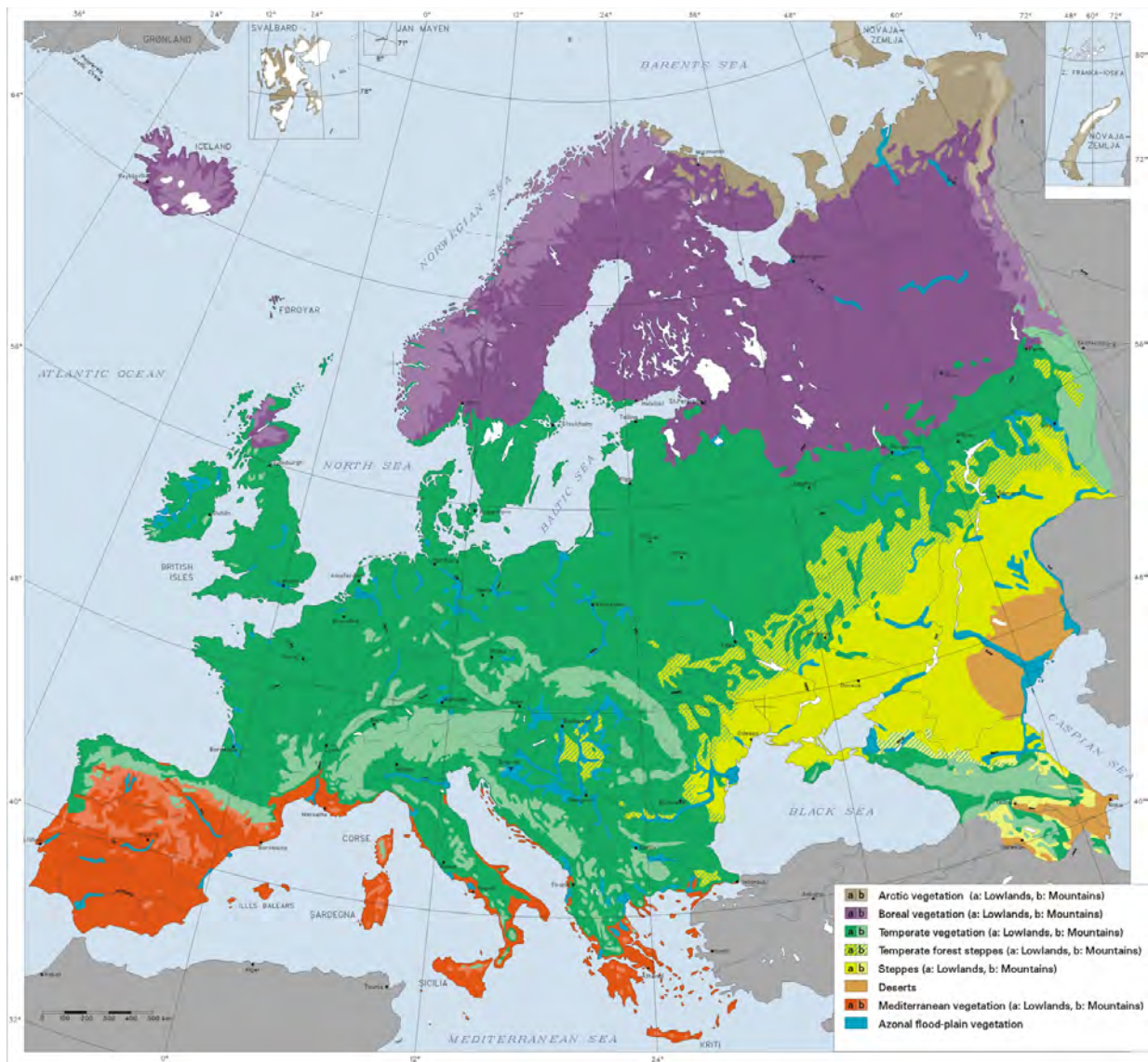


Fig. 2. Generalized Map of the Natural Vegetation of Europe, with major zones (basic colors) and mountain regions within the major zones (lighter shaded colors) (based on Bohn and Gollob 2006).

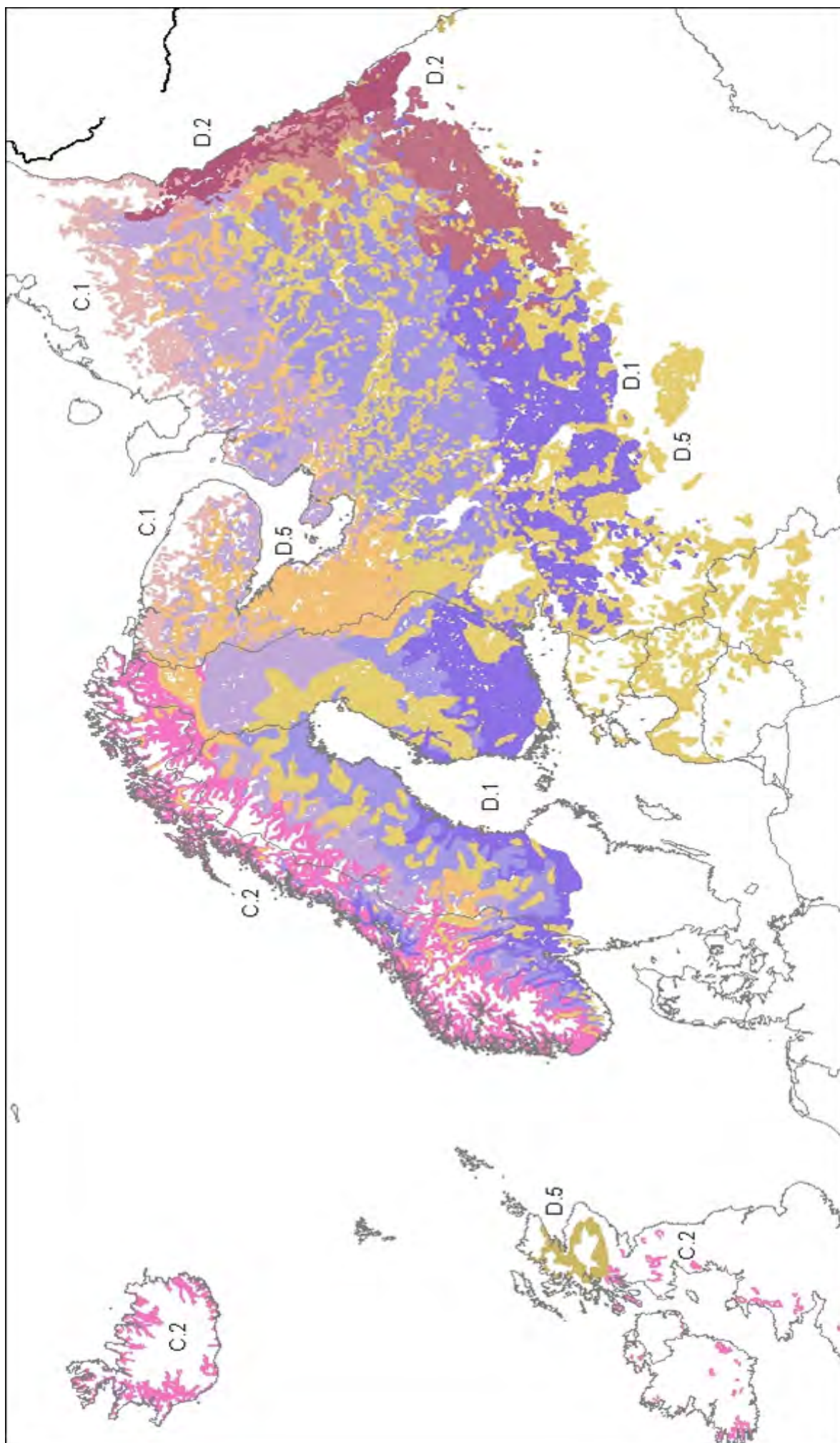
- In the lower parts of the mountains of Swedish Lapland closed birch forests dominate, and in the higher altitudes, birch forests change into low growing willow scrub and treeless dwarf-shrub heaths (see Slide 8 PP).
- The steep slopes of the West Norwegian fjords are normally covered by birch forests, and on the warmer foothills they are locally covered by temperate broad-leaved forests with *Ulmus glabra*, *Fraxinus excelsior*, and *Corylus avellana* (see Slide 9 PP).
- D.2 represents the eastern boreal pine-spruce and fir-spruce forests, which are composed of Siberian conifer species such as *Picea obovata*, *Pinus sibirica*, *Abies sibirica*, and *Larix sibirica* spreading from western Siberia over the Urals into the East European lowland.
- D.5 consists of pine forests with *Pinus sylvestris* being predominant and the changing admixture of birch and spruce trees. These forest types naturally occur only under extreme soil conditions: on nutrient-poor and dry sandy or rocky, or wet and peaty sites. Pine forests are not restricted to the boreal zone and extend on suited sites further south into the temperate zone.

Formation D—mesophytic and hygromesophytic coniferous forests. These are mainly distributed in the central and eastern parts of northern Europe and in the higher mountains. Formation D is divided into six main subgroups according to dominant conifer species. Three of these subgroups are predominantly distributed in the boreal zone and are characterized by a more continental climate (see Slide 10 PP):

- D.1 represents the western boreal spruce forests dominated by *Picea abies*, *P. obovata*

The further subdivision of western boreal spruce forests (formation D.1; see Slide 11 PP) follows the climatic gradient from north to south into northern, middle, and southern boreal subzones and types. This subdivision is caused by different lengths of

Fig. 3. Distribution of boreal forest vegetation in Europe: C.1, C.2-Subarctic, boreal and nemoral-montane open woodlands (pink colors). D.1, D.2, D.5-Mesophytic and hygromesophytic coniferous forests (purple, red-brown, and light brown colors). (Source: Bohn et al. 2004).



the growing season. But the delimitation of the three subzones is also based on floristic, structural, and ecological features; however, the boundaries between these subzones are more or less blurred.

The northern boreal spruce forests (see Slide 12 PP) are characterized by an open canopy, reduced tree growth, and low timber production. In general, due to the open tree layer, pronounced admixtures of birch trees (particularly *Betula pubescens* subsp. *czerepanovii*), *Sorbus aucuparia* and *Juniperus communis*) can be found. Characteristic plant species of the field layer are those that are mainly distributed in the tundra zone and those that are associated in more southern areas only with mires and peaty sites.

The middle boreal spruce forests represent the typical boreal forest vegetation and cover the largest area. They are characterized by a well developed tree layer consisting of *Picea abies* in the western part, and *P. obovata* and the hybrid of both in the eastern part of northern Europe. In the dwarf-shrub-rich field layer, both subarctic and nemoral species are normally absent. Special vegetation complexes often comprise aapa mires (see Slide 13 PP).

The southern boreal spruce forests are characterized by the occurrence of nemoral plant species in the tree, shrub, and especially the herb layer, such as *Tilia cordata*, *Ulmus glabra*, *Acer platanoides*, *Quercus robur*, *Corylus avellana*, *Lonicera xylosteum*, *Daphne mezereum*, *Anemone nemorosa*, *Asarum europaeum*, *Galium odoratum*, and *Lamium galeobdolon* mainly on nutrient-richer soils. But moss- and dwarf-shrub-rich types differ floristically only little from the middle boreal spruce forests (see Slide 14 PP). In the southern boreal zone the ecological and floristic differences between the western and eastern areas are clearer than they are within the other subzones, which is presumably due to a stronger climatic gradient within the southernmost subzone.

The tree layer of the eastern boreal coniferous forests (formation D.2; see Slide 15 PP) consists of Siberian conifer species that spread over the Urals to a varying extent into its western foothills and lowland. These include *Picea obovata*, *Larix sibirica*, *Abies sibirica*, and *Pinus sibirica* forming dark coniferous forests (the so-called “dark taiga”). Even in the shrub and herb layer many Uralian–Siberian species occur in addition to widely distributed boreal species.

The group of eastern boreal coniferous forests is on the first level subdivided into lowland-colline and (submontane-) montane (Ural) types, and on the second level within the lowland-colline subgroup into northern, middle, and southern boreal types.

The third group of boreal coniferous forests (formation D.5; see Slide 16 PP) consists of pine forests with dominating *Pinus sylvestris*. This group

comprises more or less azonal forest communities that are restricted to nutrient-poor acidic and/or dry sandy, rocky, or peaty sites, occurring moreover far south of the boreal zone within the temperate zone. Nevertheless, this formation can also be differentiated zonally and regionally according to the floristic composition of the field layer. Because of the lack of climatic indicator species, pine forests are divided only into two subzones: the northern and the middle and southern boreal types. On the second level there exists an altitudinal differentiation into lowland-colline and montane types. The latter types have been identified only in Scotland and the southern Urals. The altogether 10 mapping units are differentiated according to site conditions and regional indicator species.

In the PowerPoint presentation, two different types of northern boreal pine forests are presented: Slide 17 shows a well-growing primeval lichen-rich pine forest with closed canopy on a dry hilltop with less extreme site conditions in central Sweden, and Slide 18 presents an open pine forest on a very rocky slope in northern Karelia, very rich in lichens covering the bedrock.

Mountain Tundras and Alpine Vegetation Within the Boreal Zone

Another typical but unwooded formation within the boreal zone comprises mountain tundras and alpine vegetation (formation B; see Slide 19 PP). The units concerned are mainly distributed in mountain regions and occur as altitudinal belts above the belt of birch and open spruce woodlands in the subarctic and boreal zones. Because of gradual transitions between arctic and boreal vegetation it is difficult in many cases to decide whether these units belong to arctic tundras or to the boreal alpine vegetation.

The subnival-nival vegetation of high mountains and the alpine vegetation in the boreal zone are mainly distributed in the Scandinavian high mountains, in small outposts in the interior mountains of the Kola Peninsula, in the Scottish Highlands, and on the Faroe Islands (see Slide 20 PP). They consist of four mapping units.

Characteristic landscape and vegetation details of boreal high mountains in Scandinavia:

- High alpine to nival vegetation and landscape in Norway (see Slide 21 PP)
- Willow scrub vegetation during winter snow-covered hollows and dwarf-shrub heaths on normal and wind exposed sites in Swedish Lapland (see Slide 22 PP)
- Alpine grassland with flowering herbs on nutrient-rich soil in Swedish Lapland (see Slide 23 PP)

Subformation B.1.5—mountain tundras and sparse mountain vegetation. The units concerned are distributed in the mountains of Iceland, Kola Peninsula, and in the northernmost part of the Urals (see Slide 24 PP). These mountain tundras are situated in the transition zone between arctic and boreal vegetation and, therefore, are closely related to tundra vegetation in the southernmost part of the Arctic zone (see Slides 25-27 PP).

Azonal Vegetation Within the Boreal Zone

Within the boreal zone, besides zonal vegetation, natural azonal vegetation occurs on large areas too (see Slide 28 PP). Boreal azonal vegetation belongs to the following principal formations:

- E – Atlantic dwarf-shrub heaths (7 mapping units)
- P – Coastal vegetation (6 mapping units)
- S – Ombrotrophic, ombro-minerotrophic, and minerotrophic mires (17 mapping units)
- T – Swamp and fen forests (2 mapping units)
- U – Vegetation of floodplains and other moist or wet sites (5 mapping units)

These formations and their mapping units are also characteristic elements of the natural vegetation of the boreal zone.

Formation E—Atlantic dwarf-shrub heaths. The naturally treeless vegetation of the Faroe Islands was completely assigned to formation E, subgroup: boreo-Atlantic coastal and mountain heaths. Its natural vegetation forms a complex of various grassland, moss, sedge, and dwarf-shrub communities. As we have seen on the excursion guided by A.M. Fosaa, there exists a distinct altitudinal zonation. Dwarf-shrub heaths are distributed only in the lower and warmer altitudes up to 200 m, whereas the higher parts of the Faroe Islands should be assigned to alpine vegetation (see Slide 29 PP; Fosaa 2004).

Formation P—coastal vegetation comprises the vegetation of coastal sand dunes, of shingle beaches, and of rocky seashores as well as coastal halophytic vegetation. Boreo-Atlantic sand dune vegetation is mapped for example on the coast of southwestern Iceland (see Slide 30 PP).

Formation S—mires. Characteristic mire types of the northern boreal subzone are palsa mires (see Slide 31 PP). They occur in the northernmost (subarctic) areas of the boreal zone up to the southern Arctic zone. Characteristic features are structural complexes of peat mounds (palsas), caused by permafrost and ice nucleus, and wet hollows with alteration of ombro- and minerotrophic mire vegetation.

Another characteristic mire type of the boreal zone is aapa mires. These were classified as minerotrophic

mires (or fens), but their vegetation complex is consisting of ombrotrophic (on strings) and minerotrophic mire vegetation (in flarks, flat hollows) as well (see Slide 32 PP).

Formation T—swamp and fen forests are represented in the boreal zone by two mapping units: alder and birch carrs. These forest types cover only small areas on permanently very wet sites and are mainly distributed in the southern boreal subzone.

Formation U—vegetation of floodplains and other moist or wet sites is represented in the boreal zone by five mapping units assigned to specific boreal alluvial forests. Two of them belong to the subgroup of “northern to middle boreal coniferous and mixed broad-leaved alluvial forests” characterized by mixed forests consisting of boreal conifers and deciduous broad-leaved trees (*Picea obovata*, *P. abies x obovata*, *Abies sibirica*, *Alnus incana*, *Betula pubescens* s.l., *Salix myrsinifolia*) in complex with willow scrub (*Salix viminalis*, *S. acutifolia*). Their main distribution area is situated in North European Russia.

The other three mapping units are assigned to “southern boreal coniferous and broad-leaved alluvial forests.” Besides boreal conifers and broad-leaved trees there are locally occurring nemoral trees, such as *Alnus glutinosa*, *Fraxinus excelsior*, *Ulmus laevis*, *Quercus robur*, and *Tilia cordata*.

Conclusion

- According to the *Map of the Natural Vegetation of Europe*, at the scale 1:2,500,000, the boreal zone comprises ten different principal vegetation formations.
- These consist of five zonal (or altitudinal) formations: A, B, C, D, F and five azonal formations: E, P, S, T, U.
- The boreal core formations are birch forests (formation C) and coniferous forests (formation D).
- All principal formations are hierarchically subclassified according to zonal, altitudinal, geographical, and edaphical criteria.
- Within the boreal zone, there are 90 mapping units altogether, with each of them described in detail by standardized data sheets.
- All map and textual information is available in printed form and on an interactive CD-ROM in English and in German. This allows multiple use and analysis of the comprehensive database as demonstrated in the PowerPoint presentation.
- Thus, the recently published *Map of the Natural Vegetation of Europe* provides an ideal regional basis for the construction of a circumboreal vegetation map, both with regards to a suitable conception and a detailed digital database.

- A circumboreal vegetation map should contain not only the natural zonal vegetation formations and units, but also the typical azonal vegetation units covering larger areas.

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Boreal Vegetation Map of Russian Regions

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Introduction

Development of a vegetation map is the final result of detailed study of vegetation in a certain area that includes many stages (e.g., field data collection, creation of databases, classification of plant communities, ordination of vegetation, and recognition of spatial vegetation categories in satellite images or from other cartographic data). Small-scale geobotanical maps represent an integral knowledge of vegetation diversity and the spatial structure of vegetation in vast areas. They are based on well-developed vegetation classification systems and described relationships between environmental data and phytosociological subdivisions that are represented in existing patterns, such as “vegetation–climate,” “vegetation–relief,” and “vegetation–bedrocks.” Development of vegetation maps is one of the most difficult scientific tasks that can be solved by teams of experienced scientists. Moreover, it requires special techniques based on modern computational technologies and laborious procedures. Therefore, at present, there are few well-known, small-scale geobotanical maps that have been produced for large areas and that can be found in available world literature.

Small-Scale Vegetation Mapping in Russia

Vegetation mapping in Russia was historically oriented on small geographical scales because of the large area of the country. Numerous expeditions under leaderships of well-known scientists were organized during the first half of the 20th century in zones and subzones of Siberia and the Russian Far East. At that time, the Russian small-scale cartographic school was founded in the Komarov Botanical Institute in St. Petersburg. This school united many well-known geobotanists (E. Lavrenko, V. Sochava, S. Gribova, and T. Isachenko), who studied various vegetation types during numerous expeditions organized all over the territory of the former Union of Soviet Socialist Republics (USSR). A result of their activity was the small-scale map, *Geobotanical Map of the USSR*, scale 1:4,000,000 (Sochava & Lavrenko 1954). This map included 109 subdivisions of vegetation. Boreal vegetation amounted to 32 subdivisions (Fig. 1). The basic unit of the map was a vegetation formation representing a vegetation type with predominance of certain plant species (or some dominant species) in the higher layer of plant community. The monograph, “Vegetation of the USSR” (Sochava & Lavrenko 1956), in which the authors described the most important regularities of spatial vegetation structure and described all vegetation types represented in the legend, accompanied the vegetation map. Up to date, this small-scale map has been the single

map representing regularities of vegetation diversity for the whole territory of the former USSR. All maps produced later (e.g., *Vegetation of the USSR*, scale 1:4,000,000) (Isachenko 1990) contain similar content in the legend.

Development of small-scale vegetation mapping was very intensive during the second part of the 20th century and was connected with V. Sochava, one of the leaders of the Komarov Botanical Institute. In the 1960s, V. Sochava organized the Institute of Geography in Irkutsk (Siberia) and oriented the production of small-scale thematic maps of North Asian vegetation. Over a 20-year period, Sochava’s scientific teams (A. Belov, E. Lapshina, I. Ilyina, E. Denisova, and L. Meltser) produced a series of small-scale vegetation maps (scale 1:1,500,000) for some vast areas of North Asia: *Landscapes of the Southern Part of Eastern Siberia* (Sochava 1973; Fig. 2); *Vegetation Map of West Siberia* (Ilyina et al. 1976; Fig. 3); and *Vegetation Map of the Amur River Basin* (Sochava 1968). The legends of these maps are characterized by some hierarchal levels reflecting zonal-sector, altitudinal subdivisions of vegetation, and some important plant geographical peculiarities. A small basic unit in Sochava’s maps was formation. Larger units included vegetation types with predominant characteristic life forms (physiognomic types; e.g., dark-coniferous, light-coniferous, and small-leaved forests, etc.). Moreover, Sochava introduced a special hierarchal level called “fratria of formations” to reflect some very important provincial peculiarities of vegetation that are related to genesis of large zonal vegetation types.

During the second part of 20th century, a series of small-scale geobotanical maps were produced for some regions of Russia: *Vegetation Map of European Part of the USSR*, scale 1:2,500,000 (Gribova et al. 1979); *Vegetation of the Altai*, scale 1:1,000,000 (Kuminova 1960); *Vegetation Map of Yakutia*, scale 1:5,000,000 (Andreev & Shcherbakov 1989); *Correlative Ecologic-Phytocoenotic Map*, scale 1:7,500,000 (Buks et al. 1977); *Zones and Altitudinal Types of Vegetation of Russia and Neighboring Countries*, scale 1:8,000,000 (Safronova et al. 1999); and *Vegetation Map of the Southern Part of Western and Middle Siberia*, scale 1:1,000,000 (Lapshina 2004). “Vegetation of European Part of Russia” was included in the international project, *Map of the Natural Vegetation of Europe*, scale 2,500,000 (Bohn et al. 2000).

Currently, the main part of Russian territory has been covered by a series of small-scale vegetation maps (scale 1:1,500,000). However, vegetation of some vast areas (e.g., the Middle Siberian Plateau) is still poorly studied and small-scale maps are absent.

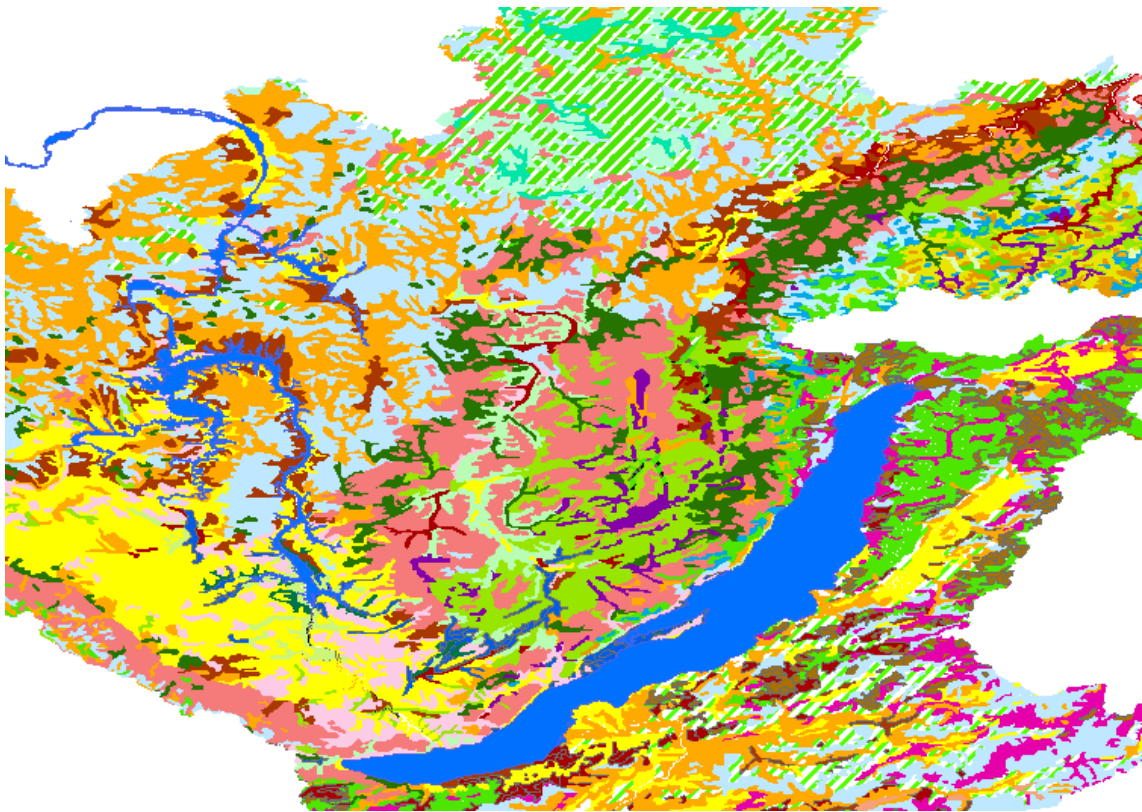


Fig. 2. Landscapes of Southern Part of Eastern Siberia, scale 1:1,500,000 (Sochava 1973).

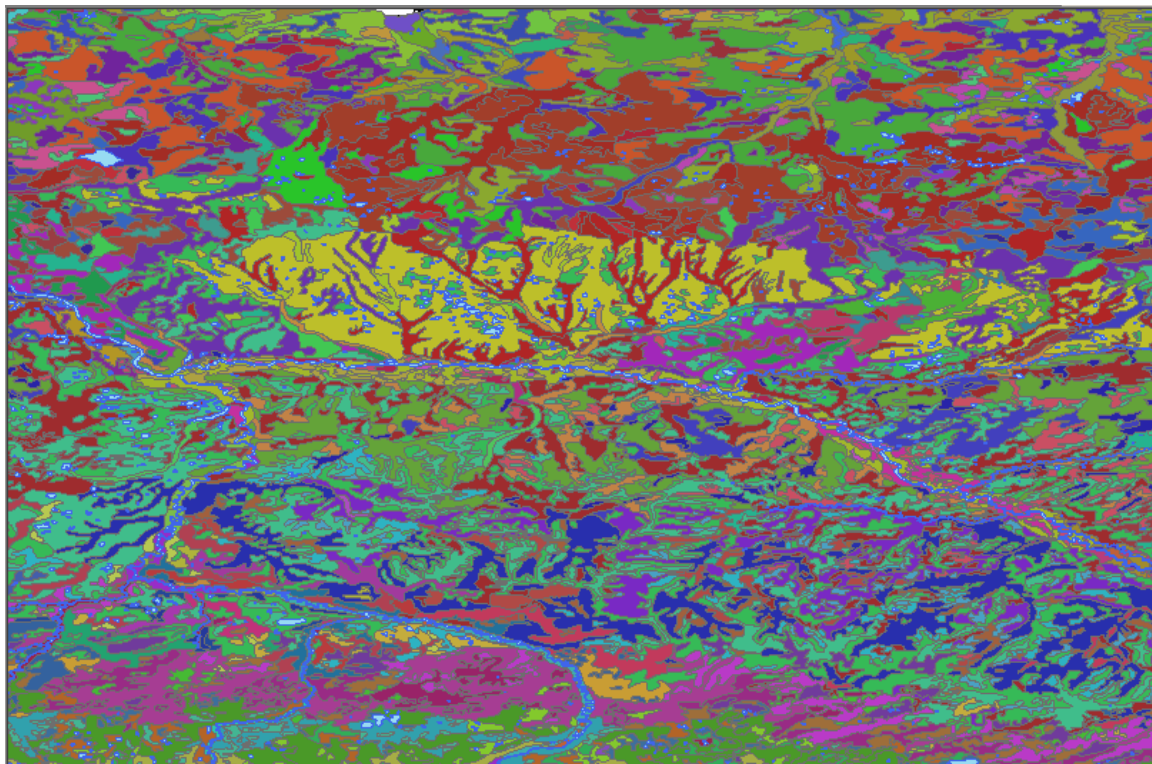


Fig. 3. Digitized vegetation map of West Siberia, scale 1:1,500,000 (based on Ilyina et al. 1976).

Approaches for New Small-Scale Geobotanical Maps

At present there is an opportunity to create a new type of small-scale map of circumboreal vegetation within the frames of an international project. It is conditioned by a progress in the development of phytosociology, plant geography, and ecology in Eurasia and North America, as well as by the active use of modern information technologies.

New Data and Approaches

1. During the last 20 years, new classification systems of vegetation in the boreal zone (forests, wetlands, subalpine, and alpine communities) of Northern Eurasia have been produced. For example, the Braun-Blanquet system includes 14 classes, 29 orders, and 47 alliances for Russian boreal vegetation (Solomeshch et al. 1997, Korotkov et al. 1991, Korotkov & Ermakov 1999).
2. Some very important relationships between boreal vegetation and environmental factors (first of all with climate) have been revealed and reflected in statistical patterns, e.g., "vegetation-climate" (Nazimova & Polikarpov 1996, Monserud et al. 1993, Tchebakova et al. 1994) at levels of biomes and smaller units.
3. New schemes of plant-geographical regions for the boreal zone of Northern Eurasia have been developed (Malyshev et al. 1999, 2000).
4. New thematic ecological maps (small-scale maps of permafrost, small-scale maps of soils) produced for large regions expose the peculiarities of ecology and natural limits of geographical subdivisions of boreal vegetation.
5. Currently, there are several Russian phytosociological centers developing databases of geobotanical relevés with the use of standard database management systems, for example, Turboveg (Hennekens 1996). Vegetation of the boreal zone is represented approximately by 15,000 relevés from various regions of Northern Eurasia.
6. Geographic information systems (GIS) allow new approaches for vegetation mapping and for creating electronic maps on the basis of the unified projection, coordinate system, as well as for cartographic modeling of vegetation on the basis of thematic maps of relief and climate.
7. The use of satellite images (Landsat 7, Terra-Modis) for distinguishing primary and secondary vegetation types in the boreal zone is the reliable and unified cartographic basis for developing small-scale maps of natural vegetation of vast areas.

Framework for Basic Zonal Subdivisions of Boreal Vegetation in Small-Scale Maps

Small-scale geobotanical maps should show the regularity of distribution of higher subdivisions of vegetation types and their combinations in relation to leading environmental factors in continents (zonal climate, influence of oceans, relief, permafrost, etc). Moreover, the concept of hierarchy of ecological factors can be applied in the development of a legend for a circumboreal vegetation map. Climate occupies an upper level in hierarchy of ecological factors determining the spatial structure of vegetation. Actually, it is divided into two global integrated factors: climatic zonation and oceanity–continentality, which play a leading role in the formation of vegetation zones and geographical sectors.

The concept of zonal subdivisions of boreal vegetation at the scale of continents has been developed in some studies (e.g., Ahti et al. 1968, Hämet-Ahti 1981). Generalized schema include seven subdivisions:

1. Boreal zone
 - 1.a. North boreal (taiga) subzone
 - 1.b. Middle boreal (taiga) subzone
 - 1.c. South boreal (taiga) subzone
 - 1.d. Hemiboreal (subtaiga) subzone
2. Oro-boreal vegetation in mountains
3. Hypo-Arctic zone

Every vegetation zone and sub-zone may be subdivided in several bioclimatic sectors according to the factor of oceanity–continentality. There are various patterns of regional bioclimatic sectors produced for Eurasia and North America. However, for discussion, it would be helpful to consider generalized schema consisting of five main subdivisions:

1. Oceanic (Atlantic and Pacific)
2. Suboceanic (Sub-Atlantic and Sub-Pacific)
3. Subcontinental
4. Continental
5. Ultracontinental

Bioclimatic sectors are able to show the main provincial peculiarities of boreal vegetation, as well as represent very important regularities in boreal vegetation diversity that are oriented from oceans to the center of a continent.

Examples of Boreal Vegetation Subdivisions for Small-Scale Maps

Following are examples of bioclimatic, geographical vegetation types (zonal and sub-zonal), sector subdivisions, and corresponding syntaxa of boreal vegetation:

1. Middle boreal subzone
 - a. Subatlantic European dark-coniferous forests (*Picea excelsa*) and boreal forests (Vaccinio-Piceetea, Vaccinio-Piceetalia, Vaccinio-Piceion)
 - b. Continental Eastern European–West Siberian coniferous mixed forests (*Picea obovata*, *Larix sibirica*, *Pinus sibirica*) and boreal forests (Vaccinio-Piceetea, Vaccinio-Piceetalia, Empetro-Piceion)
 - c. Ultracontinental East Siberian light-coniferous forests (*Larix gmelinii*) and coniferous mixed (*Picea obovata*, *Larix gmelinii*) boreal forests in zonal sites with permafrost (Vaccinio-Piceetea, Ledo-Laricetalia)
 - d. Ultracontinental East-Siberian–Central Asian light-coniferous forests (*Larix gmelinii*, *L. sibirica*) and boreal forests with participation of xeric elements (Vaccinio-Piceetea, Lathyro-Laricetalia)
 - e. Sub-Pacific North-East Asian coniferous mixed forests (*Larix gmelinii*, *Picea yezoensis*, *P. obovata*) and boreal forests (Vaccinio-Piceetea, Ledo-Laricetalia)
 2. South boreal subzone
 - a. Sub-Atlantic Eastern European dark-coniferous (*Picea excelsa*) with participation of broad-leaved trees (*Tilia cordata*) and boreal forests (Vaccinio-Piceetea, Vaccinio-Piceetalia, Vaccinio-Piceion)
 - b. Continental Eastern European–West-Siberian dark-coniferous forests (*Picea obovata*, *Abies sibirica*, *Pinus sibirica*) and boreal forests (Vaccinio-Piceetea, Vaccinio-Piceetalia, *Aconito-Abietion sibiricae*)
 - c. Sub-Pacific East Asian dark-coniferous (*Picea obovata*, *P. yezoensis*) boreal forests (Vaccinio-Piceetea, Vaccinio-Piceetalia, *Abieti-Piceetalia yezoensis*)
 3. Hemi-boreal subzone
 - a. Continental West Siberian small-leaved trees (*Betula pendula*, *Populus tremula*) and hemiboreal forests on saline soils (Brachypodio-Betuletea, Calamagrostio-Betuletalia pendulae)
 - b. Continental West and Middle Siberian small-leaved-light coniferous forests (*Pinus sylvestris*, *Betula pendula*, *Populus tremula*) and hemiboreal forests (Brachypodio-Betuletea, Carici-Pinetalia sylvestris)
 - c. Ultracontinental East-Siberian–Central Asian light-coniferous forests (*Larix sibirica*, *L. gmelinii*) and hemiboreal forests (*Rhytidio-Laricetea*, *Carici pediformis-Laricetalia*)
 - d. Continental (Sub-Pacific) Daurian-Manchurian small-leaved trees (*Betula platyphylla*) and small-leaved coniferous forests (*Betula pendula*, *Pinus sylvestris*, with participation *Quercus mongolica*, *Betula davurica*) and hemiboreal forests (*Quercu-Betuletea davuricae*)
- Bioclimatic and Geographical Types of Oro-Boreal Vegetation in Mountain Areas**
1. South Urals–South Siberian dark-coniferous forests (*Abies sibirica*, *Pinus sibirica*, *Picea obovata*) and oro-boreal forests in mountain areas with residual influence of Atlantic cyclones (Vaccinio-Piceetea, Vaccinio-Piceetalia, *Aconito rubicundi-Abietion sibiricae*)
 2. South Siberian small-leaved light-coniferous forests (*Pinus sylvestris*, *Larix sibirica*, *Betula pendula*) and oro-hemiboreal forests in mountain areas with residual influence of Atlantic cyclones (Brachypodio-Betuletea)
 3. South Urals–South Siberian small-leaved dark coniferous mixed forests (*Abies sibirica*, *Pinus sibirica*, *Populus tremula*, *Tilia cordata*) and subnemoral forests in mountain areas with active influence of Atlantic cyclones (Quercu-Fagetea, *Abietetalia sibiricae*)
 4. South Siberian–North Mongolian coniferous mixed forests (*Pinus sibirica*, *Larix sibirica*) and light coniferous forests (*Larix sibirica*) and continental and ultracontinental oro-boreal forests on long-frozen soils (Vaccinio-Piceetea, Ledo-Laricetalia, *Pinus sibiricae-Laricion sibiricae*)
 5. Ultracontinental East Siberian light coniferous forests (*Larix gmelinii*) and oro-boreal forests on permafrost (Ledo-Laricetalia, Ledo-Laricion cajanderi)
 6. Ultracontinental East Siberian open light-coniferous forests (*Larix gmelinii*) and oro-boreal forests with subalpine elements (*Betula divaricata*, *Pinus pumila*) on permafrost (Ledo-Laricetalia gmelinii, *Rhododendro aurei-Laricion gmelinii*)
 7. Ultracontinental East Siberian subalpine krummholz (*Pinus pumila*, *Betula divaricata*, *Rhododendron aureum*) on permafrost (Vaccinio-Pinetalia pumilae)
 8. East Asian dark-coniferous forests (*Picea yezoensis*) and oro-boreal forests in mountain areas with influence of Pacific monsoon (*Abieti-Piceion yezoensis*)
 9. East Asian coniferous mixed forests (*Picea obovata*, *Picea yezoensis*, *Larix gmelinii*) and oro-boreal forests in mountain areas with residual influence of Pacific monsoon trees (*Piceion yezoensis*)

10. Ulacontinental East Siberian–North Mongolian light coniferous forests (*Larix sibirica*, *L. gmelinii*) and oro-hemiboreal forests (Rhytidio rugosi-Laricetea)
11. Manchurian-Daurian small-leaved trees (*Betula platyphylla*) and small-leaved light coniferous trees (*Larix gmelinii*) and oro-hemiboreal forests in mountain areas with residual influence of Pacific monsoon trees (Querco-Betuletea davuricae)

Topics for Discussion

1. Where should the northern and southern boundaries of the circumboreal zone run? First, an answer to this question depends on phytosociological characteristic features accepted for distinguishing a boreal vegetation type. Actually, boreal forests are widely determined as plant communities with predominance of boreal cold-resistant coniferous trees. However, some transitional communities (e.g., northern small-leaved birch or aspen forests) are also included in the boreal vegetation type. Transitional vegetation of the Hypo-Arctic (forest-tundra) zone is considered as a subdivision of boreal vegetation in the legends of most small-scale geobotanical maps. According to these principles, the boreal vegetation should be restricted in the north by the southern boundary of Arctic vegetation. The southern boundary of boreal vegetation should be restricted by the northern boundary of broad-leaved (nemoral) vegetation in suboceanic regions and by the northern boundary of forest-steppe in the inner part of the continent. A point currently under great discussion is the position of the southern boundary of boreal vegetation in the mountain systems. For example, boreal vegetation spreads southward from the boreal zone in semi-arid mountains of Southern Siberia, where it predominates, and forms a continuous vegetation belt. In this case, the areas where boreal vegetation predominates in the mountain landscapes and does not show any breaks with the main part of the boreal zone should be included in the Boreal Vegetation Map.
2. The mapping scale of 1:7,500,000 that was applied to the *Circumpolar Arctic Vegetation Map* is appropriate for creation of a circumboreal vegetation map.
3. A unified legend should be represented by hierarchy of units. Higher basic units may be bioclimatic vegetation types.
4. The circumboreal map may represent both potential and actual vegetation. Information from satellite images may be used for the development of actual vegetation.
5. Geographic information system (GIS)

techniques should be applied for the project. It would be very helpful if all participants of the project accepted unified formats, geographic basis, and software.

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Large-Scale Vegetation Mapping in Iceland

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In this paper we describe and discuss large-scale vegetation mapping in Iceland as well as the vegetation classification used. We will also briefly explain how vegetation mapping in Iceland is conducted and will provide a short report on our habitat-mapping project.

Vegetation of Iceland

The botanical composition of the current vegetation in Iceland represents only partly the potential or climax vegetation of the country. This is mainly because extensive and long-lasting sheep overgrazing has resulted in large-scale damage of the vegetation cover and, in some parts of the country, resulted in serious erosion problems. Unfavorable climatic conditions and a short growing season, especially in the Central Highlands, makes the vegetation in Iceland very vulnerable and easily damaged by heavy grazing. Additionally, the volcanic soils of the country are prone to erosion, and overgrazing can induce soil erosion in a relatively short time.

Vegetation Mapping

Vegetation mapping in Iceland started relatively late in comparison to the European continent. In 1955 the Department of Agriculture of the University Research Institute, now the Agricultural Research Institute, started fieldwork for a map of the actual vegetation of the highland common grazing area, Gnúpverjafréttur in South Iceland. Most of that area lies 300 m above sea level.

The overall purpose of the mapping was to determine the sheep carrying capacity of the vegetation of the Central Highlands, an area of about 40,000 km². Reliable information on plant communities was needed to assess the nutritional value of the vegetation for sheep grazing and, thus, provide a basis for sustainable use and management of the highlands.

The Agricultural Research Institute's program for vegetation mapping in the 1950s covered the following main fields of study:

1. Vegetation classification
2. Vegetation mapping
3. Floral surveys and measurements of annual production of plant communities
4. Assessment of vegetation conditions
5. Studies of plant grazing preference of sheep
6. Determination of the nutritive value of diet

7. Studies on the nutrient requirements of livestock
8. Studies on the effects of different grazing pressure on vegetation and on the performance of livestock
9. Measurements of vegetation cover and calculations of the carrying capacity

Fieldwork was carried out with the aid of aerial photographs, and in 1957 the first vegetation map of Gnúpverjafréttur, at a scale of 1:40,000, was published (Jóhannesson & Thorsteinsson 1957).

Vegetation Classification

Vegetation classification used in the map was defined and described on the basis of botanical research conducted over several decades by the well-known botanist Steindór Steindórson, an advisor to the mapping team from the beginning.

These units were based on growth forms, or the dominant and characteristic species of vascular plants in the upper layers of the vegetation, with mosses and lichens classified only to a limited degree. The main vegetation complexes were divided into 16 orders, which were again divided into 98 associations, the smallest classification unit used. Vegetation orders were delineated in accordance with physiographical characteristics, while the smaller plant communities were classified according to dominant species of vascular plants. Borders between plant communities were often gradual and tended to overlap. On the Icelandic vegetation maps, complexes composed of a mosaic of two or more communities often covered a given mapping area.

Following are the main structures of the plant communities used in the map as described by Steindór Steindórsson (Steindórsson 1975, 1981), revised and slightly simplified by a group of specialists in 1991-1993 and by the present authors (Einarsson 1994, 1995):

Dryland Vegetation

1. *Betula pubescens* wood- and shrubland with various types of undergrowth
2. Heath vegetation dominated by mosses
3. Heath vegetation dominated by *ericaceous* dwarf shrubs, *Betula nana* and/or *Salix* spp.
4. Heath vegetation dominated by *Kobresia myosuroides*, *Juncus trifidus*, *Carex bigelowii*, and eventually other species

5. Heath vegetation dominated by various species of lichens and dwarf shrubs
6. Graminoid vegetation
7. Graminoid vegetation with *Carex bigelowii*
8. Graminoid vegetation with dwarf shrubs
9. Vegetation of sand dunes, mainly dominated by *Leymus arenarius*
10. Cultivated grassland of various types
11. Forb meadows with tall forbs
12. Forb meadows with low forbs
13. Snow bed vegetation of various types
14. Land with sparse vegetation, both in lowland and mountain areas, such as gravelly flats and river-plains, screes, cliffs, and rock-walls, classified into groups in accordance with vegetation cover percentage but not by dominant or characteristic species

Wetland Vegetation

1. Vegetation of moist land dominated by *Carex* spp., *Juncus* spp., graminoids, and *Salix* spp.
2. Vegetation of sloping mires, dominated by *Carex nigra* and various other species of *Carex*, but sometimes also dominated by *Eriophorum angustifolium*, *Betula nana*, or *Salix* spp.
3. Vegetation of sloping mires, mainly dominated by *Trichophorum caespitosum* and *Carex* spp.
4. Vegetation of sloping mires, mainly dominated by *Equisetum palustre* and *Carex* spp.
5. Vegetation of mosses around cold springs
6. Vegetation of level mires and fens, classified into several types dominated by various species of *Carex*, such as *C. lyngbyei*, *C. rostrata*, *C. rariflora*, and *C. chordorrhiza*
7. Vegetation of level mires and fens, dominated by *Eriophorum angustifolium* and sometimes certain species of dwarf shrubs, such as *Betula nana* and *Vaccinium uliginosum*
8. Vegetation of salt marshes and strand meadows
9. Vegetation of lakes and ponds, classified into types by dominating species in the emergent vegetation (swamp), submerged and floating-leaved vegetation, and the bottom vegetation

Vegetation Mapping as a Basis for Grazing Management

In the latter half of the 1950s, some additional fieldwork was carried out in neighbouring areas of Gnúpverjafréttur, but no additional maps were published. In 1961, work on vegetation mapping

began again with the plan to map the entire country, with the same principal objectives as before. Using the same scale as earlier, 1:40,000, would require 289 maps to cover the whole area of Iceland. Over the next 20 years, this ambitious plan, headed by Ingvi Thorsteinsson, with the continuing guidance of Steindór Steindórsson, was one of the major programs of the Agricultural Research Institute. Initially, emphasis was placed on mapping the commons of the Central Highlands as a basis for grazing management.

Despite limited funding at times, the mapping work proceeded relatively well, and around 1980 most of the uninhabited Central Highlands and some parts of the inhabited lowlands had been mapped. In the 1980s, mapping of the lowlands continued, but mapping work gradually receded in the 1990s because of the continuing lack of funds. Overall, there was a decline in sheep farming and grazing pressure, thus, the demand for vegetation maps decreased as well.

Publication of the maps did not proceed with the same speed as fieldwork. So far, only 64 maps, at the scale of 1:40,000 and covering 29,000 km² of the Central Highlands have been published. Additional 32 maps of the Central Highlands were prepared but not published. Furthermore, 28 maps of lowland areas at the scale 1:25,000 covering 3,000 km² have been published, where larger-scale maps are needed for planning or other land-use management. Finally, 11 lowland maps at the scale of 1:20,000 covering 4,000 km² have been published, showing property, districts, and municipal boundaries (Gudbergsson 1981; Fig. 1).

Vegetation Mapping for Environmental Work

In 1995, the Icelandic Institute of Natural History took over the task of vegetation mapping from the Agricultural Research Institute. Since then, the main thrust of the work has been to revise previous maps as a basis for environmental impact assessments of development projects in both highland and lowland areas. At the same time, budgets for traditional vegetation mapping have become even scarcer than before.

Fieldwork for vegetation mapping has now been completed for more than two-thirds of the country. Mapping for the Central Highlands is mostly completed, but more than half of the lowland still remains unmapped. Over the last decade, 16 % of the mapped area has been digitized and updated with the aid of new orthophotomaps and Spot-5 and Landsat satellite images.

In the early 1990s the vegetation mapping project in Iceland was computerized. So far, we have mainly used mapping software and geographic information systems (GIS) from Microstation and ArcInfo. However, in 2004 we started using imaging software from Erdas as well.



Fig. 1. Present status of large-scale vegetation maps in Iceland. The white areas have not been mapped.

Until 1997, vegetation mapping was based on aerial photographs of various dates and scales as well as AMS map series at a scale of 1:50,000. Since then, digital orthophotomaps, mainly with 0.5 m resolution, have been used with increased success. Recently, we have begun the use of remote-sensing data (Spot-5) to improve and verify the mapping work. The Spot-5 satellite, launched in 2002, has greatly improved remote-sensing capabilities: image resolution is now up to 2.5 meters. This new resolution creates new possibilities for cartography and the collection of geographical information, although it does not substitute for orthophotomaps. One-fourth of the country has already been covered, but sixty Spot-5 images, at a total cost of \$650,000, are required to cover the entire country. The goal is now to complete the digitizing of all our material by the end of 2008 and to store the data in our Institute's nature databank.

As described above, the objective of the vegetation mapping program was initially to provide a basis for calculating the carrying capacity of sheep grazing areas. The vegetation maps have become increasingly valuable for planning and monitoring other land uses and for environmental impact assessment. Vegetation maps also serve as historical records for the future.

Small-Scale Mapping

In 1998 an overview map, the *Vegetation Map of Iceland* (1:500,000), was published by the Icelandic Institute of Natural History (Gudjonsson & Gislason 1998; Fig. 2). The map was generated with the help

of Landsat satellite images (1:250,000) and based on all vegetation data available at the time. Before that time, Iceland had been included in maps covering the Nordic countries or the whole of Europe. The *Vegetation Map of the Council of Europe Member States*, at the scale 1:3,000,000, was published in 1979 and revised in 1987 (P. Páhlsson, L. 1994). *Map of the Physical Geographic Regions* was based mainly on natural vegetation and published by the Nordic Council of Ministers in 1983 (Nordiska Ministerrådet 1984). *Maps of the Natural Vegetation of Europe*, including Iceland, were published in the year 2000 in two scales, 1:10,000,000 and 1:2,500,000 (Bohn, Gollub & Hettwer 2000). Finally, the Icelandic Forest Research Institute has produced a map of all recent forest plantations and revised the map of natural birch woodlands in Iceland (Snorrason, Arnór & Kjartansson, Bjarki Þór 2004).

Habitat Classification and Mapping

In recent years, vegetation maps have been used by our Institute as a basis for large-scale habitat classification and for mapping programs (Magnússon & Magnússon 2002). Classification of habitat types has been ongoing in most European countries for some time. In Iceland there has been an interest to follow this line of work in order to fulfill international and national nature conservation obligations. It is essential to use similar methods as in other parts of Europe for the classification and description of Icelandic habitat types, and to allow for comparison within and among countries. Because Iceland is an isolated volcanic

Vegetation in Iceland at present

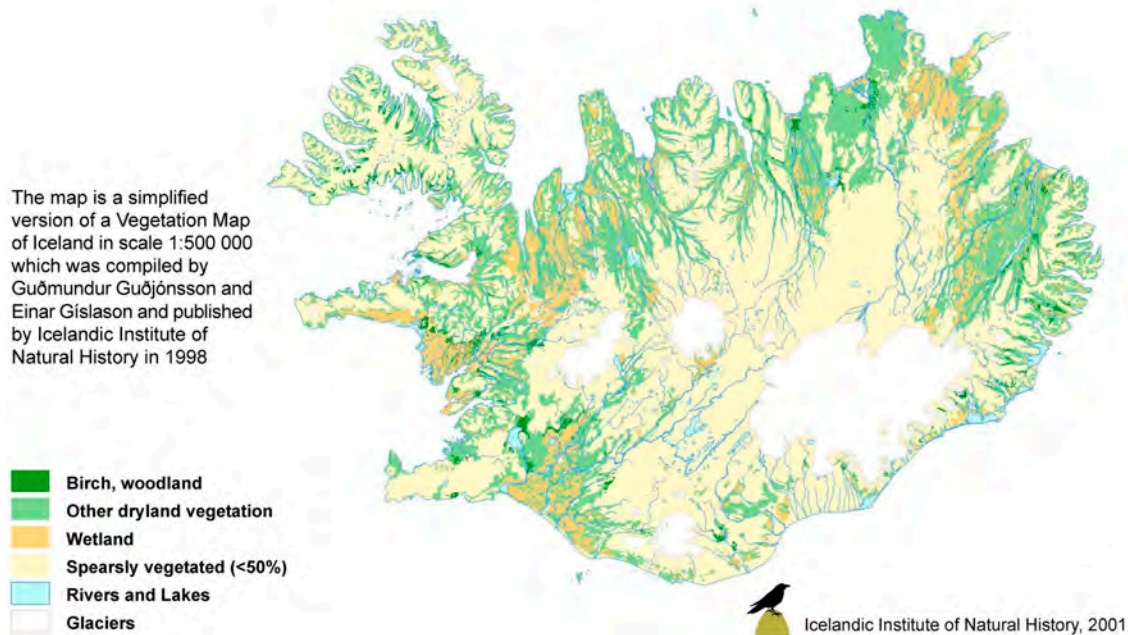


Fig. 2. Vegetation map of Iceland, in scale 1:500,000, published in 1998 by Icelandic Institute of Natural History (Gudjónsson & Gíslason 1998, modified).

island with species poor flora and fauna that differ considerably from those of the neighboring countries, a mainland habitat classification scheme could not be adopted without revisions.

In 1999, a special study, the “Habitat Project,” was initiated at the Institute. It is carried out in co-operation with the Master Plan for Hydro and Geothermal Energy Resources in Iceland.

The first phase of the work aims to classify habitat types. As the European methodology of habitat classification is based on vegetation, it was important to test if the same applied to Iceland. This was feasible because plant communities in two-thirds of the country had already been mapped.

For the field study, a stratified random sampling was used. A vegetation map of each area was explored and the existing plant communities subjectively classified or transferred into preliminary habitat types. Based on this classification, a new map of each area was produced showing the preliminary habitat types. Plant communities that are most similar to a particular habitat type are then grouped together to form a specific type. Classification of the 260 vegetation transects from four highland areas has revealed 20 different habitat types. Within these types, great variation has been found in vegetation cover and in several other characteristics. Six of these habitat types had very low vegetation cover.

Conclusions

Although considerable work remains, much has been accomplished to date in detailed vegetation mapping of Iceland. A substantial amount of data have been gathered. Information on vegetation also reveals other important aspects of natural features. Once vegetation maps in high resolution have been made, it is possible to simplify vegetation association in many ways in order to make smaller scale vegetation maps of larger areas.

Circumpolar Boreal Vegetation Map

If the decision is made to proceed and extend the *Circumpolar Arctic Vegetation Map* (CAVM Team 2003) to cover also the boreal area, we would suggest the following steps:

- Approach the boreal mapping project in a similar way as the CAVM
- Classify vegetation in the same way as the CAVM map, with additions to cover the boreal vegetation
- Establish a mapping team, to ensure that all participants work along the same lines from the beginning
- Define the southern limit
- Collect present vegetation maps from the boreal countries and produce a common classification key for the whole area

- Include two levels of classification, for larger scale and smaller scale
- Produce final map at scale 1:7,500,000

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Vegetation Mapping of Norway and Northern Scandinavia Using Satellite Data

Bernt E. Johansen & Stein Rune Karlsen

In phytogeographical context, the mainland areas of Norway represent a transition from treeless Arctic tundra in the north to deciduous broadleaved nemoral forest in the south, interrupted by large areas of treeless mountains. It also includes a transition area from humid, oceanic regions in the west and drier, undulating landscape towards the east. In order to summarize the varied and complex vegetation formations within the country, various Norwegian institutes and agencies have performed different types of large- and small-scale mapping. For large-scale mapping, Norwegian botanists have generally agreed upon the major bioclimatic zones and sections. Small-scale mapping has suffered from a lack of resources for many years, and today, vegetation maps based on traditional methods cover only restricted parts of the Norwegian mainland.

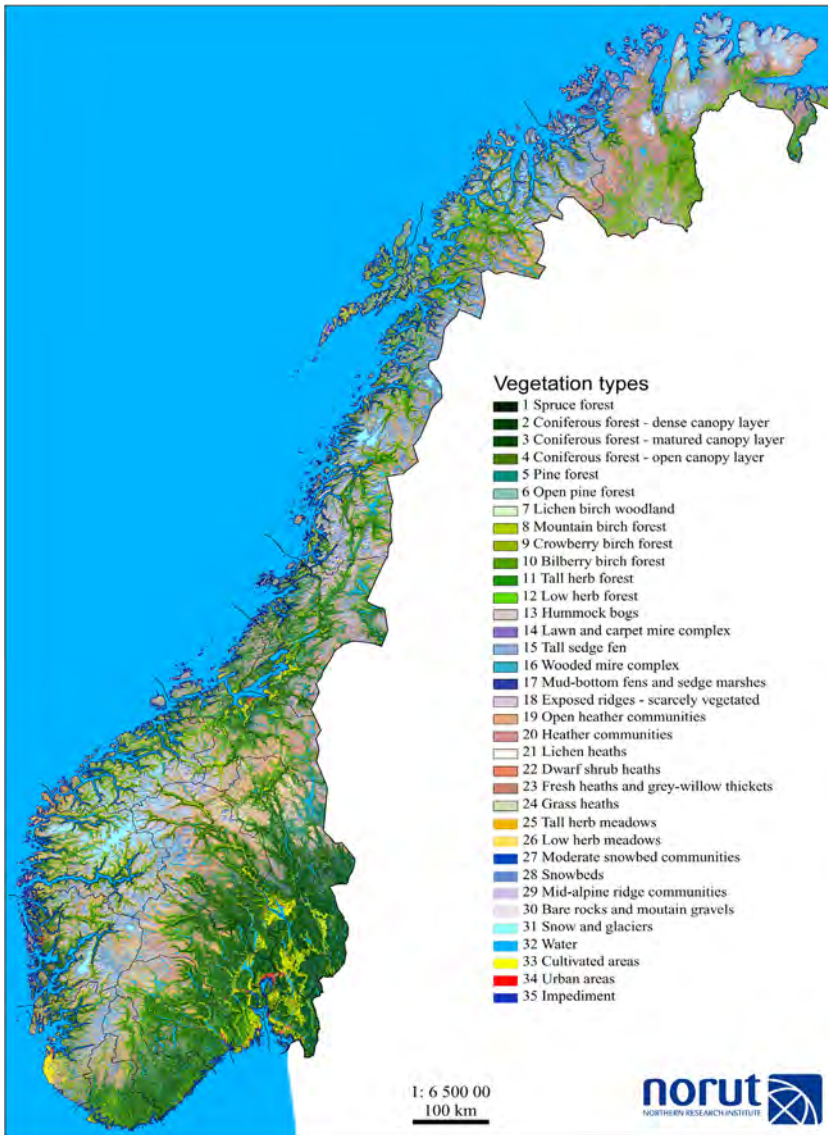
Our overall aim has been to generate a generalized, consistent, and seamless vegetation map of the Norwegian mainland, including bordering areas in Northern Scandinavia. Satellite images (Landsat, MODIS) have been selected as the main source of information in the mapping process. For the mainland of Norway a total number of 45 Landsat TM/ETM+ images are being processed during six operational stages: (1) spectral classification, (2) spectral similarity analysis, (3) generation of classified image mosaics, (4) ancillary data analysis, (5) contextual correction, and (6) standardization of the final map products. Analysis performed on the spectral-only data is often denoted the pre-classification stage of the process, whereas the post-classification process involves analysis and subsequent contextual corrections of the pre-classified image using ancillary data. The quality of the ancillary data sets highly affects the quality of the final vegetation map. For Norway, high-quality ancillary data are available for the entire country. In the final standardization part of the process, the defined classification units are related and described according to classification schemes well adapted in the Norwegian botanical tradition.

The map products created in this project portray the country of Norway at different levels. At the most detailed level, based on Landsat data, a seamless vegetation map is created with a ground resolution of 30 m, projected in Universal Transverse Mercator (UTM) map projection, zone 32, WGS 84. The map is differentiated into 35 map units, followed by detailed vegetation descriptions. Twelve forest entities are defined, five of the units are associated with bogs and mires, and 14 of the community types defined are mainly located in the mountain region.

At an overall level, the map draws the general picture of Norwegian vegetation. The coniferous forests, containing both pine and spruce forests, characterize the lowland areas of Østlandet and Trøndelag. In addition, pine forests are found in southern Norway in coastal regions of Vestlandet and in selected valleys of northern Norway. The deciduous broadleaved forests show a core center of distribution at the southernmost parts of the country. A scattered distribution is located in the coastal regions of Østlandet and in the fjord zone of Vestlandet. The birch forests in southern Norway are located at higher elevation levels, at the transitions between coniferous forests and the mountain region. In northern Norway, birch forests constitute most of the forest, covering large areas both in the lowland and upland regions. Vegetation communities associated with bogs and mires constitute large areas in the northern parts of Østlandet and on Finnmarksvidda, northern Norway. Along the coast, large mire areas are found on Andøya and on the islands Hitra and Frøya in southern Trøndelag. Coastal heather communities with *Erica cinerea* and *Calluna vulgaris* as characterizing species are developed in the outermost regions of Vestlandet, while crowberry is the most pronounced species in coastal heaths of northern Norway. In the map, the mountain regions constitute large areas in the western and central parts of southern Norway. In northern Norway the mountain range is located along the Norwegian–Swedish border. Large amounts of snow during winter, constituting varied snowbed communities, characterize the Western mountains. In the continental mountains lichen communities are well developed. These areas serve as important pastures for reindeer in the winter period. In addition, the map shows large agricultural areas in the lowlands of Østlandet, in Trøndelag, and in the surrounding areas of Stavanger.

For the areas bordering northern Scandinavia, a comparable map is produced with a ground resolution of 100 m. For Kola Peninsula, only a pre-classified image has been produced because of the lack of high-quality, ancillary data. All the Landsat map products are further compared to an overall vegetation map based on MODIS data, covering large areas of northwestern Europe. Subsections of this map are shown in the Fig. 1 (A, C). Part B of Fig. 1 shows the vegetation map covering northern parts of Finland and Sweden, Landsat data, 100-m resolution.

Through this project the first generalized, consistent, and seamless vegetation map covering the Norwegian mainland has been produced (Fig. 1). In the future, the product will serve as a reference for a



wide range of studies where spatial information is needed. From the map, new and improved delineation of phytogeographical zones and sections can be extracted. The map will provide input for research areas such as reindeer range studies, climate and pollution impact studies, as well as studies of land degradation. The produced maps will further serve as an important source of information when new types of satellite data and sensors are to be evaluated and validated. A preliminary comparison of Landsat and MODIS is performed in this study. Financial support for the project was given by the Directorate for Nature Management, the Norwegian Space Centre, and the Northern Research Institute - Tromsø.

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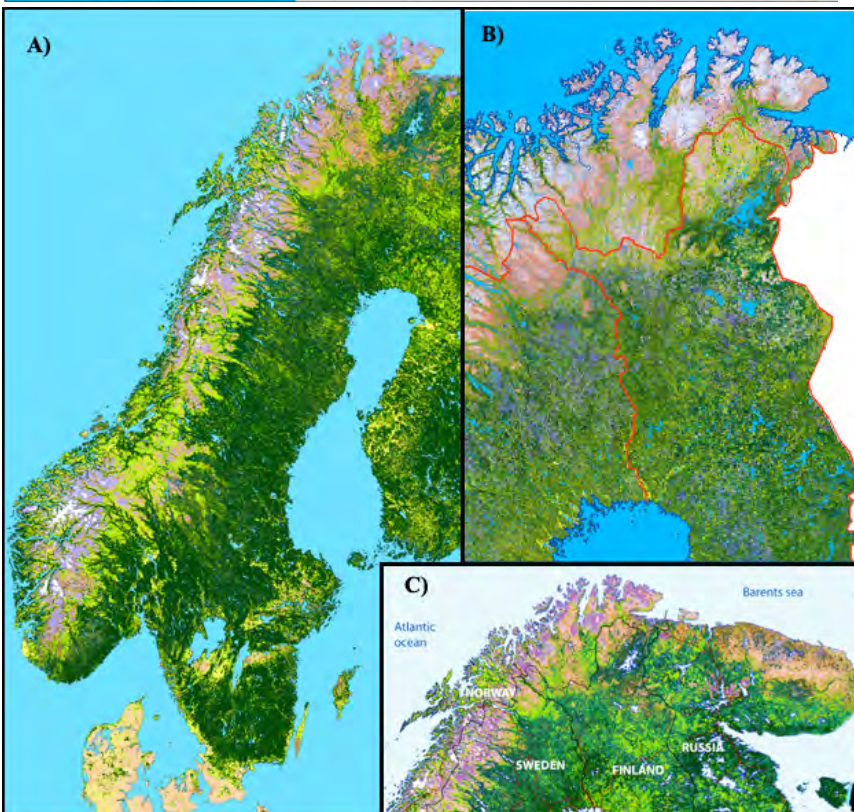


Fig. 1. Vegetation map of Norway. Subsections of this map are shown in the maps A and C. Map B shows vegetation covering the northern parts of Finland and Sweden (Landsat data, 100-m resolution).