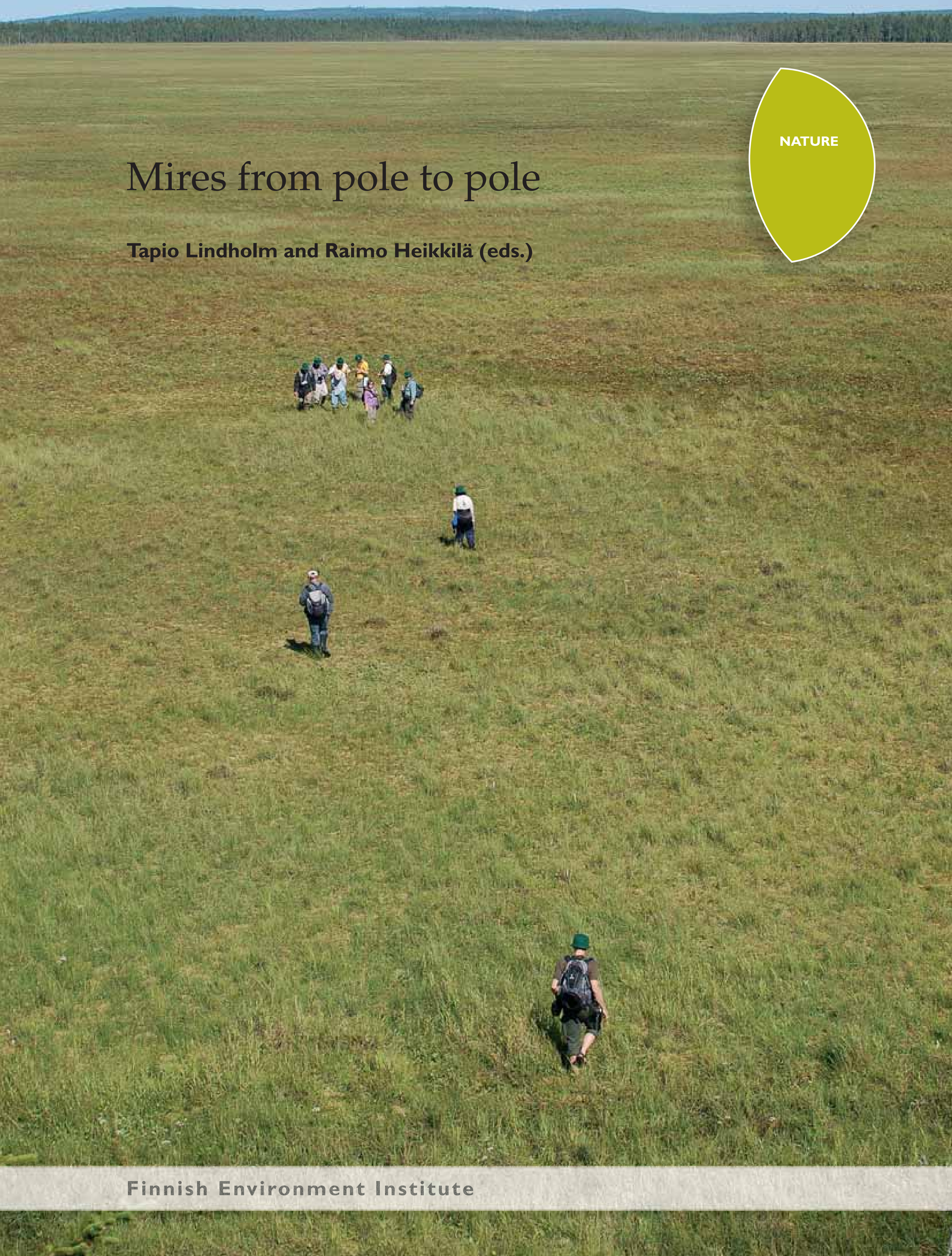
THE FINNISH ENVIRONMENT 38 | 2012

NATURE

Mires from pole to pole

Tapio Lindholm and Raimo Heikkilä (eds.)



Finnish Environment Institute

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Helsinki 2012

FINNISH ENVIRONMENT INSTITUTE

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Towards the understanding of the variety of mires and their conservation in different countries

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Introduction

The International Mire Conservation Group (IMCG) was established in Klagenfurt, Austria in 1984. The idea had emerged during a mire ecology workshop at Oulanka Biological Station, Finland in 1983, arranged by Seppo Eurola, professor of botany at Oulu university (www.imcg.net). The basic idea of the IMCG has been to gather together mire researchers and conservationists to promote the protection of mire biodiversity, carbon storage and other ecosystem services. Since 1984, biennial field symposia have been arranged in different countries in Europe, Asia, America and Africa. The 12th Biennial symposium was arranged in Finland as an excursion from Lapland to the southernmost part of the country, and a symposium at Eerikkilä Sports Institute in Tammela, southern Finland. The aim of the event was to raise international awareness about Finland's mires, their conservation, and the impacts of different types of utilization.

This publication, which contains 34 articles, includes papers based on the presentations and posters of the IMCG symposium in Eerikkilä, held from 24th to 27th July, 2006. It contains a variety of information about global mire conservation, mire ecology, biodiversity and management. Some articles are purely scientific papers and some deal with practical issues. All articles have undergone a peer review process.

Altogether 47 specialists from eight countries have contributed to the peer review work. The editors of this book wish to thank all of them. Without their contribution the editing of this book would not have been possible. Thus, our warmest thanks to all the reviewers of the articles: Dr. Petri Ahlroth, Dr. John Couwenberg, Prof. Leena Finér, Dr. Olga Galanina, Prof. Ab Grootjans, Mr. Tuomas Haapalehto, Dr. Raimo Heikkilä, Dr. Päivi Hokkanen, Dr. Timo Hokkanen, Mr. Juha-Pekka Hotanen, Mr. Antti Huttunen, Dr. Pertti Huttunen, Dr. Rodolfo Iturraspe, Prof. Hans Joosten, Mr. Eero Kaakinen, Prof. Risto Kalliola, Ms. Hanna Kondelin, Dr. Leila Korpela, Dr. Esko Kuusisto, Dr. Sanna Laaka-Lindberg, Prof. Ari Lehtinen, Dr. Tapio Lindholm, Dr. Kauri Mikkola, Prof. Jaanus Paal, Dr. Juha Pöyry, Mr. Ari Rajasärkkä, Mr. Sakari Rehell, Ms. Terhi Ryttäri, Prof. Rauno Ruuhijärvi, Dr. Sanna Saarnio, Mr. Tapani Sallantaus, Dr. Veikko Salonen, Dr. Sake van der Schaaf, Prof. Heikki Seppä, Prof. Matti Seppälä, Dr. Heikki Simola, Prof. Gert-Michael Steiner, Dr. Teemu Tahvanainen, Prof. Heikki Toivonen, Prof. Kimmo Tolonen, Prof. Anne Tolvanen, Dr. Michael Trepel, Mr. Seppo Tuominen, Dr. Tauno Ulvinen, Prof. Harri Vasander, Dr. Risto Virtanen and Prof. Leslaw Wolejko

The editing process has been far too long. There are many different steps in the editing process: requesting manuscripts, organizing the peer review process, and finally asking the authors to make the proposed corrections. One time-consuming problem has been the harmonization of the very many different scientific writing cultures into a coherent format. Between all these steps there have been periods of waiting. It must be noted that in total over 50 experts from many countries have been involved in this editing process. Finally, other, and more official, duties of the editors have also prolonged the editing period. But luckily we did notice that these articles from IMCG specialists are classical works, which do not wear out over time and will also be relevant in the future.

In connection with the event, three publications were prepared (Heikkilä & Lindholm 2006, Heikkilä et al. 2006, Lindholm & Heikkilä 2006). *Mires of Finland: Daughters of the Baltic* Sea served as an excursion guide. *Finland: Land of mires* provided a general overview of the biodiversity and state of Finnish mires in its 28 articles by altogether 29 authors. It is widely used as a textbook in several universities. The abstracts of the symposium were compiled as the third publication.

The field excursion and symposium

The excursion began at Yllästunturi mountain in Lapland, and was guided by Raimo Heikkilä, Tapio Lindholm, Aulikki Laine, Tapani Sallantaus, Pekka Salminen, Teemu Tahvanainen and Seppo Vuolanto. The starting point was the huge Teuravuoma aapamire in Kolari, followed with explorations of the calcareous rich fens of SW Lapland, wide aapamires in Martimoaapa and Hirvisuo mire reserves and Olvassuo strict nature reserve, where examples of restoration were also seen (Fig. 1., Heikkilä et al. 2006). The land uplift phenomenon and successional series of mires developing in the flat coast, which rises from the Baltic Sea at a rate of 8 mm per year, were seen in Ryöskäri, Liminganlahti and Hummastinvaara areas near Oulu town. Further south, classical examples of aapamires were visited in Salamajärvi National Park, where A.K. Cajander made the definitions of southern aapamires almost 100 years ago (Cajander 1913).

The concentric bogs of Southern Ostrobothnia were visited in Levaneva mire reserve and Kauhaneva National Park. In Lauhanvuori National Park, mires with ground water influence were seen. Seitseminen National Park was visited as an example of extensive restoration of mires drained for forestry around 1970, and as an example of spruce mires with a dense tree stand, but also a thick peat layer (Fig. 2). In Puurijärvi National Park and in Harpar Stortäsket mire reserve, wetlands and young mires developed after the lowering of the water table in shallow lakes were seen, and a plateau bog of southernmost Finland was visited in Punassuo mire reserve. During the symposium, excursions were also made to the extensive bogs in Torronsuo National Park and restored mire sites in Liesjärvi National Park. During the excursion, examples of forestry drainage of mires, peat mining areas and agriculture on former mires were also seen.

There were 46 participants in the excursion: Olivia Bragg (Scotland), Japie Buckle (South Africa), Rehana Dada (South Africa), Pascal Demaziere (France), Norman Donner (Germany), Gert-Jan van Duinen (The Netherlands), Hans Esselink (The Netherlands), Wilfried Franz (Austria), Olga Galanina (Russia), Ema Gojdicova (Slovakia), Pierre Goubet (France), Ab Grootjans (The Netherlands), Andreas Grünig (Switzerland), Raimo Heikkilä (Finland), Bettina Holsten (Germany), Rodolfo

Figure 1. Asbjørn Moen, Tapio Lindholm and Oleg Kuznetsov discussing the land uplift phenomenon in Ryöskäri mire (Photo Raimo Heikkilä).

Figure 2. Hans Esselink, Hans Joosten and Ab Grootjans in a spruce mire in Seitseminen National Park (Photo Tapio Lindholm).

Iturraspe (Argentina), Karen Jenderedjian (Armenia), Lebrecht Jeschke (Germany), Hans Joosten (Germany), Philippe Julve (France), Oleg Kuznetsov (Russia, Karelia), Aulikki Laine (Finland), Arlette Laplace-Dolonde (France), Agu Leivits (Estonia), Li Lin (China), Tapio Lindholm (Finland), Kalle Mälson (Sweden), Izolda Matchutadze (Georgia), Dierk Michaelis (Germany), Asbjørn Moen (Norway), Francis Muller (France), Maria Noskova (Russia), Mara Pakalne (Latvia), Rémy Pouliot (Canada), Tapani Sallantaus (Finland), Sake van der Schaaf (The Netherlands), Jenny Schulz (Germany), Eva Steiner (Austria), Gert Michael Steiner (Austria), Michael Succow (Germany), Simon Thibault (Canada), Michael Trepel (Germany), Jaco Venter (South Africa), Seppo Vuolanto (Finland), Jennie Whinam (Australia) and Leslaw Wolejko (Poland) (Fig. 3).

At all excursion sites we had local guides:
Sirpa Ellä, Reijo Hokkanen, Esa Härkönen, Annamari Ilola, Satu Kalpio, Pauliina Kulmala, Yrjö Norokorpi, Tuomo Ollila, Päivi Paalamo, Elisa Pääkkö, Ari Rajasärkkä, Sakari Rehell, Anneli Suikki, Eero Tikkanen, Pekka Vesterinen and Päivi Virnes from Metsähallitus Natural Heritage Services, Eero Kaakinen, Yrjö Karjalainen, Niina Pirttiniemi and Sami Timonen from Regional Environment Centres, Hanna Kondelin from Joensuu University, Seppo Eurola, Antti Huttunen and Jarmo Laitinen from Oulu University, Harri Vasander from Helsinki University, Terhi Ala-Risku, Mauri Huhtala, Jari Ilmonen, Kalevi Keynäs, Pentti Rauhala, Jukka Salmela, Heikki Susiluoma, Teemu Tuovinen and Merja Ylönen from Finnish Association for Nature Conservation, Mirva Leppälä from Forest Research Institute, Ismo Karhu from North Ostrobothnia Regional Council, and Kaisu Aapala and Heikki Toivonen from Finnish Environment Institute.

A cultural programme was included in the programme as a cultural walk and a visit to the local museum in the town of Raahe, arranged by the town administration. In Lapua we had an unforgettable singing evening in the local inn, Tiitu, and the symposium banquet in Eerikkilä was crowned by a performance of the Fenno-Ugrian singing group, Inehmo.

The bus driver, Jari Heikkinen, and the technical staff, Mauri Heikkinen, Jani Huotari and Matti Komulainen, made very valuable contributions during the excursion. They also entertained us very nicely!

In the symposium and the General Assembly there were altogether 74 participants from 22 countries. In addition to those who participated in the excursion, there were also: Kaisu Aapala (Finland), Margarita Boychuk (Russia), Natacha Fontaine (Canada), Svetlana Grabovik (Russia), Tuomas Haapalehto (Finland), Emma Ingelsson Alkbring (Sweden), Aira Kokko (Finland), Riitta Korhonen (Finland), Stanislav Kutenkov (Russia), Anatoli Maksimov (Russia), Tatiana Minayeva (Russia), Juichi Omote (Japan), Raimo Pajula (Estonia), Bjorn Robroek (The Netherlands), Matti Seppälä (Finland), Maarit Similä (Finland), Heikki Simola (Finland), Sanna-Kaisa Simula (Finland), Andrei Sirin (Russia), Kimmo Virtanen (Finland), Elena Volkova (Russia), Alma Wolejko (Poland) and Tatiana Yurkovskaya (Russia), .

Figure 3. The excursion group in Lapua (Photo Raimo Heikkilä).

Publicity

The organizers of the IMCG gathering in Finland realised the importance of publicity and social dialogue about mire biodiversity issues. This was taken into account in planning during the first half of 2006. Tapio Lindholm lead a press and communication planning group, which included information officer Anne Brax from the Ministry of the Environment of Finland, Sirpa Pellinen information officer from the Finnish Environment Institute, and information officer Matti Nieminen from The Finnish Association for Nature Conservation. It was extremely important for all journalists to have open access to the event, and thus a very tight time schedule was needed.

As a result of the media outreach, the field symposium received very good publicity. More than 100 articles about the event were published in local, regional and national newspapers and magazines. The excursion was featured four times on the prime time news of the main Finnish TV channels, and regional and national radio channels conducted numerous interviews with excursion participants and organisers.

Environmental journalist, Rehana Dada, produced a short documentary about the expedition, and itwas broadcasted on TV in South Africa, and she also conducted live interviews for a South African radio station during the excursion (Fig. 4).

Following the event, there was extensive discussion and debate in the media about mire conservation and exploitation. There was also scientific debate, especially about the renewability of peat (Heikkilä et al. 2007a, b, c, Korhola 2007a, b). In addition, in response to the event, the Finnish national committee of the International Peat Society (IPS) published a book about mires and their utilization in Finland (Korhonen et al. 2008), see also Lindholm (2009). People active in the IMCG were excluded from the IPS book project.

Figure 4. Rehana Dada interviewing Hans Joosten, with Michael Trepel using the camera (Photo Raimo Heikkilä).

The 12th General assembly of the IMCG

After the symposium, the IMCG held its general assembly in Eerikkilä. Three resolutions from Ireland, Russia and Finland were presented.

IMCG resolution for Ireland 2006

The International Mire Conservation Group (IMCG) is a worldwide organisation of mire (peatland) specialists who have a particular interest in the conservation of peatland habitats. IMCG recognises the peatlands of Ireland as being among the most important wetland sites remaining in North–West Europe. The IMCG held its 12th biennial General Assembly in Tammela, Finland in July 2006. At that Assembly the following resolution for Ireland was adopted. The IMCG acknowledges that the Irish Government has progressed in their conservation of peatlands since our last resolution in 1990. This includes the completion of a national blanket bog survey and evaluation, a national survey of raised bog Natural Heritage Areas (NHAs), the provision of legal protection for the Irish raised and blanket bog NHAs and the adoption of approximately 225 peatland sites as part of the Natura 2000 Network. However, despite this progress, there are a number of issues that the IMCG feel require the urgent attention of the Irish Government.

1. Fens (alkaline mires) in Ireland are highly threatened ecosystems and are being damaged by drainage and infilling for either agricultural or development purposes. The IMCG urges the Government of the Republic of Ireland and particularly the Department of the Environment, Heritage and Local Government to urgently make an inventory of un-drained, actively peat-sequestering fens in the Republic of Ireland. The objectives of this survey should include:

- to identify the distribution of fen habitats throughout the Republic of Ireland and to assess the conservation significance of each site, including the 67 sites that were identified by the IPCC in the Irish Fen Inventory (2000)
- to identify habitat sites for species threatened in the European Union
- to immediately and effectively protect these peatlands (including their hydrological catchment areas) as Natural Heritage Areas
- to select a representative sample of these peatlands as Special Areas of Conservation in a European context.

2. Ireland has the most significant area of raised and blanket bog habitat in Northwest Europe. Sites of conservation importance have been designated as Special Areas of Conservation (SACs) and Natural Heritage Areas (NHAs). Current Government and EU Policy permit the practice of turf cutting (turbary rights) on designated sites, which is affecting the hydrological integrity of each mire system. The IMCG calls on the Government of the Republic of Ireland and the European Union to immediately ban the practice of peat extraction on all peatland sites of conservation importance. The IMCG furthermore urges the Irish Government to draft and implement restoration plans for all peatland sites of conservation importance.

3. The Renewable Energy Policy of the Irish Government threatens upland blanket mires by regarding wind farm construction as sustainable development within these sensitive habitats. The IMCG urges the Government of the Republic of Ireland and particularly the Department of the Environment, Heritage and Local Government to encourage the construction of wind farms away from sensitive upland blanket bog areas.

IMCG resolution for Russia 2006

The International Mire Conservation Group (IMCG) is a worldwide organisation of mire (peatland) specialists who have a particular interest in the conservation of peatland habitats. The IMCG held its 12th biennial General Assembly in Tammela, Finland in July 2006, attended by members from 21 countries and 6 continents, including 8 participants from the Russian Federation.

IMCG is aware that the Russian Federation has the largest area of peatlands in the world containing a great diversity of mire types.

IMCG recognizes:
- the significant input of Russian science to the global knowledge on mires and peatlands,
- the significant achievements in mire protection within the well developed system on Strict Nature Reserves (Zapovedniks) and National Parks,
- the strictly enforced and environmentally friendly forest, water and land use legislation, especially the designation of mires as water objects and providing forest protected zones in river sources and around mires, and
- the recent adoption by the Russian Federation of the Peatlands Action Plan, as well as input by the country into promotion of peatlands in the Ramsar process.

At the same time IMCG expresses concern about the new tendency of the Russian policy makers to allow the non sustainable exploitation of mires and peatlands rather than actively promoting conservation and the wise use of these valuable natural assets. Evidence of this tendency includes: current attempts to amend legislation giving the opportunity to misuse mires; serious losses of protected areas at the regional and local level; active lobbying by the peat industry to allow large-scale development of peat extraction; mismanagement of abandoned peatlands, resulting in extended peat fires in 1999, 2000 and 2002.

We stress that the excellent background information for mire wise use available from Russian mire scientific schools is not being used by decision makers and funding for research activities has significantly declined. To avoid moving backwards in mire conservation, IMCG calls for several specific actions to be adopted in the environment policy of the Russian Federation:

- To sustain existing environmentally friendly legislation, which is the background for the current good status of Russian peatlands;
- To maintain and secure the developed system of protected areas in Russia, especially on regional and local levels, where 20 million hectares of mires are currently preserved;
- To promote an integrative approach to mire ecosystems management as part of river basins, especially taking into account the achievements of Russian mire hydrological science;
- To introduce environmentally friendly management of abandoned peatlands, excluding peat fires and other activities that negatively affect the ecosystems;
- To introduce rewetting and restoration of mires after use;
- To minimize the impact of oil and gas industry development on the unique mire ecosystems;
- To prioritise conservation efforts to mires vulnerable to climate change – in permafrost areas, steppe and forest steppe zones;
- To designate peat as non-renewable energy resource;
- To avoid the overexploitation of peat by foreign companies especially on the western borders;
- To promote peat free horticultural products;
- To promote, extend, disseminate and apply on practical level the unique knowledge of Russian mire science;
- To promote and develop transboundary cooperation in mire conservation;
- As a Contracting Party to the main biodiversity related conventions as well as to the UNFCCC and its Kyoto protocol, to promote peatland conservation and actively use convention mechanisms to achieve this.

IMCG resolution for Finland 2006

The International Mire Conservation Group (IMCG) is a worldwide organisation of mire (peatland) specialists who have a particular interest in the conservation of peatland habitats. The IMCG held its 12th biennial General Assembly in Tammela, Finland in July 2006. At that Assembly the following resolution for Finland was adopted.

The IMCG is extremely impressed by the variation in the mires of Finland. With peatlands covering 30% of its area, Finland is one of the most important peatland countries in the world. In particular the aapa mires illustrate the surface patterning resulting from the complex and long-term interactions between plants, water, snow, ice and peat.

The Finnish-Saami terms “aapa” and “palsa” have been adopted internationally to describe specific mire types. Finnish mire scientists have substantially contributed to global understanding of peatlands. In recognition of this important role, the IMCG has conferred honorary membership on two distinguished Finnish mire scientists and conservationists Seppo Eurola and Rauno Ruuhijärvi.

And last but not least IMCG has enjoyed the extensive areas of protected mires and the impressive interpretation facilities that are so necessary to convey the values of mires to the national population and foreign visitors.

We have, however, also observed issues of concern.

- The IMCG is shocked that so many Finnish mires have been irreversibly destroyed by drainage for forestry, agriculture and peat extraction. The national statistics of the condition of the peatlands give a biased impression. In contrast to our expectations raised by a figure of 30 % of remaining pristine mires, we did not experience pristine mire landscapes - not even in National Parks, where traces of former (and persisting) drainage are evident.

The IMCG strongly urges the local and national governments of Finland to meet their international responsibility and to protect and conserve the remaining pristine peatland ecosystems. This includes the cessation of drainage and peat extraction in intact mire sites and the abandoning of current and planned groundwater extraction that may affect these sites.

- None of the Parks we have visited covers the complete hydrological system, so that present and future conflicts with competing land use outside the park boundaries are inevitable. To our amazement we observed, for example, how groundwater extraction sites are situated or planned in (e.g Kauhaneva) or directly adjacent (e.g. Olvassuo) to groundwater-dependent peatland national parks and reserves.

Finland should urgently revise the boundaries of its protected areas to enable the restoration and protection of the natural hydrologic systems. This will require a substantial increase in eco-hydrological landscape analyses and research.

- Finland should improve its recognition of the ecosystem services that pristine mires provide, along with their consequent economic value. These include biodiversity conservation, water regulation, carbon storage, the provision of palaeo-ecological archives, opportunities to experience wilderness, preservation of human heritage and the satisfaction of recreational needs, such as wild berry collection. By continuous neglect of these services, Finland progressively destroys the integrity of its country. Many of these values are irreversibly destroyed by peatland drainage, cannot be restored and often cannot be substituted. Conserving intact mires is therefore much more cost-effective than restoration of drained mires.

The IMCG noted that current Finnish environmental legislation does not give sufficient emphasis to protection of mires.

We request Finland to modernize and update its environmental legislation so that the full range of peatland ecosystem services will be duly considered in decision making.

- Mire and peatland destruction in Finland is facilitated by the misleading argument of peat being a "(slowly) renewable biofuel". There is no scientific basis to the claim that burning peat contributes any less to climate change than other fossil fuels. Peat grows so slowly that its rate of renewal is – like that of coal and lignite – irrelevant for society. Equally wrong is the argument of sustainable peat mining by pointing at accumulation elsewhere. Peat accumulation elsewhere cannot compensate for the losses of ecosystem destruction at a valuable site. We ask Finland to take note of the statement of the Global Environmental Facility (GEF) to the IMCG (April 13, 2005): “We share your concern about the preservation of peatlands. Not only are they not renewable on a societal time scale; their low rate of renewal is also too slow to be relevant for the objective of climate change mitigation. As a matter of general policy, we therefore do not endorse peat as a renewable energy resource.

We will pay heed that in the further development of this project and the GEF renewables portfolio, peat will be excluded from the support of the GEF. Unfortunately, however, this might not influence the definitions and terminology that governments are using for their national legislation, as we are a country driven mechanism, but it will ensure that GEF resources are not used for promoting peat.”

The IMCG requests the Finnish government to refrain from using (and internationally promoting) misleading labels such as “slowly renewable biofuel” as it obstructs a factual exchange of information and prevents wise decision making.

- **The IMCG urges Finland to rapidly develop and implement an energy strategy - based on truly sustainable resources - that includes:**

- phasing-out of fuel peat mining by the year 2025
- the prevention of peat mining in areas that have a high conservation value
- an immediate end to peat mining in those areas that can easily be restored, or that are important for the protection of high conservation value areas or provide key ecological services
- a restriction of the remaining peat mining activities solely to deposits that had already lost their ecological values before 1990, such as old forestry drainage sites or abandoned agricultural fields on peat soil.
- The 2006 IMCG field symposium in Finland will stimulate further international interest in research, education and conservation management of this globally important resource. The IMCG feels privileged to have had the opportunity to see such a historically important area for peatland research and thanks the Finnish Environment administration and the symposium organizers for their much-valued support. The IMCG would like to work with the Finnish Government to ensure that this resource is conserved for future generations.

The national strategy for Finland’s mires and peatlands

The national strategy for mires and peatlands of Finland was prepared after the IMCG symposium under the leadership of the Ministry of Agriculture and Forestry in 2010. It was based on the ecosystem services approach, but contrary to the Millennium Ecosystem Assessment, mire biodiversity was treated separately as conservation services, and not taken into account when dealing with the destructive ways of utilizing mires, such as peat mining, tree plantations and agriculture. The consequence was that, in the strategy, biodiversity interests were treated in accordance with the wishes of peat industry, forestry and agriculture organizations. In August 2012, a committee to develop a complementary mire conservation programme for Finland began its work. The Finnish Association for Nature Conservation has been active in mire conservation since the IMCG event in Finland.

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Patterns in polygon mires in north-eastern Yakutia, Siberia: The Role of Vegetation and Water

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Introduction

Polygon mires cover large areas of the Arctic (Zoltai & Tarnocai 1975, Zoltai & Pollett 1983, Chernov & al. 1997) where the cold climate leads to polygonal frost cracking in the developing permafrost on river terraces or dry falling lake bottoms (Mackay 1999). In spring meltwater fills the frost cracks, refreezes and forms ice veins. In the course of time, these veins push up adjacent sediments as they grow laterally due to repeated cracking. This leads to the development of low-centred ice-wedge polygons (Mackay 2000) that consist of ridges surrounding deeper lying centres. This waterlogged microrelief supports a peat forming vegetation of sedges and mosses in a wetland environment where, due to climatic conditions, decomposition is anyway reduced (Billings 1987).

Since previous research related to polygon mires has largely focussed on patterned ground development (Mackay 1988, 1999) and classification (Washburn 1973, Mackay 2000), little is known about their spatio-temporal dynamics. The patterns of polygon mires are generally explained as the sole result of ice-wedge growth (Kutzbach 2000, Mackay 2000, Ellis & Rochefort 2006). This paper describes the feedback mechanisms between vegetation, water and ground ice in these mires and the hydrological connections between adjacent polygons.

Materials and methods

We studied polygon mires in the Yana-Indigirka Lowlands (north-eastern Yakutia; fig. 1). The study area (Lc05), a 5 ha large polygon mire complex composed of ca 70 low-centred polygons, is situated at a tributary of the Indigirka River 8 km south-west of Chokurdakh (70°37’N, 147°55’E). The mire complex lies between a small thermokarst lake and the approximately 10 m high plateau Boskho-Tumul that consists of yedoma sediments (Popov 1969, Ping 1995, Minke 2005). The mean annual temperature of Lc05 is -14.2°C, with a January mean of -34.3°C and a July mean of 9.7°C. The area experiences subzero temperatures from October to May. Precipitation is minimal, at only 215 mm per year (2004 data from local climate station). A representative transect (T) was studied every metre from the mire margin to the lake shore (sites 0 to 140.8), crossing seven low-centred ice-wedge polygons. For every site the vegetation was described in 1 m² plots using a percentage scale (cf. Londo 1976). Nomenclature of vascular plants follows Cherepanov (1995), and mosses are named after Abramov

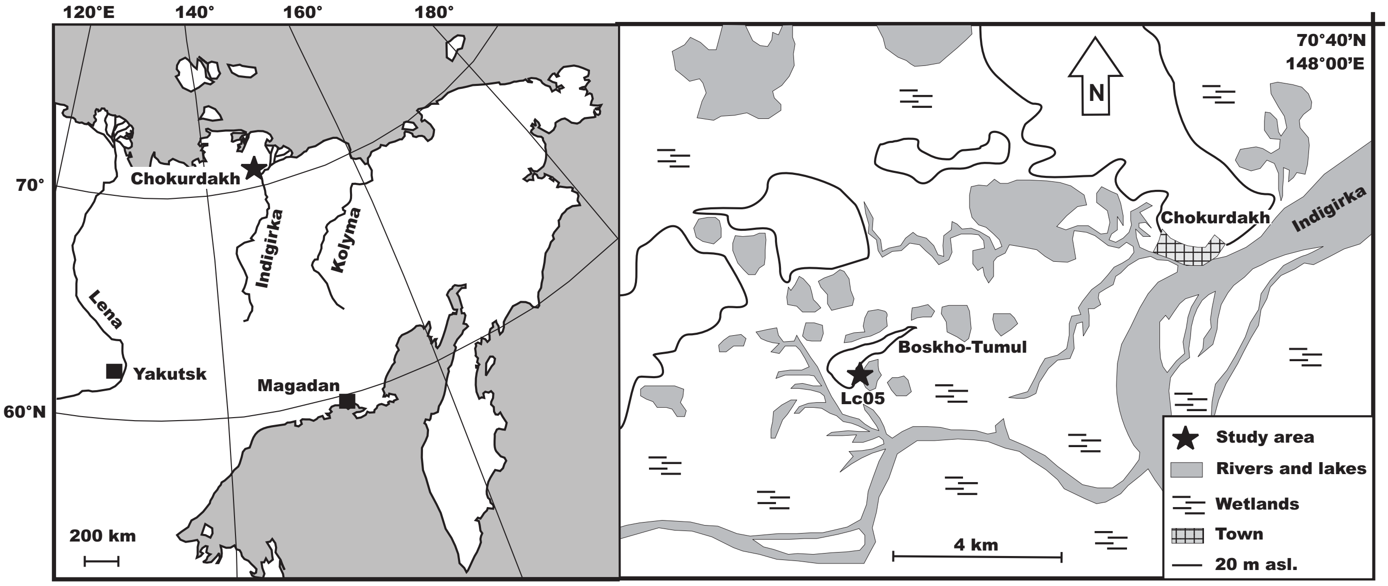

Figure 1. Location of the study area in north-eastern Yakutia, Siberia.

& Volkova (1998) (reference for *Sphagnum lenense* is USDA, NRCS 2007), liverworts after Frahm & Frey (1992), and lichens after Wirth (1995). The relevés were clustered using the software K-means2 (Legendre 2001) and the Hellinger transformation (Legendre & Gallagher 2001).

Measurements from the central spot of each transect site included ground surface height (GSH, referring to the surface of the living moss, litter, peat or bare ground), frost table height (FTH, determined with an iron rod), active layer thickness (i.e., the difference between GSH and FTH), water level, peat thickness, and depth of silt surface (recorded in excavated pits). Additionally, GSH and FTH were measured in a regular grid within an area of 26 x 135 m along transect T. All height measurements were related to a horizontal reference plane above the ground surface, established by horizontally stretched strings.

Soil temperatures were measured once at every site every 10 cm in depth down to the frost table. More detailed temperature records were taken at temperature monitoring plots with a calibrated thermistor on a 7 mm thin copper rod that allowed recurring temperature measurements every 5 cm in depth at nearly the same spot without substantial disturbance. The plots were located at a well developed polygon ridge with a dry vegetation cover of brown mosses and lichens, at a degraded ridge with a wet trench and ridge fragments covered by brown mosses and *Sphagnum* and in a polygon centre with typical wet *Carex*-lawns and irregularly spread moss-hummocks. Temperature profiles were recorded every third day during 5–19 August 2005.

At all sites, surface pH (pH-electrode HJ 98127 pHep, Hanna; with automatic temperature correction) was measured in open water or in water pressed out of wet mosses or litter. From selected soil profiles the water content was determined by weighing volumetric wet samples with a pocket balance (TCB 200-1, Kern), drying (105°C for 12 hours) and weighing again. Hydraulic conductivity (K) was measured with a piezometer (outer diameter 2.2 cm, inner diameter 1.9 cm, filter length 10 cm, perforation 20%, 10 cm falling head; Van der Schaaf 1999) at two sites of transect T and at a short transect (c) crossing a degraded ridge. As the method requires placing the filter at a minimum of 10 cm below the water table in the saturated peat (K_s), hydraulic conductivity could be measured only for some microrelief spots.

Results

Vegetation

The 141 vegetation relevés in the wetland part of transect T contain 32 vascular plant, 32 moss and 7 lichen taxa. The partitioning program K-means2 indicated to separate the relevés into two groups (Calinski-Harabazs criterion; Legendre 2001). As these groups only coarsely reflect the microrelief pattern (sites above and below the water table), a separation into five groups was chosen to reveal the finer differences in vegetation composition between the relevés (fig. 2).

The *Ptilidium ciliare-Sphagnum lenense* community covers the polygon mire margin directly adjacent to the slope with the highest ground surface and a water table below or around the frost table (fig. 2). *Ptilidium ciliare* and *Sphagnum lenense* have the highest average cover (33.50% and 40.83%, respectively) and occur in 100% of the relevés. Other species with 100% presence include *Salix pulchra, Vaccinium vitis-idaea, Ledum decumbens, Rubus chamaemorus, Carex concolor, Aulacomnium turgidum* and *Sphagnum balticum*. Of all the studied polygons, this community has a water table nearly 20 cm below surface, the lowest pH values (median 3.9), and the thinnest active layer (around 25 to 30 cm thick).

The *Carex concolor-Sphagnum balticum* community, is characterized by a high presence of *Sphagnum balticum* (100%) and *S. warnstorfii* (80%). *Carex concolor* is present in every relevé with an average cover of 12.52%, but as this species is present in 99.29% of all mire relevés it is not regarded as being characteristic of this community.

The *Dicranum angustum-Aulacomnium turgidum* community has a high average cover of *Aulacomnium turgidum* (22.57%) and *Dicranum angustum* (10.53%). Additionally, the community is characterized by a high average cover of *Sphagnum warnstorfii* and S. *subsecundum* (8.63% and 8.60%, respectively).

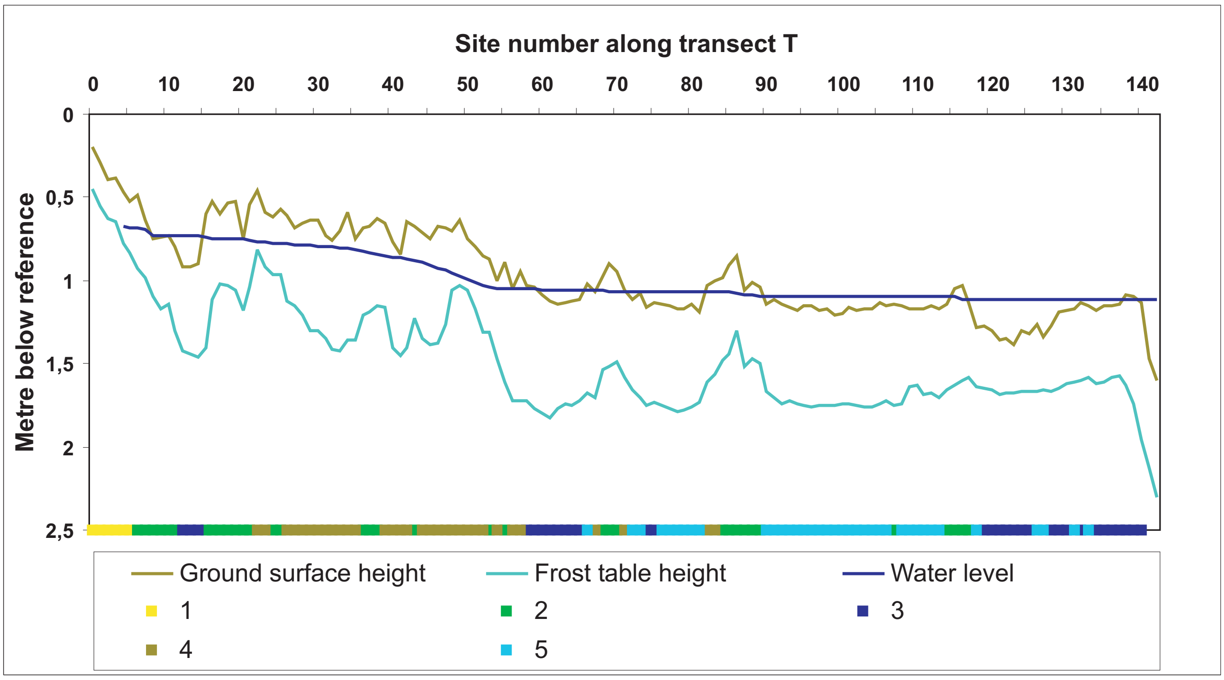

Figure 2. Vegetation types at transect T. Communities: 1) *Ptilidium ciliare-Sphagnum lenense*, 2) *Carex concolor-Sphagnum balticum*, 3) *Carex concolor*, 4) *Dicranum angustum-Aulacomnium turgidum*, 5) *Carex chordorrhiza*. Water level interpolated from average water level measurements taken in August 2005.

Sites with *Carex concolor-Sphagnum balticum* and *Dicranum angustum-Aulacomnium turgidum* vegetation are found on ridges and in hummocky centres where the water table is 4 –19 cm below the surface. The pH median is 4.4 and 4.6, respectively.

The *Carex concolor* community comprises relevés where *Carex concolor* is the dominant species (100% presence and 14.58% average cover). Also, *Carex chordorrhiza* is present in 54.84% of the sites but only covers 1.78% on average. Other species do not feature as significantly in the community.

The *Carex chordorrhiza* community is dominated by *Carex chordorrhiza* (100% presence, 13.41% average cover). *Eriophorum polystachion* and *E. scheuchzeri* are present at their highest abundance in this community.

The two latter sedge communities occur in the concave polygon centres, which are covered by open water (depth approximately 8 cm) and have the highest pH values (median of 5.6) of all the communities. The active layer of the latter four vegetation types, ranging from 40 to 65 cm, is clearly thicker than that of the *Ptilidium ciliare-Sphagnum lenense* community.

The temperature measurements show that the warmest active layer is found at areas with open water (fig. 3, sites 10-15, 60-65, 75-80, 95-115, 120-135). Here the heat is conducted to greater depths than at the ridges (site 22, 50, 69 and 85), and the frost table is deeper. Also the sparsely vegetated zone between sites 44 and 48 has a high surface temperature. On the other hand, the hummocky surface of the polygons between sites 17 and 43 yields the coldest temperature of all surveyed sites. The temperature monitoring plot of a typical dry ridge (between sites 46 and 50) carries *Dicranum angustum-Aulacomnium turgidum* vegetation with a dominance of *Cetraria laevigata*, brownmosses and some shrubs. This plot yields the largest ground surface temperature fluctuation (7.5 – 23.2°C) of all surveyed sites. The first 15 cm of the profile showed rapid cooling to below 5°C, whereas in larger depths temperature was observed to conspicuously decrease more gradually. Water level and frost table depths measure at 37 cm and 45 cm, respectively. The soil profile includes a 5 cm thick organic top layer over the silt. The volumetric water content of the dry ridge (0.38) is low compared to that of the degraded ridge and wet centre.

The degraded ridge plot (near sites 66 and 70) contains *Carex concolor-Sphagnum balticum* vegetation, with 90% moss coverage including 60% of the *Sphagnum* species. The surface temperature was noted to be a few degrees lower than at the dry ridge on the three warm and sunny days of 5, 15 and 17 August. Under cloudy and rainy conditions (other dates) the surfaces of both ridges had almost the same temperature. At the degraded ridge, the temperatures did not markedly decrease in the 15 cm thick top moss layer, which was above the water table and air-filled. In this profile the temperature decreased more gradually in the water saturated layer than in the unsaturated soil of the dry ridge. The profile includes 20 cm of living (recently grown) *Sphagnum* and around 10 cm of higher decomposed peat covering 30 cm silt above the frost table (60 cm below surface). The volumetric water content in the top layer (0-5 cm) measures at around 0.5, reaching 0.8 in the peat layer below.

The wet centre plot near site 80 is covered by a water body (depth approximately 6 cm) in which the measured water temperature did not exceed 15°C. In the open lawn of *Carex chordorrhiza, C. concolor* and *Eriophorum angustifolium* the warmest spot of each profile was the ground surface (dark brown litter or peat). Below this, temperature decreased much more gradually than at the other sites. The active layer

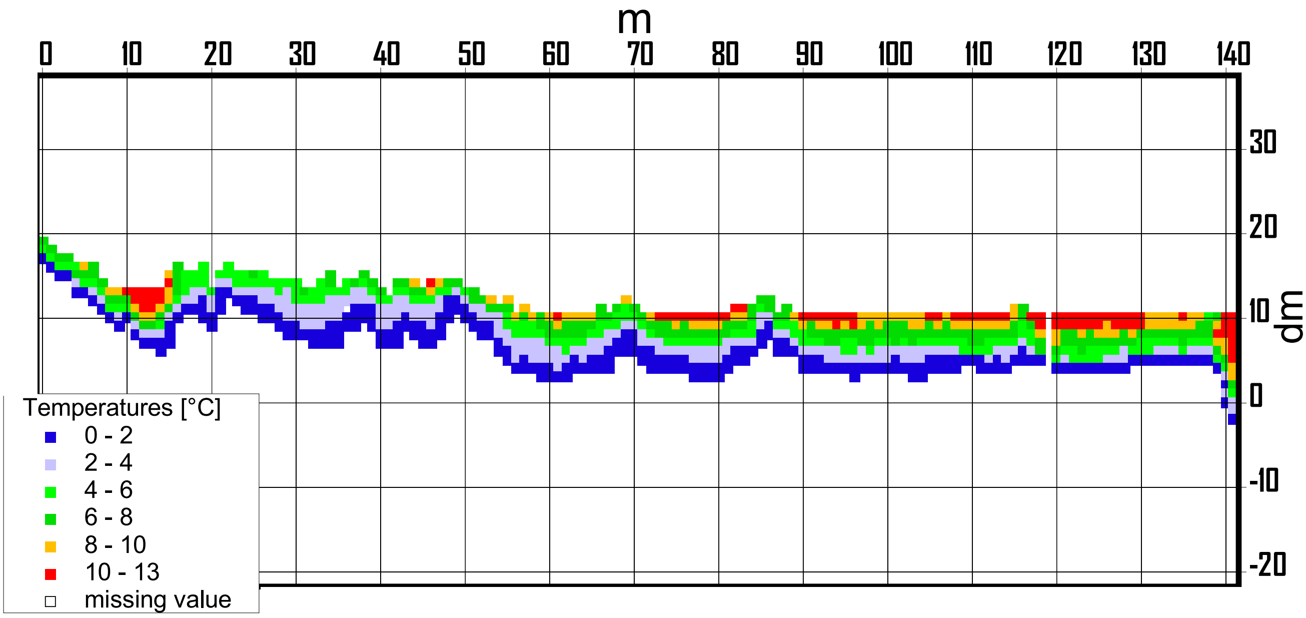

Figure 3. Temperature profile of transect T. Measurements taken at consecutive depths of 10 cm between 6 and 9 August 2005. Air temperature during measuring period was 6 – 9°C.

thickness measures 67 cm, not distinctly thicker than below the degraded ridges. The soil profile consists of 20 cm of peat over 43 cm thick silt (until the frost table). The volumetric water content in the uppermost peat layer is 0.7- 0.8.

Relief, frost table and water levels

Ground surface height and frost table are strongly correlated, with a Spearman-Rho coefficient of r^2=0.799; the active layer thickness ranges between 14 and 99 cm with a mean of 48.73 cm (N=1 573). The ground surface height (fig. 4.GSH) in the area near the slope (0 to 50 m) is characterised by an unclear polygonal pattern, small wet pools and hummocky polygon centres, whereas the area near the lake (50 to 140 m) has a regular pattern of four low-centred polygons with nearly rectangular ridges. The ridges are partly dissected and reach a depth low enough to almost match the level of the centres.

The frost table (fig. 4.FTH) shows the same pattern as the ground surface, but height differences are more explicit. Gaps in the frost table ridges are clearly visible. In the 0 – 50 m zone the frost table depressions constitute a continuous channel similar to that of a meandering brook or an erosion channel. In the zone near the lakeside, the frost table underneath the ridges is more frequently lowered and depressions appear in nearly every ridge. The polygonal pattern is less pronounced towards the lakeside.

Frozen ground above the mean water level is only found below the highest and driest ridges, and at the mire margin near the plateau slope. In general, the frost table is covered by a water-saturated layer with an average thickness of 40.41 cm.

The peat thickness averages 25.29 cm and ranges from 13 to 38 cm (N=14). The upper peat layers are highly permeable with K_s of 4.09 to 6.21 m d^{-1}; the lower peat and silt layers have lower conductivities of 0.44 to 0.06 m d^{-1} (Table 1).

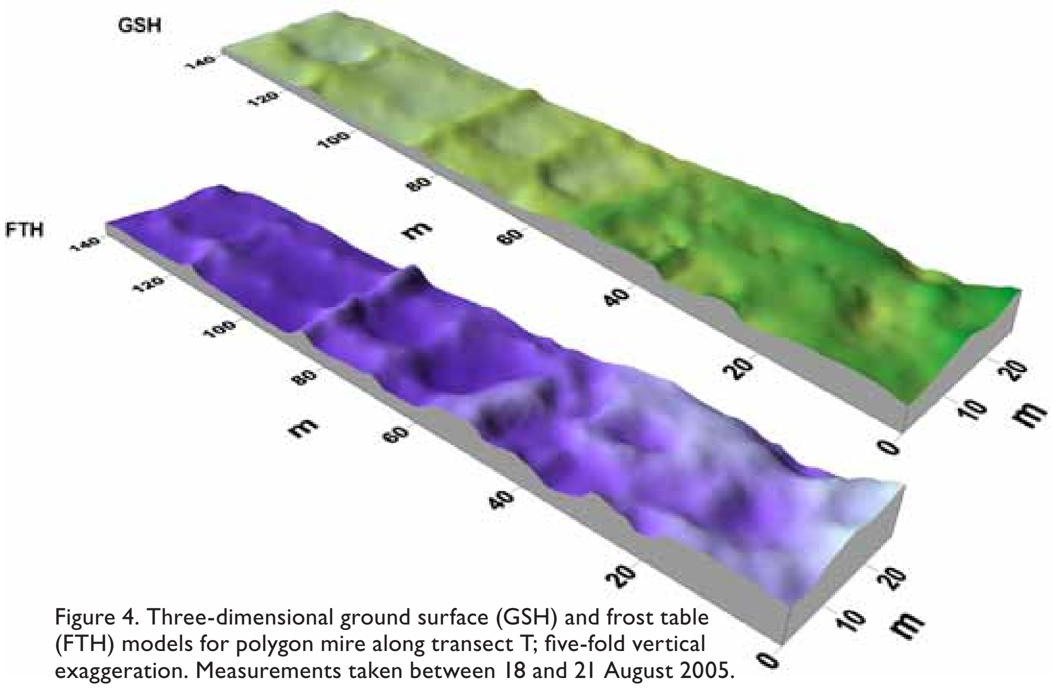

Figure 4. Three-dimensional ground surface (GSH) and frost table (FTH) models for polygon mire along transect T; five-fold vertical exaggeration. Measurements taken between 18 and 21 August 2005.

The water level decreases constantly from site 0 to 50 with a mean of 0.59 cm per metre. After site 50 the water table is nearly level. A second slight drop in the water level (4 cm) was recorded at the ridge between site 82 and 90. At the plateau slope (site 4) the water table is 44.6 cm above the lake water level (fig. 5). Water level fluctuations differ between parts of the polygon mire complex. The first 50 metres of the transect (hummocky polygons) show larger fluctuations than the following pond-like polygons (sites 50-140, fig. 5.A). The deeper the water table below the ground surface, the more pronounced the fluctuations in the water level (fig. 5.B, 5.C). A sloping water table was found between sites 35 and 50, with a fall of 24 cm over 15 m. There, a ridge of silt occurs with a thin inclined water-saturated layer over the frost table (fig. 5.A).

Discussion

Vegetation and polygon mire development

Next to peat (litter), water and ice, living vegetation is an important regulator of energy fluxes in arctic ecosystems. As insulator (especially dry moss carpets), reflector of solar radiation (light vegetation like lichens), heat conductor (especially wet moss carpets), and snow trap (e.g. stiff structures of shrubs), vegetation affects ground

Table 1. Hydraulic conductivities (K_s) in the polygon mire complex

Site	Relief type	Substrate	Depth below ground surface [m]	K_s [m d^{-1}]
T 85.5	ridge	peat	0.28	6.21
c 3.2	degraded ridge	peat	0.26	4.50 (N=3)
c 1.0	centre	peat	0.30	4.09
T 85.5	ridge	silt	0.40	0.44
T 41.3	centre	silt	0.23	0.22
c 3.2	degraded ridge	peat	0.36	0.21
c 3.2	degraded ridge	silt	0.47	0.07
c 1.0	centre	silt	0.40	0.06

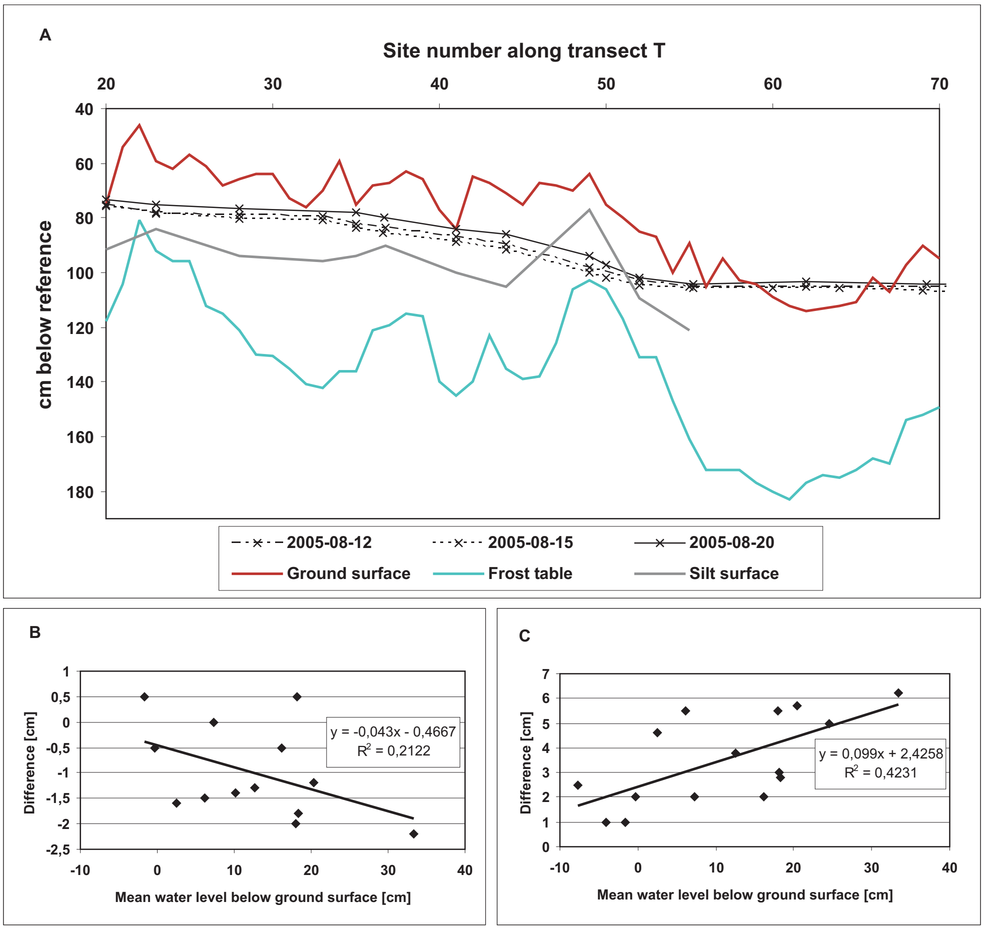

Figure 5. Three sets of water level measurements by date. A) Section of transect T with hummocky centre, ridge and wet centre. B) Water level change between 12 and 15 August 2005. C) Water level change between 15 and 20 August 2005. Mean water level averages three sets of measurements.

temperature . For an accurate interpretation of soil temperature profiles, these effects as well as substrate properties and weather have to be taken into account.

The observation that dry ridges have the largest temperature fluctuations in their upper part and experience the most rapid soil temperature decline with depth can be ascribed to the low water content of the organic surface layer and the consequent small heat conduction/convection and restricted cooling by evaporation. Largely lacking high and stiff vegetation structures, the dry ridges in the study area are susceptible to a total absence of insulating snow cover in winter (cf. Seppälä 2004). This results in strong ground cooling, frost cracking, and ice-wedge growth. Depending on the actual thermal contraction coefficient of the substrate, cracking (under frost conditions) requires a rapid temperature drop of 2°C (pure ice) to 10°C (rock) (Lachenbruch 1962). On several dry ridges of the polygon mire, 2 – 3 cm wide cracks were found. As active layer thickness strongly depends on the content of pure ice, which needs a high amount of latent heat to thaw (Woo & Xia 1996), ice-wedges and segregation ice reduce thaw speed and active layer thickness. At places were the active layer is thinner than in their near vicinity, liquid water migrates towards the frost front, thus enhancing the formation of segregation ice (Shur 1988, Shur & al. 2005). These processes constitute a positive feedback that builds up ridges (Minke 2005, Minke et al. 2007).

The degraded ridge has a water table that is ca 22 cm nearer to the surface than that of the intact dry ridge (water level 37 cm below ground surface), a totally different vegetation consisting of especially *Sphagnum* species, and a 30 cm thick peat layer. Temperatures at the top do not exceed 17°C, which is probably due to the high heat capacity and evaporation of the water in the moss layer. Constant depth temperatures for the unsaturated *Sphagnum* carpet (15 cm thick) indicate that heat is effectively conducted through the layer, probably by heat conduction in the wet mosses. Only the two warmer days (5 and 15 August) show slightly decreasing temperatures in depth in the top layer, which points to insulation of the ground. In the saturated strata of the degraded ridge, the temperature was higher than in the intact (dry) ridge at a same distance to the ground surface. Heat conduction through liquid water should be considered as the main reason for this phenomenon (cf. Boike 1997, Miller & al. 1998).

In the wet polygon centre the soil is completely water-saturated and due to heat conduction, the temperature gradients between surface and frost table are nearly linear. Temperature fluctuations in the upper part of the profile are lower than at the other sites due to the high heat capacity of the saturated substrate. The highest temperatures are reached in the dark brown litter at the bottom of the shallow ponds, where solar radiation running through the water is absorbed. The temperature of the water body itself remains low, because of its high heat capacity and the chilling effect of evaporation.

Polygon mire hydrology and hydrological windows

Large water level fluctuations were recorded at sites with a water level deep below the surface (fig. 5.B/C), indicating a lower specific yield at greater depth. Low permeable peat (probably highly decomposed and with a low proportion of large pores) was found at the bottom of these sites, whereas the highest permeability was measured in the top peat layer (Table 1). Such a steep decrease in hydraulic conductivity with depth brings to mind the acrotelm concept of hydrological self regulation (in terms of discharge control) of a mire (Joosten 1993, Couwenberg & Joosten 1999). During summer, lateral inflow to a tundra wetland is small and precipitation low, and even possibly exceeded by evaporation (Woo & Young 2006). Under such conditions the continuing existence of a wetland benefits from additional water input, resulting from snowmelt in spring, from a greater catchment (Rovansek & al. 1996, Woo & Young 2006) or from an inundation supply from rives and lakes. The vertical gradient in conductivity holds back this water since it reduces lateral runoff from the mire. The high permeability of the surface peat layers explains the level water tables over wide areas of the mire complex, especially in the polygons next to the lakeside (fig. 2). Water level steps between single polygons seem to be caused by the low hydraulic conductivity of the bottom peat and silt (Table 1, fig 5.A) that may project over the water level as a result of ice wedge or segregation ice formation. We found that in low-centred ice-wedge polygons a high correlation exists between ground surface and frost table (i.e., both surfaces being nearly parallel) but in the frost table stronger relief differences develop during the thawing season (Minke 2005). Some parts of the ridges develop an unusually thick active layer - a phenomenon also found by Minke et al. (2009). In these parts the summer frost table may be below the water table, thus facilitating subsurface water flow through the active layer. The main flow generating event in arctic wetlands is snowmelt in spring (Woo & Young 2006). In the tundra the distribution and thickness of the snowcover is strongly affected by wind redistribution. At exposed sites the snow is blown away and deposited at snow traps, such as protruding vegetation or lee sites. When the snow melts, discharge primarily takes place as surface flow because the underlying soil is still frozen (Roulet & Woo 1986).

Later, running meltwater also penetrates the active layer (Lewkowicz & French 1982, Woo & Guan 2006). The subsurface runoff is controlled by the hydraulic properties of the substratum,especially taking place in the uppermost slightly decomposed, porous organic matter (Quinton & Marsh 1998). Running water is a very powerful agent for ground frost thawing in permafrost areas: water has a high heat capacity (Woo & Xia 1996) and flowing water in the active layer enhances thawing of the frozen soil along its flow paths (Woo & Winter 1993). A rapid increase in soil temperatures after snow melt was observed by Boike (1997). In extreme circumstances, this process causes piping (i.e. formation of erosion channels within the permafrost) or gully erosion (Seppälä 1997).

When the polygon mire is flooded by meltwater in spring (Woo & Young 2006), the polygon depressions are filled with water and the lowest parts of the enclosing ridges act as thresholds for and preferential points of, further discharge. This flowing water stimulates ground thawing in spring and summer, leading to a locally thicker active layer than in the adjacent ridge parts. Such thermal erosion channels in ridges, which we term "hydrological windows", are shown in the frost table model (fig. 4).

The positive feedback of ridge uplifting causes a higher water storage capacity in the polygon centre (Minke 2005) because water is dammed by the rising frost table (Woo 1990). The larger amount of meltwater in the depression can store more latent heat received from solar radiation and as a result it enhances the thawing of the frozen ground. If the water table is below the lowest spot in the ridge frost table relief, the thaw front migrates sideward and in depth. If the water level is above the lowest part of the ridge frost table and higher than the water level of the adjacent polygon, thawing is most effective at this threshold due to continued heat input by running water. This lowers the threshold until the water level equals the level of the adjacent polygon or latent heat in the water is insufficient for further thawing (due to autumn cooling). By lowering the threshold, the water level of the polygon is lowered so that the amount of latent heat stored in the polygon depression is reduced. This slows down ground thawing and protects the remaining frost table ridges.

The model in Figure 6 summarizes the water pathways in the polygon mire landscape of thaw lake basins, which we presume to be typical for the East Siberian artic lowlands. The mire receives its water from precipitation (1), meltwater runoff from local snow melt and a catchment area (2), flooding from lakes and rivers (3) and thawing of ground ice (4), the latter being a system internal source. Pathways in the mire are overland flow (5) especially during snow melt and after storms and subsurface flow (6), which constitutes only a small part of total wetland flow, but important all the same for microrelief patterning. Flow through the frozen ground (7) is negligible. Water sinks of a polygon mire consist of internal sinks or freezing water transforming into segregation and ice-wedge ice (8), evapotranspiration (9), and outflow (10).

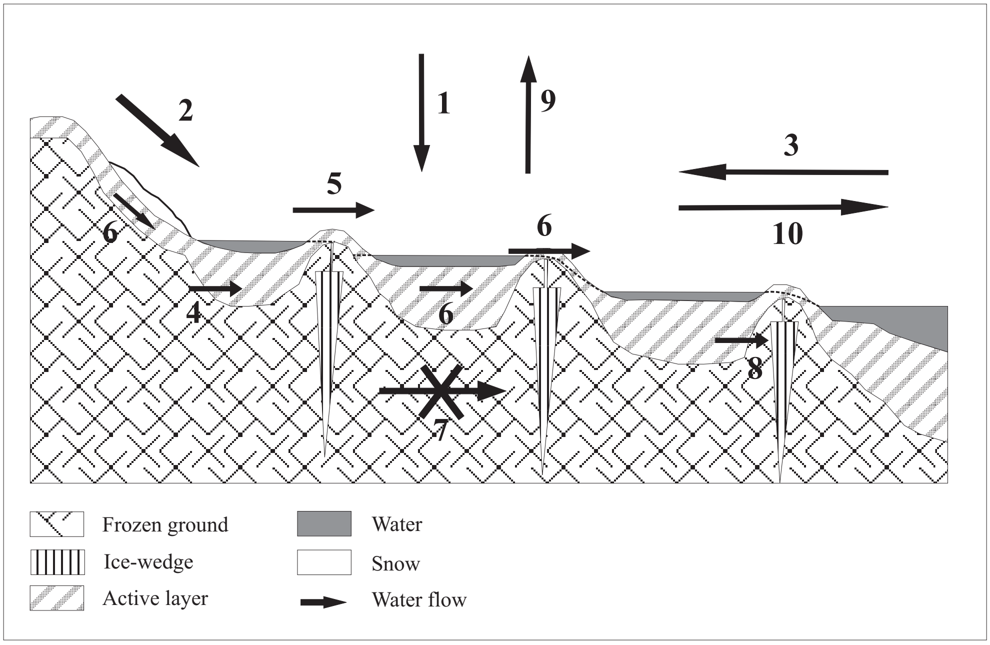

Figure 6. Water pathways in a polygon mire. Sources: 1) precipitation (rain and snow), 2) meltwater runoff from local snow melt and upland tundra, 3) flooding from adjacent lakes or rivers, 4) thawing of ground ice (internal source). Pathways: 5) overland flow, 6) subsurface flow, 7) no relevant flow through frozen ground. Sinks: 8) freezing water transforming into segregation and ice-wedge ice (internal sinks), 9) evapotranspiration, 10) outflow.

Conclusion

The vegetation distribution in the investigated polygon mire is mainly controlled by the relief and related parameters such as water level and pH. Vegetation and soil moisture strongly influence the thermal properties of the active layer, thus controlling the development of the frost table, which in turn determines the height of the microrelief. These feedback relations suggest that pattern formation in polygon mires is not merely a passive reaction to cryophysical processes, but also a result of self-organisation from the interaction of vegetation, ice and water (cf. Couwenberg & Joosten 2005).

The observed degraded ridges in the Lower Indigirka region are probably caused by thermal erosion through meltwater flow in spring and early summer. Surface and subsurface flow enhance thawing of the active layer and create deeply thawed ridge parts – hydrological windows – that facilitate water exchange between polygons during snowmelt and after intensive rainfalls. By carrying off the relatively warm water, the windows protect the remaining ridges and stabilize the polygon pattern.

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Mires on the map of Russia

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Introduction

In 1980 in Laboratory of Vegetation Geography and Cartography of Komarov Botanical institute the series of 10 analytic geobotanical maps of European part of the USSR were created (Грибова et al.1980). In this series I published map of mires in scale 1: 7 500 000 as a supplement to text (Юрковская 1980).

At present, under my supervision, research assistants of the Laboratory are working on new series of analytic vegetation maps (scale 1: 10 000 000) for the whole territory of Russia. The map of mires of Russia considered in this paper is the first in this series.

A map is a necessary mediator between man, extremely limited in his scope of observation, and a huge object of investigation, in our case the mires of Russia. At all levels the cartographical method of investigation is directed to the elaboration of the most actual theoretical and methodological problems with the goal of deciding the important practical tasks. At present, among these goals are the study and conservation of environment, the sustainable use of natural resources, the study of biodiversity and ecological relations and ecological prognosis.

The role of map as an instrument of knowledge undergoes permanent evolution. While addressing to a map investigator deals with not only noncoordinated or systematized factual data but with the system of notions arised in the process of mapping and fixed in the map itself and in its legend. Various scientific lines base upon cartographic analysis finding in it , first, a means for receiving the mass qualitative information; second, a method of scientific cognition and, third, the way of presenting the results, conclusion and practical recommendations. Map is an effective way of compacting information and a source of the quite new information arising as a result of combination of cartographic symbols and images in the space of map (Берлянт 1986, Ozenda 1986, Ozenda& Borel 2000).

In this case the possibility of the systems approach appears (hierarchization, classification, logical grouping etc) together with studying the objects and phenomena which couldn’t be observed directly as a whole, at the expense of such qualities of map, as the survey and synthetic character. The last one includes the macrostructure of vegetation cover at the planetary and subplanetary levels, for instance, the latitudinal and altitudinal zonation and longitudinal division into sectors.

Materials and methods

As a rule, the analytic maps are compiled on the basis of universal geobotanical maps with the aim of an element analysis (Емельянова&Огуреева 2006). In the general mosaic of universal map it is difficult to trace in space "the behaviour" of separate large subdivisions of vegetation cover and to recognize the geographical regularities, characteristic of precisely this category of vegetation. Besides, at the creation of analytic maps, a chance arises to shift, to some extent, the accents preassigned by the general map legend to show the objects in more detail than at the universal map or, in contrast, to give the generalization or even some schematization as it may be required by tasks and purposes of map.

The main source for the compiling of mire map was Vegetation map of the USSR for higher schools scale 1:4 000 000 (Карта…, 1990). The legend of section «Mires» in this map was constructed by me (Юрковская, 1989). Vegetation map of the European part of the USSR (Isachenko & Lavrenko 1979) was also used for the maximization of map capacity as a well as regional maps and atlases for the territory of Siberia. To analyse the map I applied some theoretical approaches used by us at the creation of vegetation map in National atlas of Russia (Юрковская, 2000; Юрковская et al 2005).

Legend of map

The key to a map, its logical basis is the legend. The legend is constructed on the basis of classification elaborated by me for the aims of small-scale mapping (Yurkovskaya, 1992). Undoubtedly the legend doesn't copy the classification but interprets it depending on tasks and scale of map. At the foundation of the legend the botanical characteristics, morphology of mires and the pattern of surface are laid. The legend of this map numbers 32 mapping units (Table 1).

The legend and map have two levels. The first one presents the large sub-titles which correspond to classes or botanical-geographic groups of the mire massif types; on the map they are showed by color, and in the legend by numbers. The information of the first level is read at once. It gives the possibility to see the essential regularities of macrostructure, that is main geographic features in the distribution of mires – the latitudinal and regional characteristics.

The second plan corresponds to the types of mire massifs. On the map and in the legend they are designated by letter indices: a, b, c, etc. (Table 1). The second plan includes more detailed information and is destined for the deepened analysis of the distribution of mires within the definite regions, latitudinal strips, or longitudinal sectors.

In the legend (Table 1), the botanical (floristic) characteristics of types (mapping units) are given since this map was created in a series of geobotanical maps. But the text of the legend may be completed by other characteristics of the type of mire massif and also by their geographic names (Fig.1). I, however, agree with those cartographers who believe that the legends must be short. The detailed characteristics of mapping units must be given in explanatory text to a map. But in some cases it has to give formulations including indication of morphological, structural and other features.

Table 1

Legend	
1 UNPATTERNED FENS	
a	sedge-cottongrass with *Carex stans, Eriophorum medium, Dupontia fisheri*
b	small- and tall-sedge with *Carex nigra, C. lasiocarpa, C. rostrata, Equisetum fluviatile, Menyanthes trifoliata*
c	ridge-flark, eutrophic
d	sedge braunmoss and sedge-peatmoss
e	grass-sedge with *Carex omskiana, Agrostis stolonifera*
f	reed-sedge in combination with “ryam”
g	reed-calamagrostis-sedge in combination with wet meadows
i	sedge and calamagrostis with *Carex minuta, Calamagrostis angustifolia, C. langsdorfii*
2 POLYGONAL MIRES	
3 PALSA MIRES	
a	with *Betula nana* treeless
b	with *Betula nana*,locally with *Pinus sibirica*
c	with *Betula exilis*, locally with *Larix gmelini*
d	with *Larix gmelini, Sphagnum orientale*
4 RIBBED FENS	
5 REGRESSIVE RAISED BOGS	
a	with *Calluna vulgaris, Empetrum nigrum, Trichophorum cespitosum, Carex rariflora, Sphagnum lindbergii*
b	with *Calluna vulgaris, Trichophorum cespitosum, Rhynchospora alba, Sphagnum magellanicum, S. rubellum*
c	with *Sphagnum fuscum, S. lenense*
d	with *Empetrum nigrum* s.l., *Carex middendorfii* (blanquet bog)
e	with *Empetrum subholarticum, Chamaedaphne calyculata, Vaccinium vitis-idaea* in combination with lake
6 TYPICAL RAISED BOGS	
a	with *Calluna vulgaris, Chamaedaphne calyculata, Sphagnum cuspidatum, Sphagnum fuscum, Sphagnum magellanicum*
b	with *Chamaedaphne calyculata, Sphagnum majus, S. fuscum*
c	locally with *Pinus sibirica* in combination with pine-dwarfshrub-peatmoss bogs
d	with *Pinus sylvestris*, locally with Pinus sibirica in combination with ridge-flark- meso-eutrophic fens
e	with *Pinus sylvestris, Ledum palustre, Sphagnum magellanicum*
f	with unpatterned dwarfshrub – peatmoss, locally with *Larix sibirica* or *L. gmelini*
7 TRANSITIONAL PEATMOSS MIRES	
a	with *Carex lasiocarpa,C. rostrata, Scheuchzeria palustris, S. fallax*, treeless
b	with *Betula pubescens, Pinus sylvestris*
c	pool-swamp with *Myrica tomentosa*
d	with *Larix cajanderi*
e	with *Sphagnum obtusum, S. orientale*
8 WOODED SWAMPS	
a	with *Betula pubescens*
b	with *Picea abies* x *P.obovata, P.obovata, Betula pubescens, Pinus sylvestris*
c	with *Alnus glutinosa, Betula pubescens, Picea abies, P. abies* x *P.obovata*
d	with *Alnus glutinosa, Fraxinus excelsior*
e	with *Betula pubescens, Picea obovata, Pinus sylvtestris, P. sibirica*

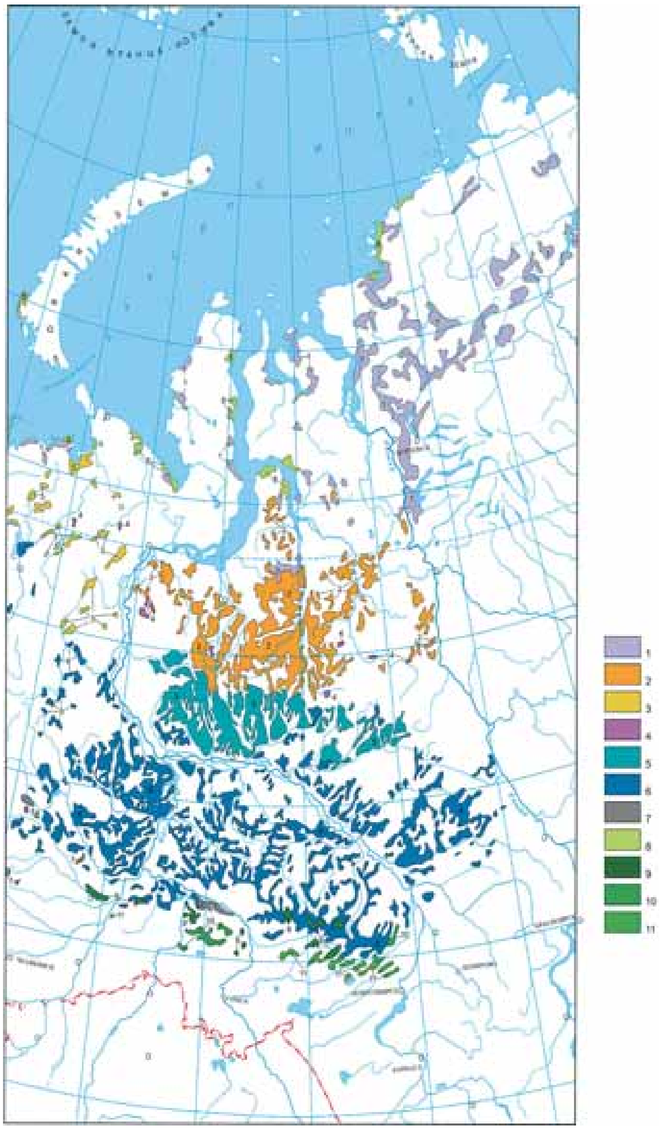

Figure 1. Mires in theWest-Siberia and adjacent territories. A fragment of map.

1. polygonal mires (2); palsa mires :
2 - locally with *Pinus sibirica* (3b),
3 - treeless (3a) ;
4 - ribbed fens, herb-brownmoss-peatmoss with strings and flarks (4),
5 - regressive raised bogs liverwort-lichen-peatmoss with ridge-pool-black hollows with *Empetrum subholarticum*, *Chamaedaphne calyculata, Vaccinium vitis-idaea* in combination with lake (5e),
6 - raised bogs with ridge-pool and ridge hollow complexes with *Pinus sylvestris*, locally with *Pinus sibirica* (6c, locally 6d),
7 - wooded swamps with *Betula pubescens, Picea obovata, Pinus sylvestris, P. sibirica* (8 e); unpatterned fens:
8 - grass-moss poor fens arctic (1a),
9 - ridge-flark, eutrophic
10 - grass-sedge with *Carex omskiana, Agrostis stolonifera*
11 - reed-sedge in combination with "ryam" (pine bog).
The numbers according to the general legend of map (See Table 1) are given in brackets

Results and discussion

According to latest data (Vompersky et al. 2005), mires as a whole occupy only ca. 8% of area in Russia. Considering that mires are spread unevenly and centered mostly on the North of country, their share in to landscape structure and in plant cover in the Arctic, temperate-continental and suboceanic regions of the Boreal area considerably increases ranging from 20 to 80 %. This uneven distribution of mires is markedly pronounced on the map. Relation between the distribution of mires and physiographic environments reveals itself distinctly at the comparison of mire map with the other maps of the same scale (hypsometric, climatic, etc.).

The distribution of mires is connected with bioclimatic zones and subzones, but their latitudinal boundaries do not coincide, only “cores” , i.e. areas with the optimal distribution of type coincide. For instance, the northern taiga is optimal for the development of ribbed fens, but they occur often in forest-tundra and in middle taiga. The optimum of the geographical distribution of raised bogs is in taiga but in suboceanic regions they are found also in the hemiboreal area. The latitudinal differentiation is responsible for the distribution of the highest subdivisions of mire vegetation. From north to south main mire types follow each other sequentially: polygonal, palsa, ribbed fens and raised bogs.

The latitudinal regularities in the distribution of mires in Russia are sufficiently well studied. Therefore, when analyzing the map, special attention has been paid to the zonality within longitudinal phytogeographical sectors. The idea of the analysis of latitudinal structure of mire vegetation within longitudinal sectors arised owing to the vegetation map in the National atlas. It has been revealed that sectors have a specific latitudinal differentiation of mires. The following sectors have been delimited: West-Russian (1), East-European (2), Ural (3), West-Siberian (4), East-Siberian (5) and Pacific (6) (Fig. 2). The borders between sectors are distinguished according to zonal vegetation. In three sectors in west part of Russia (1, 2 and 4) a pronounced zonality is established in contrast with the sectors in the east part of Russia (5 and 6).

Figure 2. Schematic map of longitudinal sectors
1 West-Russian, 2 East-European, 3 Ural, 4 West-Siberian, 5 East- Siberian, 6 Pacific

Within the West-Russian sector (its eastern boundary goes along 40° E) there is pronounced zonality from north to south – from palsa mires (in tundra and forest-tundra) to tallgrass fens (in steppe). The peculiar feature of the latitudinal sequence in this sector is the absence of a stripe of polygonal mires. This incompleteness of spectrum of subzonal mire types correlates entirely with the subzonal division of zonal vegetation. In this sector there are no arctic and north tundra subzones. Another characteristic feature is the prevalence of ribbed fens (aapa mires) above raised bogs in the northern and middle taiga that in its turn correlates with prevailing of quasinatural pine forests above zonal spruce forests in this territory. Let us pay attention to the ecotone character of mire vegetation in the sector, occupying the intermediate position between the East-European (continental) and Central-European (subcontinental) ones. This manifests itself sharply in the floristic and syntaxonomic composition of mire vegetation cover, especially in the west and south-west parts of the sector and is determined by the influence of Atlantic and northern seas (suboceanity).

In the East-European and West-Siberian sectors the pronounced zonality and full spectra are recognized. From the north to south polygonal, palsa, ribbed fens, raised bogs and unpatterned fens follow each other consecutively. Vegetation and flora of both sectors are rather similar, only some European species disappear and some Siberian appear. But these insignificant changes are essential for the differentiation of regional types of mires. The similarity of these two sectors is accounted for by the distribution of regressive dystrophic raised bogs of liverwort- lichen- sphagnum group in the continental (mainland) parts of taiga whereas in the West-Russian and Pacific sectors they are restricted only to suboceanic territories along the sea shores.

The main peculiarity and difference in the latitudinal differentiation of mires within these sectors is asymmetry in the zonal position of regional mire types belonging to one class, in other words their different connection with the zonal types. Polygonal mires of the East-European sector are restricted to the Northern tundra whereas in West-Siberia they occur as far as the northern forest-tundra. In the East-European sector palsa mires are spread in the south tundra and forest-tundra. In West-Siberia they are distributed from the south forest-tundra to the limit of Middle taiga. In Siberia geographical boundaries of raised bogs are shifted to the south. The latitudinal diapason of aapa mires is larger in Siberia. Unfortunately they are insufficiently studied in Siberia and, chiefly, are described by different authors under various names. Their geographical ranges are established now mainly on the basis of aerial and space images. Besides, there are differences in the composition of wooded swamps. In the East-European sector alder swamps occur in the hemiboreal subzone and southward whereas in West-Siberia they lack completely being replaced by spruce-birch, birch-pine and birch swamps (with *Betula pubescens, Picea obovata* and *Pinus sibirica* (see Лапшина, 2003). This coincides completely with the absence of broadleaved forest zone and with the peculiar features of subtaiga (hemiboreal subzone) and forest-steppe in West Siberia, where forests are formed by small-leaved trees (birch and aspen).

Ural is mountain sector which divides the East-European and West-Siberian sectors. The distribution of mires is subordinated here, first of all, by altitudinal zonality.

In three sectors in West part of Russia (1, 2, 4, Fig.2) the pronounced zonality is established to the contrast with the sectors in the eastern part of Russia (Sectors 5,6). Latidudinal zonality is traced with difficulty in these two sectors because of prevailing mountains in relief and wide distribution of permafrost spreading sporadically up to Mongolia in the East-Siberian sector, and the influence of monsoons in the Pacific.

The most characteristic of the Central and Eastern Siberia is the absence of raised bogs. The essential peculiarity of the Pacific sector is the presence of blanket bogs (Kamchatka) and grass-sedge fens with *Calamagrostis angustifolia, C. langsdorfii* and *Carex minuta* (lower Amur river basin).

The map gives an idea of dimensions and configuration of mires. For instance the phenomenon of mires in West Siberia is clearly represented (Fig.1). They have no analogues in Eurasia, and even the largest mire "Ocean" located in the East-European sector, appears to be infinitesimally small.

It has to be emphasized that in all sectors the overlapping of the ranges of several mire types was noted within the limits of one latitudinal stripe, i.e. each latitudinal stripe is characterized by no one mire type but several. This fact we also interpret as an evidence of correlation between the distribution of mires and zonal vegetation. In each zone or subzone there is attendant vegetation along with zonal one. Some researchers call it 'azonal", some time it predominates.

The relationship between dark coniferous (spruce, fir, Siberian pine) forests, so called zonal forests, and light coniferous (pine, larch) forests in taiga zone may serve as a classic example. In the steppe zone it will be vegetation of steppe etc. Striving to emphasize this phenomenon A.V.Korolyuk (Королюк 1999) proposed the concept of background vegetation. As to mire vegetation this phenomenon is universal. In one latitudinal stripe the polygonal and grass-moss fens spread, in the next stripe palsa mires, unpatterned and ribbed fens, then raised bogs, unpatterned and ribbed fens, transitional mires etc. Therefore it is nessesery to revise the traditional names of so called mire zones. This situation should be taken into account specially at the laying of study areas for the analysis of diverse processes (accumulation of carbon, rate of paludification, etc.) and for calculation of economic activity.

The mire map of Russia has been used in an effort to study biodiversity. Cartographical method was used for the study of biodiversity at species and coenotical levels long before the problem of biodiversity conservation was perceived and formulated in global aspect as the basis of human environment. The map is not only the accumulation of data, but a vigorous source of information. It should be noted that modern computer technologies provide a way for completely new analysis of maps.

The vegetation map manifest itself in this case not only as an independent subject for studying the biogeographic structure of biodiversity but also as the basis for the organization of biodiversity material allowing its analysis at the different levels (from species composition of separate plant communities to large phytochorological categories) in a unified basement.

Conclusion

A new analytic map of mires in Russia S 1: 10 000 000 is compiled. The cartographic method still contains great unrealized potentialities for investigation. The value of cartographical method lies in the fact that map is not considered as an illustration and final product but as an instrument of investigation. The map markedly shows latitudinal and regional regularities in the distribution of mires, which is connected with bioclimatic zones and subzones. Analysis of the zonal structure of mires has been conducted within the longitudinal phytogeographical sectors. The sectors have specific latitudinal differentiation of mires.

The connection between mire vegetation and zonal vegetation types is not less essential in direction from the west to the east than from the north to the south but it reveals itself on the different levels of organization of plant cover. I am sure that the strategy of mire conservation has to be based on the map, which permits to coordinate the regional initiatives.

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Development of large-scale aapa mire hydrotopography on land-uplift coastland in northern Finland

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Introduction

Aapa mires form the dominant type of mire massifs on the flat lowland area near the northern end of the Bay of Bothnia. On this coastland, the land-uplift (Kakkuri 1985) has been rapid enough for continuous sea level regression (Taipale & Saarnisto 1991) since the last ice age. This process has resulted in belts along the coastland increasing in age with distance to the coast, rendering estimates of the above-sea time period simply by altitude. In this area, the proportion of primary mires formed directly from seashore vegetation has been assessed to be little more than half the total area of developing mires (Huikari 1956). The paludification of heath forests accounts for nearly all the rest of primary mire formation, because terrestrialisation of shallow lakes has not been extensive (Backman 1919). Earlier studies of the development of mire complexes on the land-uplift coastland have concentrated mainly on the more southern districts (Aario 1932, Brandt 1948), where such mires tend to develop into ombrotrophic bogs. Studies from the Hudson Bay land-uplift coastland in Canada also describe a development into mire systems dominated by bogs (Klinger & Short 1996).

Aapa mires have been identified as a mire complex type with concave morphology and string–flark patterning (Cajander 1913), or more broadly, a mire complex with a mire expanse indicating minerotrophic vegetation in its centre (Ruuhijärvi 1960). The most recent treatise on aapa mire morphology and typology (Laitinen & al. 2007) deals with the relations of morphology and water flow. The main division into a wet centre and lawn-hummock level-dominated periphery (clearly visible in aerial photographs, Laitinen & al. 2005) is interpreted to be dependent on the water flow pattern: the lawn to hummock level dominated peripheral part forms a donor segment from where the water flows to the wet receiver segment in the central part. The receiver segments can be identified as large, coherent areas with a large proportioned mud bottom or sedge-dominated flark level. Receiver segments are normally situated away from the water divides although in some occasions water flow may be bifurcated. On the contrary, donor segments are those parts of the massif, which are outside the receiver segment. They are normally Sphagnum-dominated open or treed mires near the water divides.

The transect line studied in this work follows a chain of basins in the land-uplift area of the aapa mire zone (Ruuhijärvi 1960). The main objective of the study was to determine how the typical large-scale morphology of aapa mires with donor and receiver segments is discerned at different stages of development. We assume that successive basins form a chronosequence. Of course, it is impossible to find two basins identical in all other respects than age and development stage. However, in comparing a sufficient number of sites, it is possible to gain information otherwise difficult to obtain. The main questions guiding the study are: 1) Is it possible to distinguish donor and receiver segments in a chronosequence using aerial photographs, and if possible, what vegetation types could serve to distinguish these segments? 2) How do the position and proportions of donor and receiver segments change over time?

Material and methods

The main transect line (Fig.1) is situated near the Bay of Bothnia, in the Middle Boreal zone (see Solantie 2006, Tikkanen 2006). The bedrock, soil and topography are homogenous from the seashore to the inland sites. The lowermost areas are on the littoral belt (< 1.5 m a.s.l., Elveland 1976, Siira 1999), and the uppermost areas are old enough (over 4 000 years in the primary mire formation parts) to be considered to have reached their climax state according to chronosequence studies of ombrotrophic bogs (Aario 1932, Brandt 1948, Klinger & Short 1996). The bedrock is mainly acidic granitoid gneiss (Geologic Survey of Finland 1997) overlain by a layer of bottom moraine. The research sites along the transect are paludified basins (see Fig.1) unaffected by ditching. Each of them consists of one or two catchment areas with mire vegetation dominating on the centre and heath forest dominating on the margins. The lines under study were positioned across the basins so that a representative picture of the paludified area with its hydrologically different parts could be obtained. The age of primary mire formation (Table 1) in the basins was determined using published diagrams for the region (Taipale & Saarnisto 1991), transformed into calibrated years (Weninger et al. 2005), that enabled calculation from the elevation of the bottom of the mire (m, above the sea level).

Vegetation sample (releve) plots (10 x 10 m) were studied along the lines at 100 m intervals. If the line crossed a mineral soil island, plots were placed on both sides of the island. At some sites, on each line the area of the plot was extended by adding 10 x 10 m area to the original to make the data set also applicable in a study of microtopographical patterning (Rehell & al. 2010). Eventually, only every second plot was studied in a part of Area 4 (Fig.1) with a very wet flark fen and minor variation between plots. Study quadrats (1 x 1 m) were placed in each plot so that each observed vegetation type on the plot was represented by at least one quadrat. Altogether 90 large plots with 300 quadrats were studied along the lines. The vegetation types (see Rehell et al., in press) correspond to mire surface levels (Eurola et al. 1984) and can easily be recognized on aerial photographs. The relative coverage of these vegetation types in the whole plot was also assessed, and plant species coverage (%) in the quadrats was estimated. The quadrats were first divided into groups using Twinspan and then ordinated, using Non-metric Multidimensional Scaling (NMS), a method that has been found to be most suitable for unconstrained ordination of ecological data possessing arbitrary scale or lacking statistical normality (Clarke 1993, Minchin 1987). Additionally, peat thickness and water level were measured in each quadrat, and the altitude of the plots was approximated from field maps. The fieldwork was carried out during July–September of 2001 and 2002. Vegetation studies were conducted on the mire and paludified heath sample plots. Seashore meadows and thickets on the littoral zone were studied as well. Ordinary heath vegetation and permanent water bodies were not studied.

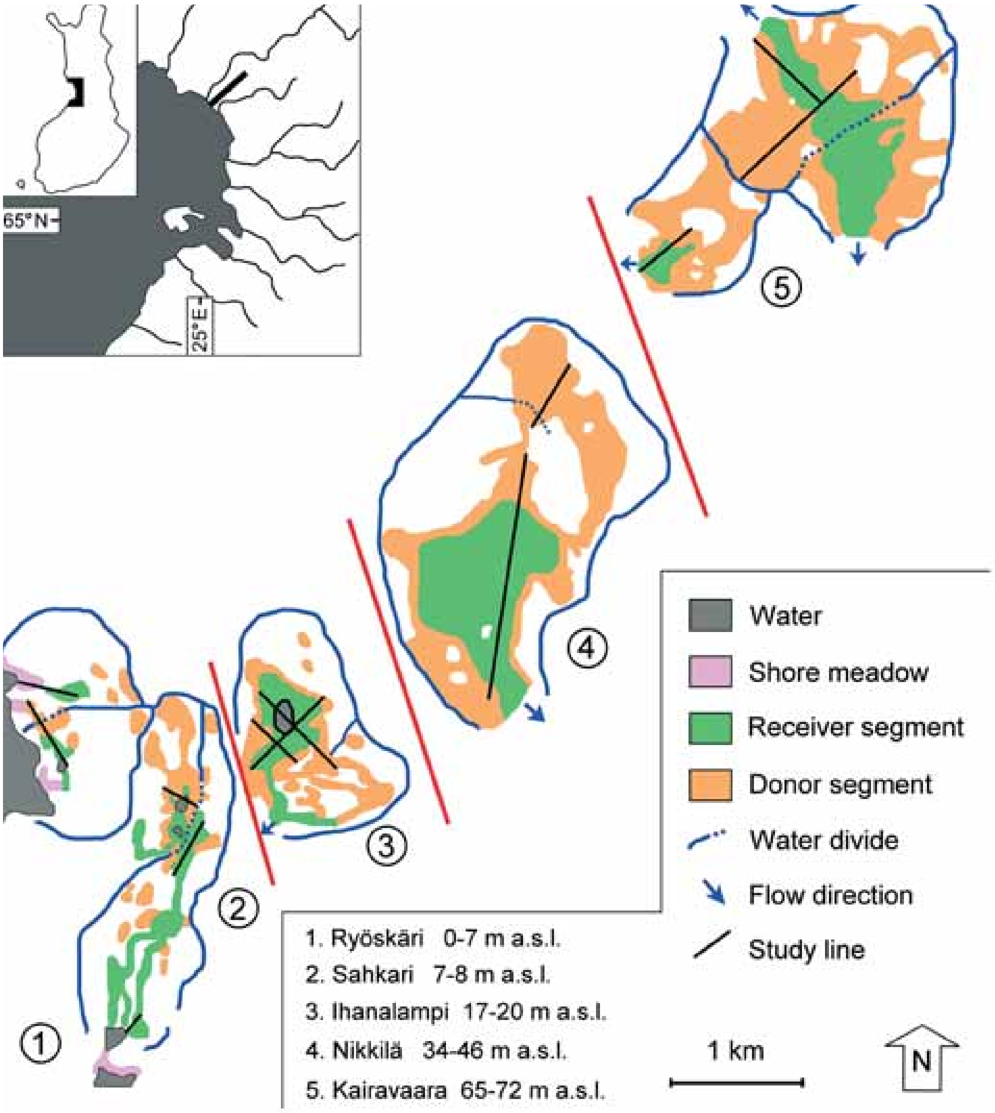

Figure 1. Transect chain of mire basins studied and their division into donor and receiver segments.

Table 1. Study areas along the transect chain. Elevations refer to the main sites of primary mire formation. Ages are expressed as calibrated years Before Present (AD 1950, Weninger & al. 2005)

Site name	Elevation of mire nuclei m a.s.l	Age of primary mire nuclei cal yr	Total length of lines m
1. Ryöskäri	0 - 6	0 - 700	980
2. Sahkari	6 - 7	700 - 800	710
3. Ihanalampi	18 - 19	1900 - 2000	2050
4. Nikkilänaapa	34 - 37	3900 - 4200	2500
5. Kairavaara	67 - 69	6000 - 6200	2250

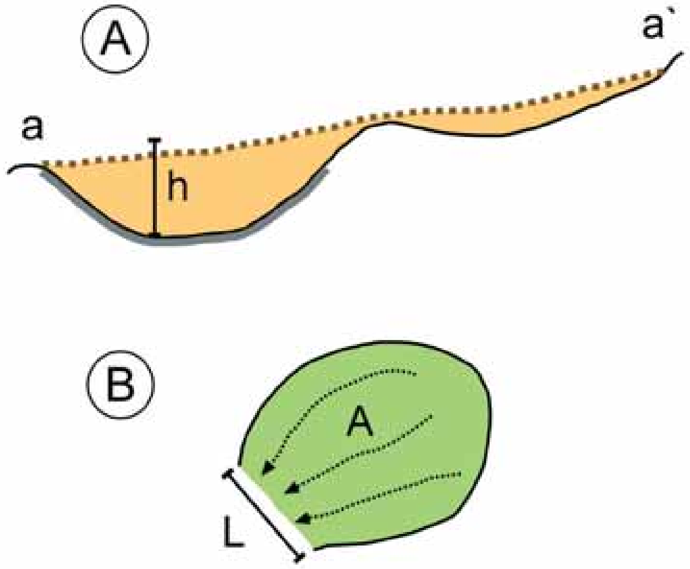

Figure 2. A. Determination of the "lower part" of the basin a a`, the altitude of the bottom less than h. B. Determination of the index A/L. A = the catchment area, L = the width of water pathway.

The catchment areas were approximated to be bordered by surface water divides (Fig. 1). The positions of water divides as well as the values of surface slope were determined from height maps with the help of aerial photographs and field observations. In this geological situation, with only small-scale groundwater flow, surface water divides do not deviate much from the groundwater divides (Sallantaus 2006). The main division into donor and receiver segments (Fig. 1) was interpreted from aerial photographs showing the mire wetness. Also smaller scale patches of uniform vegetation type (used for the water flow analysis) were derived from aerial photographs. In the large-scale topography of a mire basin bottom, the upper boundary of the lower part was placed 1.5 m above the lowest point of each study line (Fig. 2A). To get some quantification of the amount of water flow in the studied basins a shape factor (A/L) (Fig. 2B) was calculated for each patch of uniform vegetation having at least one vegetation sample plot. The used factor A/L is simply the relation between the catchment area and the breadth of the patch and thus has the dimension of length. It is based on the work of Ivanov (1981) who established relationships between specific discharge, upstream catchment area, surface slope and transmissivity of the acrotelm. Because the study areas form a set of successive basins, where water flow is concentrated in the acrotelm of mires, the value of A/L can be roughly correlated with the mean annual flux of water through the acrotelm of different patches. Further, potential acrotelm capacity (van der Schaaf & Streefkerk 2003) was calculated for the same patches by dividing A/L by surface slope. The resulting value shows the capacity of the acrotelm to conduct water from the catchment. Being very similar to the "topographic wetness index" (Beven & Kirkby 1979) potential acrotelm capacity can also be correlated with surface wetness.

Results

Maximum values of peat thickness were observed to increase with altitude, i.e. the chronosequence (Fig. 3). The increase of mean thickness was stable within the receiver segments, but less stable on the donor segments. The Twinspan statistics of plant cover reveal bisection by dividing the quadrats into two main groups: Tw+ and Tw–. The sectioning gives the possibility to evaluate the character of the plant cover. Typical taxa (Table 2) of the Tw+ group include species of paludified forests and *Sphagnum* hummocks, lawns and carpets, while the Tw– group includes species of wet seashores, swamps and fens. This first Twinspan division, which fits into the donor and receiver segments of the large-scale division, is very sharp on belts higher than/> 30 m a.s.l. (Fig. 4). On the youngest belt, nearly all quadrats in receiver segments and more than half in the donor segments have Tw– vegetation.; however, on the belt that is >30 m a.s.l. 93 % of the quadrats have Tw– vegetation on the receiver segment and Tw+ vegetation on the donor segment. Comparing the vegetation and large-scale topography of the basin bottom (Fig. 5), it can be said that the setting is quite similar: the mires that developed on the lower part of the basin on older belts are predominantly Tw–, whereas those that developed on the higher part of the basin are predominantly Tw+. The difference is less clear on younger belts.

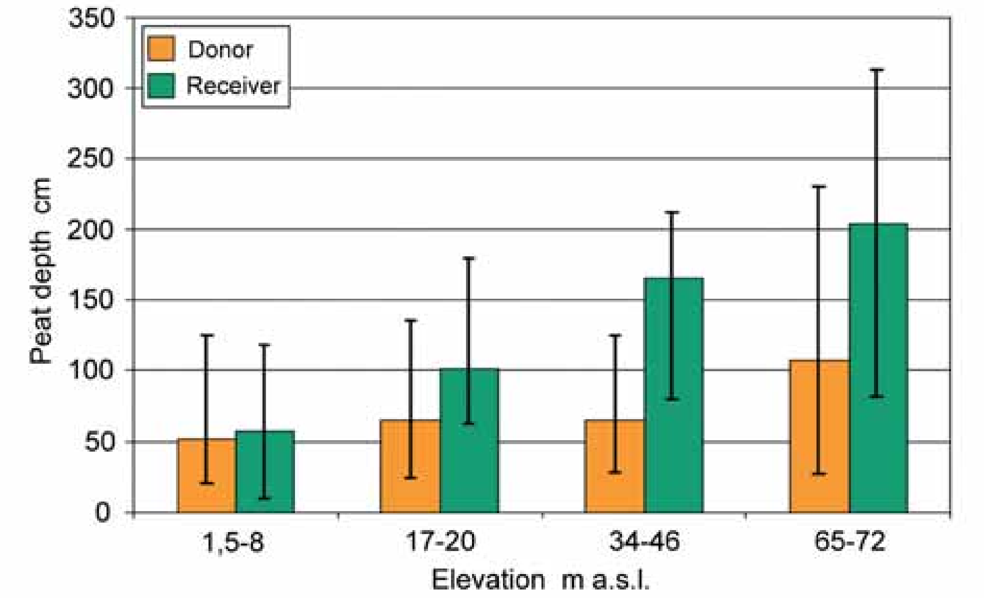

Figure 3. Mean peat depths of large plots on donor and receiver hydrological segments in different altitude classes (with minimum-maximum ranges).

Table 2. Typical plant species indicating Tw– and Tw+ groups

Tw + species
Eriophorum vaginatum, Empetrum nigrum, Rubus chamaemorus, Carex globularis, C. pauciflora, Equisetum sylvaticum, Scheuchzeria palustris, Polytrichum commune, P. strictum, Sphagnum angustifolium, S. balticum, S. capillifolium, S. fuscum, S. girgensohnii, S. magellanicum, S. russowii
Indifferent
Andromeda polifolia, Vaccinium oxycoccos, Aulacomnium palustre
Tw– species
Carex chordorrhiza, C. livida, C. nigra, Equisetum fluviatile, Molinia caerulea, Potentilla palustris, Rhynchospora alba, Trichophorum alpinum, Campylium stellatum, Scorpidium spp. Sphagnum subsecundum, S. teres, Warnstorfia exannulata, W. procera

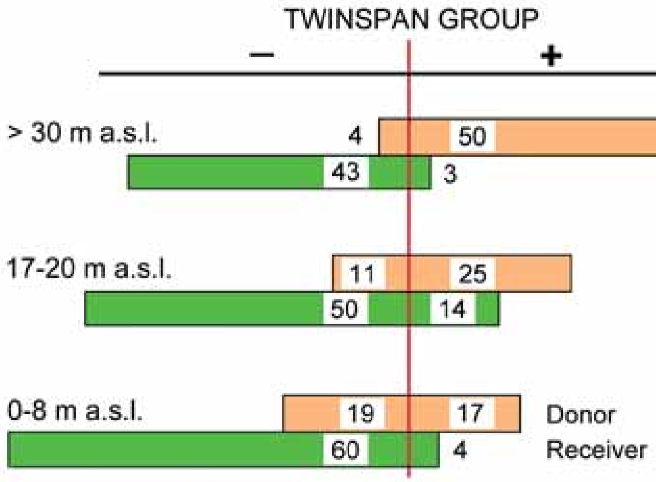

Figure 4. Vegetation of small plots, expressed as proportions (%), falling into Twinspan groups + and – on donor and receiver segments at different elevations.

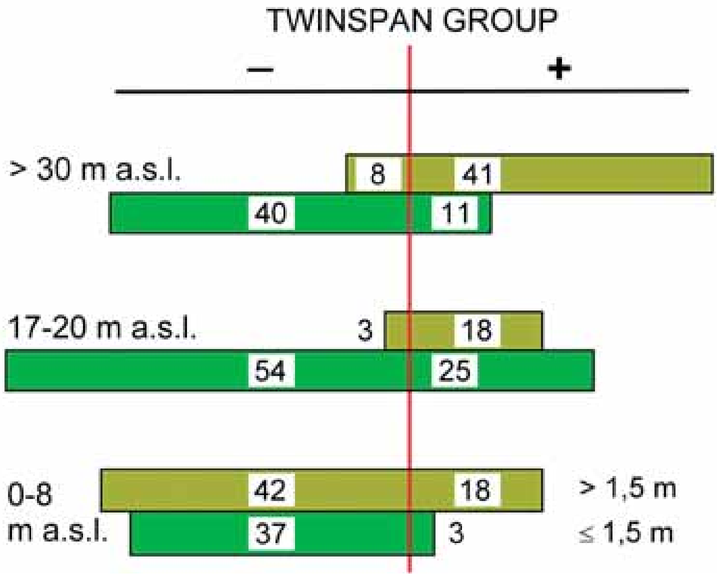

Figure 5. Vegetation according to Twinspan grouping in relation to the large-scale profile of mire basin bottoms. Calculated from above the lowest point of the basin, lower and upper blocks represent parts of basins that are ≤ and ≥1.5 m respectively.

The 1–2 axis projection in the NMS ordination (Fig. 6) shows the gradient from forming mires to mires with a thicker peat layer. The 2–3 axis projection (Fig. 7) shows clusters relative to poor–rich and wetness gradients: the wet sites (water depth <7.5 cm) form a cluster in the right hand top corner (moderately poor to rich fens) and another cluster on the left (ombro-oligotrophic carpet). The main division of the sites into Tw+ and Tw– groups in the 2–3 axis projection is clearly visible (Fig. 8). The ordination divides the data into two sections resembling the line, which separates the donor and receiver segments. The deviating sites are situated in two areas of the projection: in the lower part (right) Tw– sites on the donor segment are typically treed forming mires with shallow peat on younger belts, covered largely by demanding Sphagna. On the upper part (left) Tw+ sites on the receiver segment are small *Sphagnum fuscum* –hummocks on strings.

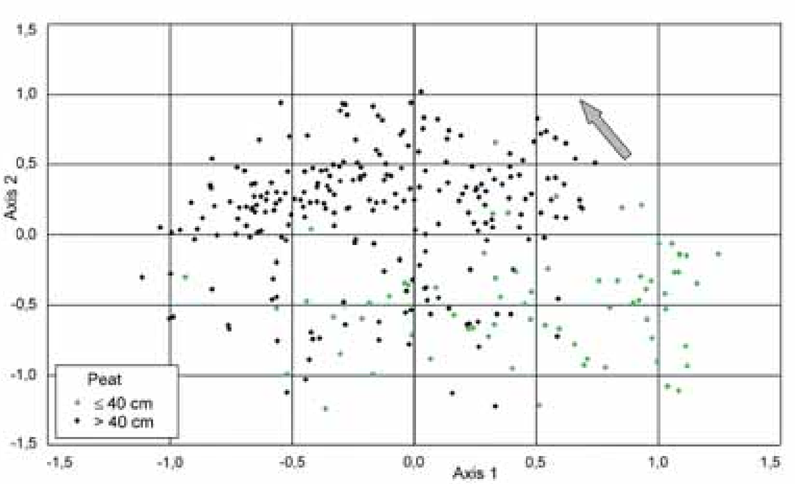

Figure 6. The 1–2 axis projection in the NMS-ordination of small plots, interpreted to show the development grade of mires (indicated by an arrow).

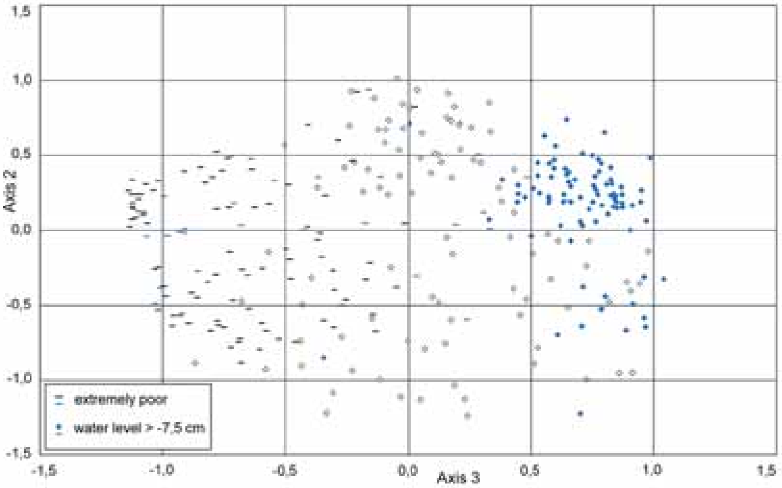

Figure 7. The 2–3 axis projection in the NMS ordination of small plots, in relation to water level depth and a poor–rich gradient.

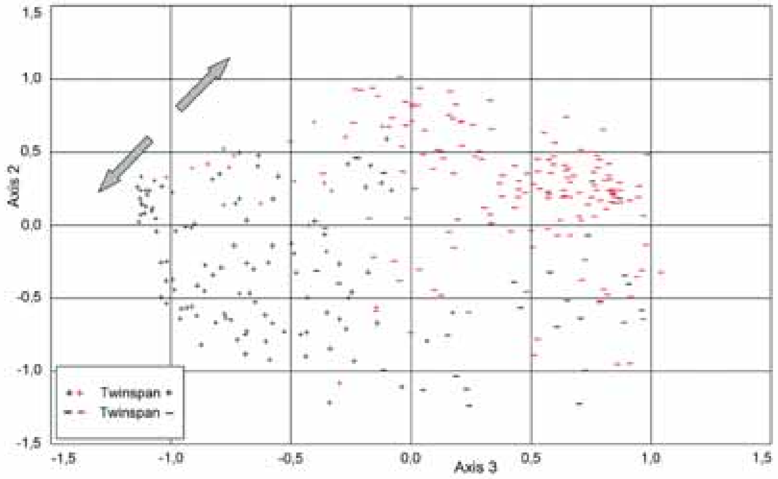

Figure 8. The 2–3 axis projection in the NMS ordination of small plots, interpreted to show the division into donor (black) and receiver (red) segments.

The proportions of *Sphagnum* (Fig. 9A,B) and mud-bottom coverage (Fig. 9C) in the large plots in older aapa mires seem bimodal: there is a peak in the *Sphagnum* dominated end (> 90 % of *Sphagnum*, < 10 % of mud bottom) and also in the mud-bottom dominated part (30-40 % of *Sphagnum*, 50-60 % of mud bottom). On younger belts this is unclear (Fig. 9A). Comparing the *Sphagnum* and mud-bottom coverages with the value of A/L in older aapa mires, a clear stepwise change is notable at the A/L value of 700–900 m (Fig. 10). In the area with a large water flow, the mud bottom often covers a larger proportion than *Sphagnum* (the very small amount of Bryales is not shown). In the belt 1.5–8 m a.s.l. the number of observations is smaller, but also there the sites with the least water flow seem to be always Sphagnum-dominated. The proportion of mud bottom is quite small here and Bryales are the most common mosses on sites with a marked water flow.

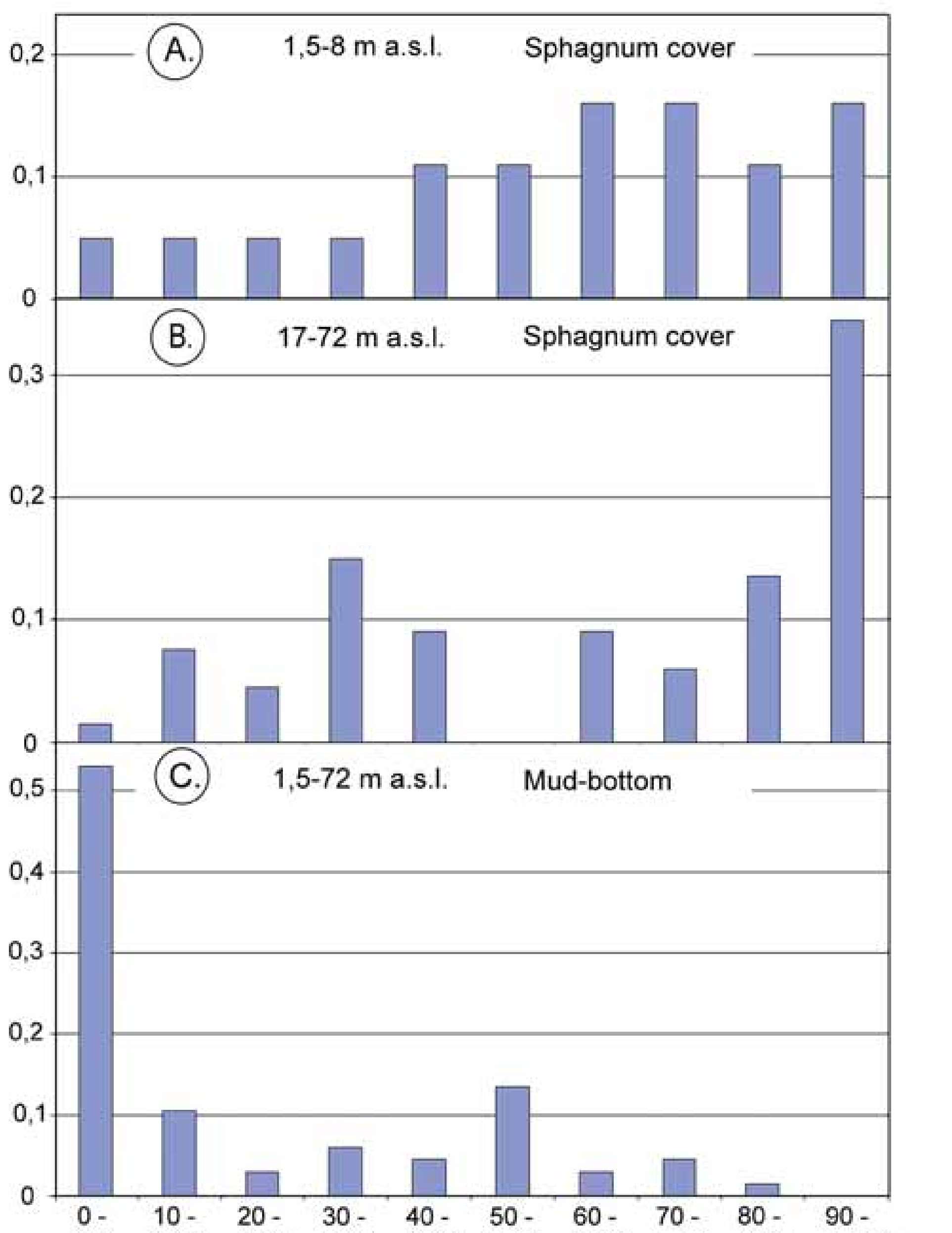

Figure 9. Cover frequencies of Sphagna at low altitude (A) and at higher levels (B), and of mud-bottom (C) in large plots (expressed separately in each cover percentage class).

The older transects (above 15 m a.s.l.) have a gently inclined profile typical of aapa mires. The surface slopes on the plots do not vary very much; nearly three quarters of the approximated values are between 0.002 and 0.003. Values under 0.001 or above 0.007 are quite exceptional. So the values of potential acrotelm capacity are largely dependent on A/L and A/L curves (not shown) versus *Sphagnum* or mud-bottom coverage having a very similar shape as the A/L curves (Fig. 10). On the younger transects (1.5 – 15 m a.s.l.) the profiles are typically a little more stepwise and so the values for surface slope have more deviation than on older mires, although the total amplitude as well as the mean values are very similar. Here the values for potential acrotelm capacity are more scattered and do not show any clear correlation, as regards their position, with donor or receiver segments or the *Sphagnum* and Bryales coverages on the plot.

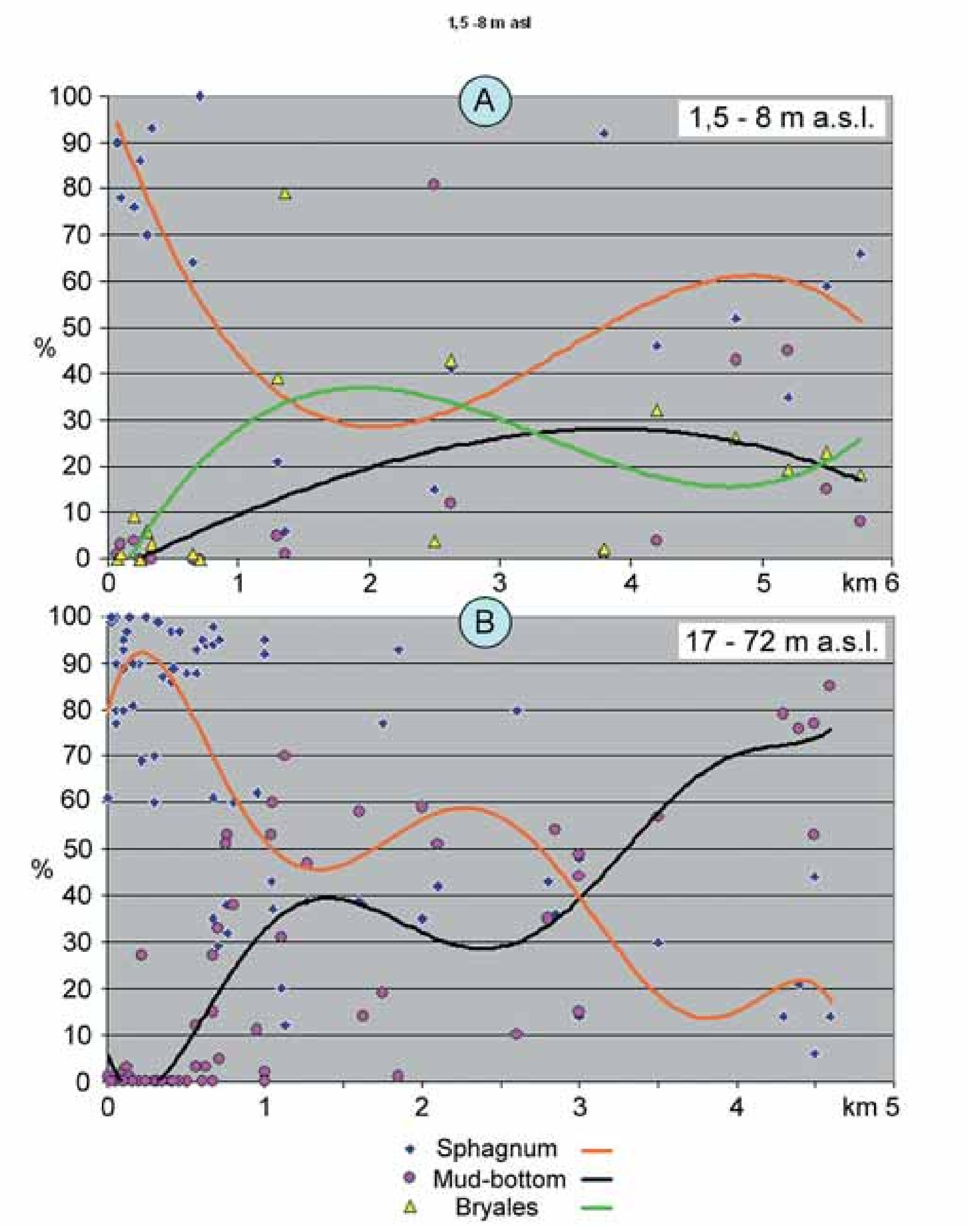

Figure 10. Sphagnum, mud-bottom and Bryales coverage (%) versus A/L ratio (km) at altitudes 1.5-8 m (A) and 17-72 m a.s.l. (B). Best fit polynomial curves are indicated (3th degree in A and 6th degree in B).

Discussion

The maximum values of peat thickness both on donor and receiver segments occur in depressions which have undoubtedly formed primarily from seashore meadows and ponds. Thick peat layers are even encountered very near the sea, expressing the rapid growth rate of young mires and supporting the regional peat increment results of Mäkilä (2006). The mean peat thickness on the belt 1.5-8 m a.s.l. is similar on both segments but on the belts 17-20 m and 34-46 m a.s.l. the values for donor segments are clearly smaller. On the lowest belt, nearly all mires have formed primarily, while above that they consist much of sites with shallower peat layer on secondarily paludified peripheral parts of the basins (Huikari 1956, Foster & Jacobson 1990). Hence, the mean thickness on the youngest belt can be correlated with the peat growth rate, but on older mires different parts have different ages and the donor segments seem to have larger parts of the younger, secondarily paludified parts. On the highest altitude studied the difference between the segments is again smaller. That may reflect the decrease of lateral expansion as mire systems become older and large-scale morphology becomes more stabilized.

In the study, aapa mires with broad receiver segments appear to be different from the mires on the southern part of the land-uplift coastlands on the Bay of Bothnia (Aario 1932) and on Hudson Bay (Klinger & Short 1996), where two clearly distinguishable starting points (primary mire formation and paludification) were noticed; however, their differences vanish when both develop mainly into vast ombrotrophic bogs. In the study area, the mires develop into aapa mires and ordination results in two continuous chains: one from constantly wet seashore swamps to aapa mire flark fens, and one from paludifying forests to pine mires and bogs. This could be interpreted as the primarily paludified basins forming the centres from where the typical vegetation of receiver segments develops or starts to spread. In the same way the paludifying forests of the peripheral part form a base for donor segments.

The large-scale development of the morphology of aapa mires on till-covered terrain seems to fit into the oligoperipheral development (Ivanov 1981) typical for minerotrophic mires. The lowest parts of the basins, which consequently have most water flow in the beginning, tend to have most flow also in the developed aapa mire phase. In that kind of development, the place of water divides usually does not change. However, it is clear that when the youngest belts, with a lot of small-scale variation, develop into large aapa mires, development in the individual sites may differ from each other. Basins with a permeable bottom (Laitinen & al. 2005) or strong ground water flow (Heikkilä & al. 2001) may behave in a much more complicated way.

The simplified term A/L can be considered valid for comparing the fluxes of water flow through vegetation patches if the entire outflow from each catchment area flows in the acrotelm of the patch being studied. So the flow in the mineral soil or in the catotelm is supposed to be insignificant. In the strictest sense, this is of course incorrect, especially as it applies to locations near the borders of mineral soil; nevertheless, because the bottom soil is uniformly composed of quite poorly permeable silt, till and bedrock, the inaccuracy can be considered to be small. Because the surface slope on the older transects is quite uniform, the values of A/L can therefore demonstrate the large-scale variation of surface wetness along the flow path in nearly the same way as the values of potential acrotelm capacity. Surface slope measurements were coarse so much so that the smaller scale variation in wetness is not visible.

The A/L value reflects the position of the site in its catchment area. When interpreting Fig. 10, it must be kept in mind that polynomials of a higher degree than 2 often show fluctuation, which is caused by the statistical model rather than by the data. However the results suggest quite clearly a stepwise change from drier *Sphagnum*-dominated vegetation to mud-bottom flarks about 700–900 m from the water divide in cases where the flow lines are parallel. That can be correlated with the conspicuous border between the donor and receiver segments of the aapa mires. On young, developing mires (1.5–8 m a.s.l.) the sites with least water flow have a continuous *Sphagnum* cover at the beginning. Where the flow increases, the coverage of *Sphagnum* decreases, while that of Bryales mosses increases (with a smaller amount of mud-bottom). This reflects the adaptation of most *Sphagnum* species to acidic, stagnant water conditions (Clymo & Hayward 1982). On the other hand, flowing minerotrophic water can assist other plant groups in displacing the *Sphagnum* mosses. In the older aapa mires, the hydrologically based separation to *Sphagnum*-dominated donor and mud-bottom dominated receiver is clearest. The general setting thus forms a kind of analogy to divergent succession (on a a smaller scale), which prevails both in raised bogs and aapa mires (Sjörs 1990). The existence of mud-bottom on the older belts depends on the water level determined by the strings (Ivanov 1981). In both diagrams (Fig. 10) there is, however, a large variation especially in the right hand side of the diagrams, revealing that in some situations mires with even a very large amount of water flow can have quite a large coverage of *Sphagnum*. This can be the case, for example, with outlet fens (Laitinen & al. 2007), which do not have clear strings and flarks, but a dense growth of sedges and also quite a large share of *Sphagnum*.

A common situation with Finnish aapa mires is that ditches have been created on the margins to prevent water from flowing to the centre (Lindholm & Heikkilä 2006).Such a situation would warrant a consideration of curves (Fig 10) to help in assessing the minimum area needed for restoration planning. It can be supposed that at least the sedge and leaf-moss growing flark level vegetation with unclear patterning reacts very sensitively to the amount of water flow. If the water flow decreases, the receiver segment begins to turn *Sphagnum*-dominated and the donor segment margin becomes expanded with respect to the shift in the water divide. The effect of stagnant water bringing benefit to most *Sphagnum* species and disadvantage to demanding fen species undoubtedly applies also to patterned aapa mires. However, mud-bottom and open water, found in connection with clear string-flark topography, might persist even if the surfaces otherwise develop into drier states (Belyea & Clymo 2001). The directing of water flow into too narrow pathways will not help to gain the original flark vegetation with demanding fen species and mud-bottom. On the contrary, the result can be a set of narrow joints resembling outlet fens with dense cover of sedges and *Sphagnum* mosses.

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The development of patterning on a succession series of aapa-mire systems on the land-uplift coast of northern Ostrobothnia, Finland

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Introduction

The microtopographic patterning composed of alternating wet and dry features perpendicular to the direction of water flow is typical for both minerotrophic and ombrotrophic mires. The stability of this type of vegetation structure is basically thought to be due to its stabile water regime in fluctuating water flow (Ivanov 1981, Belyea & Clymo 2001). Patterning can be caused by biotic and mechanical factors, generally the first of which have been considered to be more important (Sjörs 1961, Seppälä & Koutaniemi 1985). So, the prerequisite for the patterning lies in that different levels on the mire have different rates of peat growth as a result of differences in primary production, especially decomposition. It has been assessed, that patterned aapa mires have the fastest growth rate on the lawn level and bogs on the hummock level (Sjörs 1990). In mud-bottoms, where vegetation can become very sparse although decomposition may still be considerable, the growth rate is smallest or even negative (Sjörs 1961, 1990). The development of the patterning can be progressive (when strings or hummocks grow on a wet surface) or regressive (when flarks or hollows develop into a drier surface) (Nilsson 1899, Cajander 1903). A progressive development has been observed to be dominant on northern aapa mires (Rancken 1911). The vigorous sedge tussocks on the wet surface with *Sphagnum* at their roots have been considered to behave as the starting points in the development of strings (Богдановская-Гиенеф 1936, Кузнецов 1982). In the first phase, wetter sites with sparser vegetation develop in front of the obstacles, which dam the water flow (Sjörs 1990). When the vegetation and peat layer grow, the wetter depression tends to spread laterally along the contours (Eurola 1960, Foster & al 1983, Swanson & Grigal 1988). Regressive development, where hollows develop as a result of wetting of lawn or hummock level vegetation has been reported mainly in large bogs (Богдановская-Гиенеф 1936, Aartolahti 1965, 1967). Recently, microtope patterning has been explained by a simple, spatially explicit model that assumes predominantly lateral water flow through an acrotelm (Couwenberg & Joosten 2005).

The established patterning is known to be very stable both in bogs (Aartolahti 1967) and aapa mires, although local shifts have been recorded in the latter (Seppälä & Koutaniemi 1985). The patterning often becomes more clear cut as the mires age (Кузнецов 1982), because accumulation in flarks stays constantly low, or may in places, turn to eroding the peat layer to form open ponds (Sjörs 1961). Also the pressure of ice and the persistence of ground frost in hummocks can make strings and flarks more stable

(Helaakoski 1912, Ruuhijärvi 1960). Additionally, erosion of strings caused by small brooks can sometimes change the vegetation (Ivanov 1981, Кузнецов 1982).

The land-uplift coastland around the Bothnian Bay gives the possibility to directly study the development of patterning on mires. Because of sea level regression, there is a full series of mire basins forming a chronosequence, from coast to inland (see Rehell & al. 2010). On the northern end of this land-uplift coastland, the mires have developed into typical aapa mires of the Northern Ostrobothnian type (Ruuhijärvi 1960). The aapa massifs normally have string-flark patterning in their centres (receiver segments), and *Sphagnum* lawns and hummocks on their peripheries (donor segments) (Laitinen & al. 2007). Even local bog massifs with their own hummock-hollow patterning can belong to the same system with the donor segment. Hence, it is possible to compare the development of patterning on both minerotrophic and ombrotrophic mires. In this study, we have followed the patterning on developing mire basins from the littoral belt upwards. We suppose, that the same processes, which are now prevailing were also active when the oldest basins in our sampling area rose above sea level. The main question guiding the study is: How has the patterning in the developing mires changed over time? We have chosen three different ways to approach this problem: 1) detailed mapping of the patterns on mires of different ages; 2) statistical ordination of the vegetation data obtained from the mires under study; and 3) study of peat stratigraphy on successive basins.

Material and methods

As part of a broader study, much of the material and methods employed in this study has been principally explained in the article on large-scale topography of aapa mires by Rehell et al. 2012. For the investigations carried out as part of this study, the chain of lines (Fig. 1) stretches from the littoral belt to the established aapa mire belt. Landforms are of basal till, covering the siliceous bedrock, which indicates small-scale groundwater flow and minimal difference between the surface and groundwater divides. Studies were conducted on catchment areas with mire basins in their central parts. The altitude of the bottom of the basin gives the age for primary mire formation (Table 1).

Table 1. Study sites along the transect chain. Ages for basins at different elevations are approximations from the land uplift curve in Taipale & Saarnisto (1991), expressed as calibrated years Before Present (AD 1950, Weninger & al. 2005)

Site name	Basin elevation m a.s.l	Basin formation (yr, a.s.l.)	Line length (m)
1. Ryöskäri	0 - 6	0 - 600	980
2. Sahkari	6 - 8	700 - 800	710
3. Ihanalampi	18 - 20	1900 - 2200	2050
4. Nikkilänaapa	34 - 46	3900 - 4700	2500
5. Kairavaara	67 - 72	6000 - 6600	2250

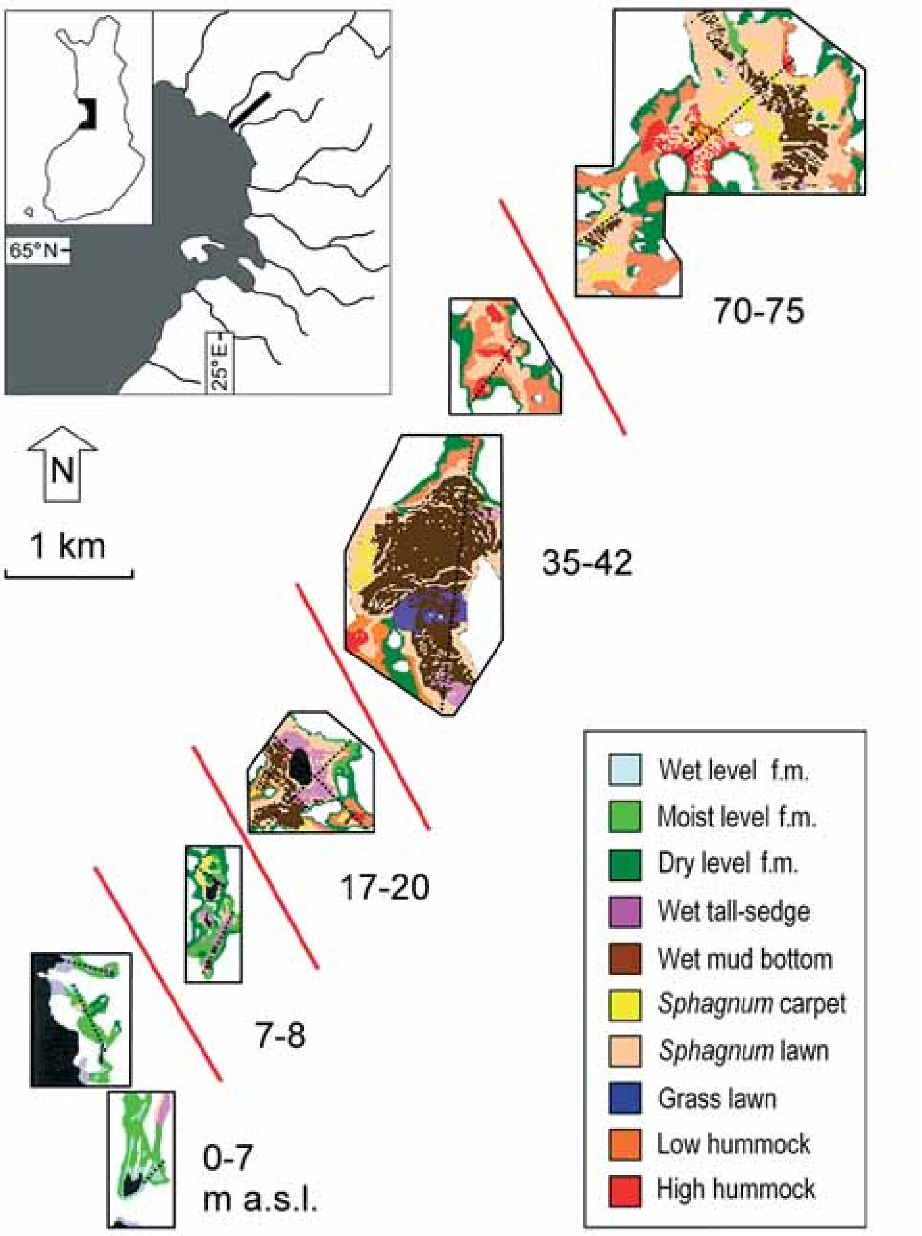

Figure 1. Series of mire basins studied and a priori vegetation types showing microtopographic features. Dashed black lines indicate sampling transects.

The lines across the basins were positioned in such a way as to cover hydrologically different parts of the developing aapa mires. Division into donor (peripheral parts with less water flow) and receiver (wet central parts with abundant water flow) segments was done with the aid of aerial photographs (see Rehell & al. 2010): The lines were sampled plot-wise, at 100 m intervals. The plots were normally 10x10 m in size, but on each line, in some places, the size was enlarged to get a clearer picture of the microtopographic variation. Detailed mapping of the vegetation types was done on each plot using a priori classification modified for young developing mires.

The list of vegetation types used here (Table 2) is such that they correspond to mire surface levels (Sjörs 1948, Eurola & al. 1984) and each type can easily be recognized on aerial photographs. The seashore types, meadows and thickets, contain parts of the littoral belt without peat and a very restricted amount of typical mire vegetation. The “forming mires” refer to sites dominated by mire vegetation, but with only a thin

Table 2. A priori classification of vegetation

Name	Control of water level	Indicator species of moss layer	Indicator species of field layer	Indicator species of tree/bush layer
1 .Sea-shore types	by sea	*(Drepanocladus aduncus)**	*Eleocharis palustris Carex nigra*	*Myrica gale, Salix phylicifolia.*
2 .Wet level forming mire	by mineral soil thresholds	*Sphagnum squarrosum, Calliergon cordifolium*	*Calla palustris, Carex rostrata, C. diandra*	–
3 .Moist level forming mire	by mineral soil thresholds	*Sphagnum teres, S. warnstorfii, S. squarrosum*	*Carex rostrata, Equisetum arvense*	*Alnus incana, Betula pubescens*
4. Dry level forming mire	by mineral soil thresholds	*Sphagnum girgensohnii, S. capillifolium*	*Equisetum sylvaticum, Carex globularis*	*Picea abies, Pinus sylvestris*
5. Wet tall-sedge	by mineral soil threshold and peat	*(Sphagnum subsecundum Campylium stellatum)*	*Carex lasiocarpa, Menyanthes trifoliata*	*typically absent*
6. Wet mud bottom	by peat layer	*typically absent*	*(Menyanthes trifoliata Rhynchospora alba)*	*typically absent*
7. Sphagnum carpet	by peat layer	*Sphagnum majus aggr., S. balticum*	*Scheuchzeria palustris*	*typically absent*
8. Sphagnum lawn	by peat layer	*Sphagnum papillosum S. recurvum coll.*	*Carex lasiocarpa, Vaccinium oxycoccos*	*typically absent*
9. Grass lawn	by peat layer	*(Sphagnum papillosum)*	*Molinia caerulea*	*(Pinus sylvestris)*
10. Low hummock	by peat layer	*Sphagnum magellanicum S. angustifolium.*	*Eriophorum vaginatum*	*Pinus sylvestris*
11. High hummock	by peat layer	*Sphagnum fuscum*	*Empetrum nigrum*	*(Pinus sylvestris)*

*Species in brackets typically form a very sparse vegetation layer.

peat layer and a water level typically ruled by mineral soil thresholds. In true mires, the classes refer to the mean depth of the water table and the coverage of different vegetation layers. The water level in true mires is mainly determined by the peat layer, but especially by the "wet tall-sedge" level (wet level with a very thick sedge-dominated field layer and moderately sparse moss layer, "Magnocariceta", in Sjörs 1983), which often resembles a transitional stage between "forming mires" and true mires. The employed a priori classification was tested statistically by Multi-Response Permutation Procedures (MRPP), a suitable method for testing the validity of groups when data is lacking normality or variable homogeneity (Berry et al. 1983).

The vegetation coverage, water level and peat thickness were studied in 1x1 m quadrats representing all separated vegetation types in each sample plot (Rehell & al. 2010). The quadrats, with a bottom of at least 20 cm above the lowest point of the 10x10 m plot, were considered to be representative of the "upper part" of the plot (Fig. 4). The vegetation data was ordinated to study the vegetation in relation to the development stage of the patterning, with NMS (Non-metric Multidimensional scaling) used as a method that has been found to be highly suitable for dealing with this type of ecological data (Minchin 1987, Clarke 1993). In the ordination, the quadrats were classified in relation to patterning (Table 3). Nomenclature of plant species follows Hämet-Ahti et al. (1998) for vascular plants, and Ulvinen et al. (2002) for mosses. The used category *Sphagnum recurvum* coll. includes *S. angustifolium, S. fallax* and to a lesser extent, *S. flexuosum*. *Sphagnum majus* aggr. includes *S. majus, S. annulatum* and *S. jensenii.*

Peat stratigraphy was studied in every sample plot; some sites from both the donor and the receiver segments were chosen for laboratory studies. In cases where there was evidence of visible patterning, profiles were taken from both the wetter and the drier surfaces. Altogether 32 peat profiles were taken from 22 sample plots. The uppermost (40 cm) part of the profile was sampled with a metal cylinder 11 cm in

Table 3. Classification of quadrats in relation to patterning

Nr	Mire surface level	Microtopographic patterning in relation to donor (D) and receiver (R) segments	Relation to a priori vegetation classes (Table 2)	Occurrence on lines (m a.s.l.)
1	Wet or moist forming mires / seashores	Exclusively created by a mineral soil topography	1, 2, 3	0-20
2	Dry forming mires	Exclusively created by a mineral soil topography	4	4-72
3	Wet level	Unclear, developing strings and flarks on R.	Nearly all of 5; small part of 6	2-20
4	Lawn	Unclear, developing strings and flarks on R	Part of 8	6-20
5	Hummock	Unclear, developing strings and flarks on R	Part of 11	6-20
6	Mud-bottom	Clear strings and flarks on R	Nearly all of 6; small parts of 5 &7	32-68
7	Lawn – (hummock)	Clear strings and flarks on R	9; part of 8; sporadic 11	32-68
8	Wet (carpet)	Probable developing patterning on D	Part of 7	40-70
9	Lawn – hummock	Probable developing patterning on D	Parts of 10, 8 & 11	40-70
10	Wet (mainly carpet)	Ombrotrophic hummocks and hollows on D	Part of 7; one site of 6	70
11	Lawn – hummock	Ombrotrophic hummocks and hollows on D	Parts of 11& 8	70
12	Wet (mainly carpet)	No patterning visible. D	Part of 7, sporadic 5 & 6	7-70
13	Lawn – hummock	No patterning visible. D	Parts of 11, 10 & 8	4-70

diameter. The deeper parts were taken with a Russian borer (Jowsey 1966). In the laboratory, the composition of plant macrofossils was studied microscopically at 10 cm intervals after samples were rinsed with water and sieved. The results were classified according to indicative plant remains (leaves or leaf bases of mosses and vascular plants, seeds and fruits) (Table 4). Deep roots were not taken into account (except for the most typical seashore species, e.g. *Phragmites*). The indicator species were chosen using recent vegetation data (Rehell & al.2010):

Table 4. Classification of peat layers according to the occurrence of indicative plant remains

Nr	Position in the profile. Occurrence of wood remains	Indicative plant remains in peat	Indicated vegetation type or mire-forming process
1	Horizon just above the mineral soil or gyttja. Possible presence of wood or nanolignids	*Phragmites, Potentilla palustris, Carex diandra, C. aquatilis, C. rostrata, Menyanthes, Hippuris, Potamogeton spp., Drepanocladus spp., Warnstorfia spp., Calliergon spp., Sphagnum squarrosum*	Primary mire formation from wet-moist sea shores
2	Horizon just above the mineral soil with wood remains	*Eriophorum vaginatum, Carex globularis, Polytrichum spp., Sphagnum girgensohnii, charcoal particles*	Paludification from heath forests
3	Horizon just above the mineral soil. Possible presence of wood remains	*No indicative plant remains*	Mire formation of unknown type
4	Peat layer. Possible presence of Nanolignids	*Menyanthes, Equisetum fluviatile, Carex lasiocarpa, C. limosa, C. chordorrhiza, C. rostrata, Scorpidium spp., Campylium stellatum, Warnstorfia spp., Hamatocaulis spp., Meesia spp., Calliergon spp., Sphagnum subsecundum, S. contortum, S. platyphyllum, S. teres*	Wet mire level in receiver segments
5	Peat layer. Possible presence of Nanolignids	*Eriophorum vaginatum, Scheuchzeria palustris, Sphagnum majus aggr., S. balticum, S. recurvum coll., S. papillosum*	Wet to lawn level in donor segments
6	Peat layer. Possible presence of Nanolignids	*No indicative remains or mixture of species mentioned in 4 and 5*	Wet to lawn level of unknown type
7	Peat layer: Possible presence of Nanolignids	*Carex lasiocarpa, C. chordorrhiza, Molinia caerulea, Trichophorum spp., Sphagnum papillosum, S. recurvum coll., S. teres, S. warnstorfii, S. subfulvum, S. centrale*	Lawn level in receiver segments
8	Peat layer with wood or nanolignids	*Eriophorum vaginatum, Sphagnum magellanicum, S. russowii, S. recurvum coll., S. papillosum, Polytrichum strictum*	Lawn-hummock level in donor segments
9	Peat layer with wood remains	*No indicative plant remains*	Lawn-hummock level of unknown type
10	Peat layer with nanolignids	*Empetrum nigrum, Sphagnum fuscum*	Sphagnum fuscum hummock

Results

The employed a priori classes differ clearly from each other in the MRPP analysis. The most coherent groups (mean dissimilarity < 0.1) are high hummocks, wet mud-bottoms and wet tall-sedge levels. Most heterogeneous (mean dissimilarity 0.3-0.5) were *Sphagnum* lawn and *Sphagnum* carpet levels. The coverages of the a priori classes in sample plots give a picture of the development of vegetation of receiver and donor segments of the basins (Fig. 2), although the amount of margins with shallow peat may be underrepresented. On the littoral belt (not shown), true mire vegetation covers only a small part of the area, mainly where there is water flow (Elveland 1976, Rehell 2006). Above that (1.5-8 m a.s.l.), many hydrotopographical levels may exist side by side. The swamps and swamp forests with shallow peat (wet and moist forming mires) are abundant in both segments. The paludified forests (dry forming mires) concentrate in the donor segment and the wet tall-sedge levels in the receiver

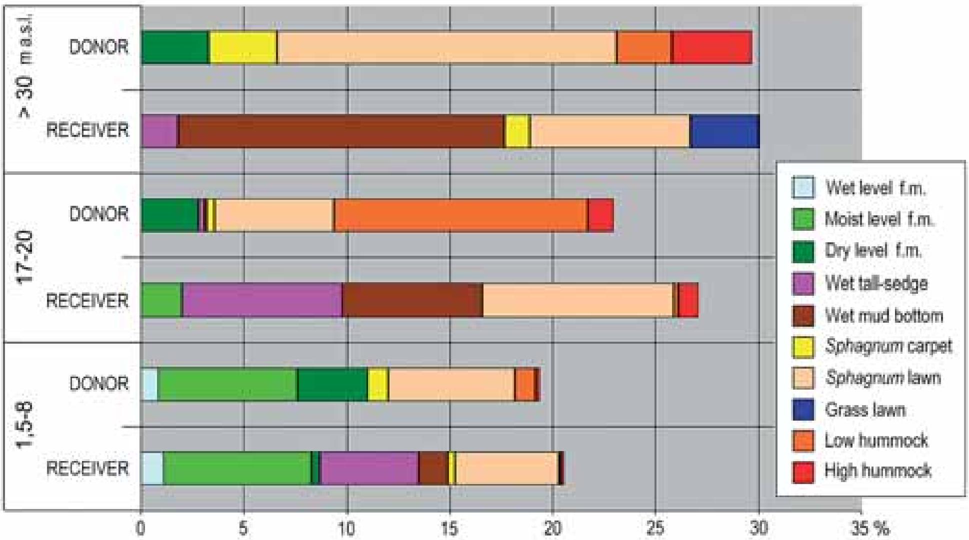

Figure 2. Proportions of mire surfaces with different vegetation types on large plots on donor and receiver segments (see Rehell & al. 2010). Sites other than mires (heath forests, sea shore meadows, etc.) are not shown. Mire total cover is determined from mapping data in Rehell (2006).

segment. On the belt 17-20 m a.s.l., mud-bottom and wet tall-sedge level dominate together in the receiver segment, while pine mires (low hummock level) dominate in the donor segment. Open *Sphagnum* lawns and hummocks are abundant (mainly in thick peat-concentrated parts) in both segments. Above 30 m a.s.l., the vegetation is typical of aapa mires, with mud-bottom covering a large part of the receiver segment and *Sphagnum* hummocks concentrating in the donor segment. The *Sphagnum* lawn is abundant in both segments.

Some typical examples of the patterning on different elevations is displayed in Fig. 3. In the lower belts (1.5-8 m a.s.l.), the wet surfaces concentrate in the sites of local depressions and form typically wet tall-sedge soaks on the receiver segments (Fig. 3A). Drier surfaces are found mainly on more elevated ground near the edges of the basin, but in places, these surfaces can form thresholds, which dam small areas of mud-bottom. In the next stage (17-20 m a.s.l.), the patterning on the receiver segment seems to indicate a phase of rapid development. On the surface, small patches of *Sphagnum* lawn are combined with wet tall-sedge level surrounding true mud-bottom sites. On the older belts (> 30 m a.s.l.), the receiver segment has the typical patterning of aapa-mires: mud-bottom flarks alternating with lawn-level strings and bottom topography does not affect the patterning anymore.

On the donor segments an unclear patterning is visible in the Belts 3 and 4 (20 and 42 m a.s.l.). Different hummocks can be situated side by side perpendicularly towards the direction of water flow (Fig. 3B), and small lags of *Sphagnum* carpet or lawn can be situated above some hummock level patches. However, only the highest basin (about 70 m a.s.l.) studied has a clear patterning on the donor segment; *Sphagnum fuscum* ridges (kermis) alternate with *Sphagnum* lawn and carpet hollows on an eccentric bog.

The relation between the small-scale topography of the bottom soil and mire levels can be seen in Fig. 4; on the lower belt, the lawn and hummock level is clearly concentrated in parts with a bottom of 20 cm or more above the lowest point of the large plot. In the upper belts, their occurrence seems to become independent of the bottom level.

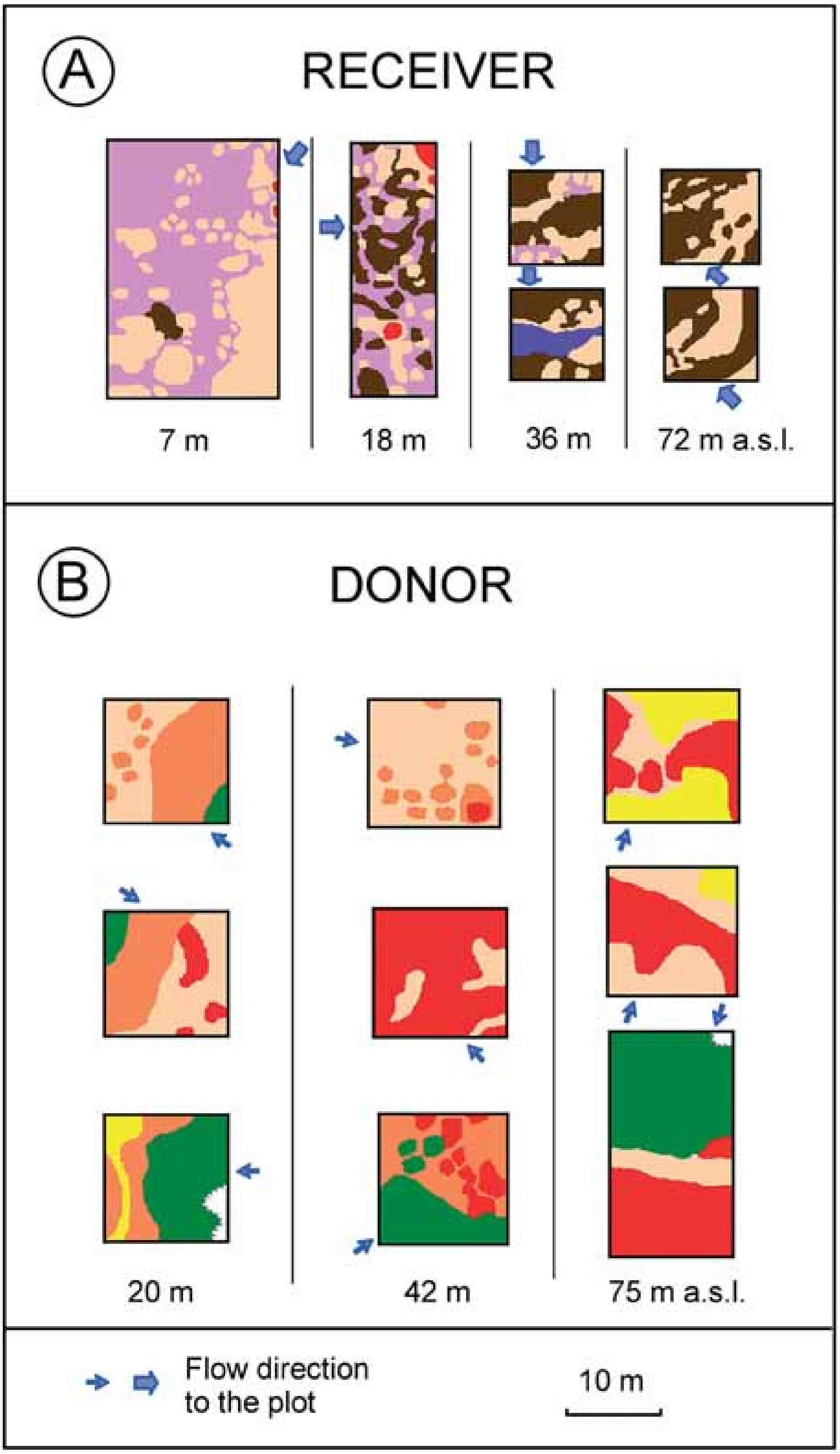

Figure 3. Examples of large plot detailed mapping on receiver segments (3A) and donor segments (3B). See Fig. 1 for colour referents.

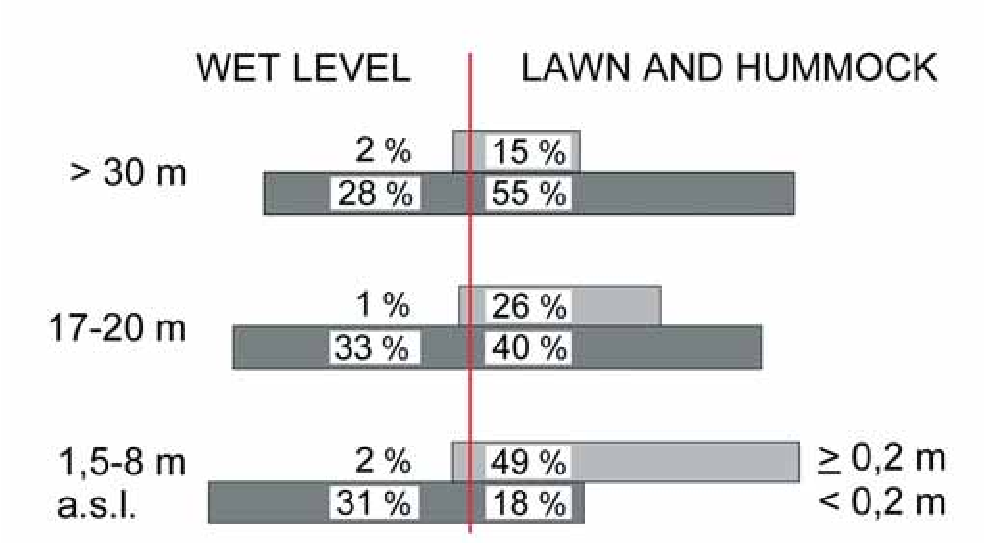

Figure 4. Vegetation cover percentages (wet level versus lawn to hummock level) for different parts in the basin bottom topography. Calculated from above the lowest point of the large plot, the upper (light) block shows the proportion of small plots with a bottom of ≥ 20 cm

The development of patterning can also be seen in the ordination picture of the vegetation (Fig. 5); on receiver segments, the wet surfaces with unclear patterning (3) are situated between the swampy (primary) forming mires (1) and the mud-bottoms and lawns of aapa-mire centres (6, 7). The arrows in Fig. 5 do not show every possible development route, e.g. a part of primary forming mires and seashore types (area 1) with little water flow can develop into donor segment types (areas 12 and 13).

The peat types of the profiles (Fig. 6) indicate the vegetation that has formed the peat layers. In some samples, however, the peat is so humified, that no indicative plant remains can be found. In all profiles (except one) there are signs of quite a shallow peat profile in the central part of the basin (17-20 m a.s.l.), where possibly open mire vegetation had rapidly covered an island; in these profiles, there is a separable 10-40 cm thick bottom layer indicating either primary mire formation or paludification (types 1-3). Profiles of the central parts of basins usually indicate swamps or swamp forests of primary mire formation. (type 1) and the layers above, indicate typically wet, rich fen (type 4), which quite often reaches up to the surface. However, there are examples of basins with a smaller amount of water flow, where the wet swamp (1) develops into poor *Sphagnum* carpet (5) either directly (3 m a.s.l.) or (at 7 and 17 m a.s.l.) after a short period dominated by richer vegetation (4). On the peripheral parts of the basins, the bottom layer is usually formed by paludification (2) and the layers above it usually indicate poor *Eriophorum* and *Sphagnum* lawn or hummock vegetation (8). On the older mires (40 and 70 m a.s.l.), the surface layers may also indicate poor carpet (5) or *S. fuscum* hummocks (10), or even sedge-dominated wet levels (6).

The origin of patterning can be seen in profiles taken side by side. The effect of bottom topography is seen on lower belts (7 and 17 m a.s.l.), for example, in how the site with a higher bottom elevation develops into poorer, *Sphagnum*-dominated types. However, most cases on receiver segments are typically string-flark patterned, where there is no bottom effect and both sites have similar levels of peat that are quite high up in the profile. Typically the peat indicating rich wet level vegetation reaches the surface in flarks, but the same type of peat is also found in the strings below the shallow lawn layer near the surface. One string-flark pair on the highest level (68 m a.s.l.), however, differs from this in many ways: it has quite shallow peat, probably formed via palu-

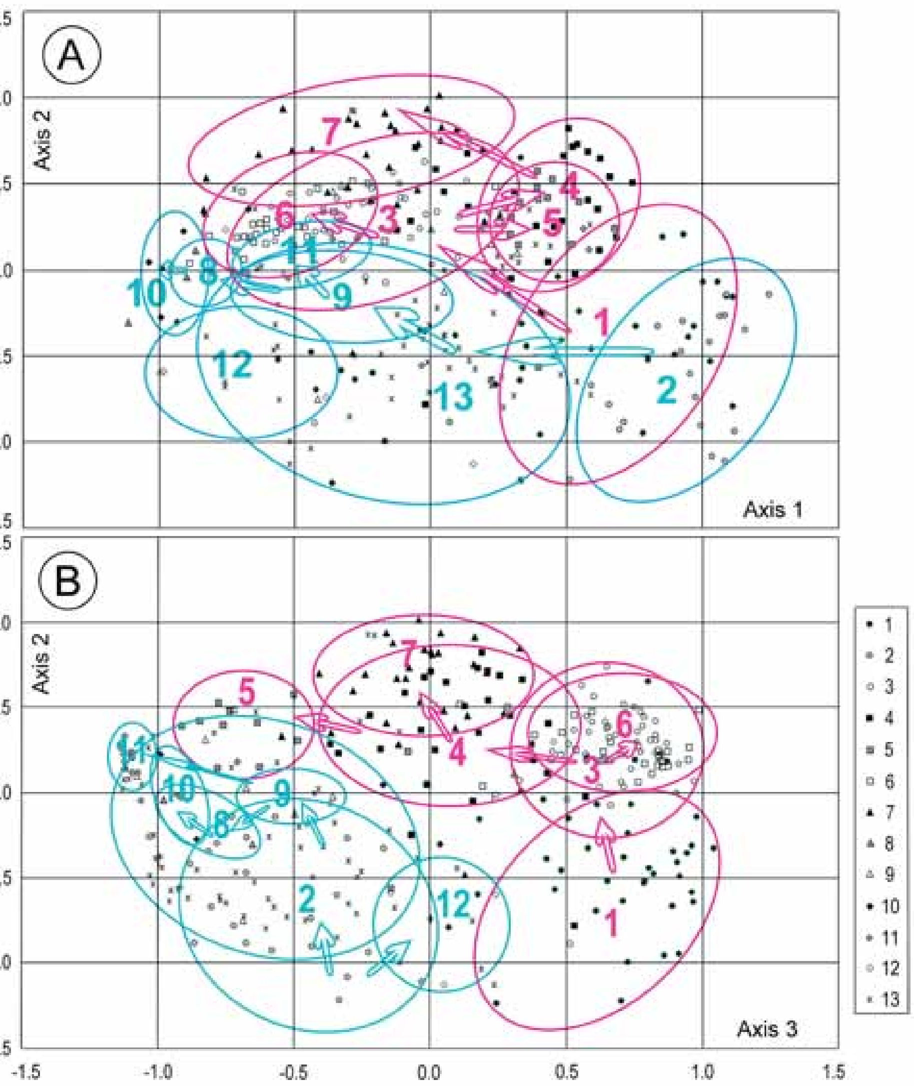

Figure 5. 1-2 (A) and 2-3 (B) axis projections in the NMS ordination of vegetation. See Table 3 for number referents.

dification of heath forests. Its patterning has developed on a *Eriophorum-Sphagnum* lawn. The profiles of the patterned ombrotrophic bog (70 m a.s.l.) show a sequence starting from paludification of heath forest and poor *Sphagnum* lawn and hummock level. The patterning, however, seems to have formed when *Sphagnum fuscum* hummocks emerged on carpet level vegetation.

Discussion

Most of the development of the mire basins studied dates to the last half of the Holocene, when the main features in vegetation as well as climate were directed towards the current situation. The development did not adhere to any particular linear trend, but was framed by the local topography, proceeding with variations in strength and oscillations (Korhola 1995). On the younger belts (1.5-8 m a.s.l.) the visible patterns in vegetation are largely due to the topography of the mineral soil. String-flark pat-

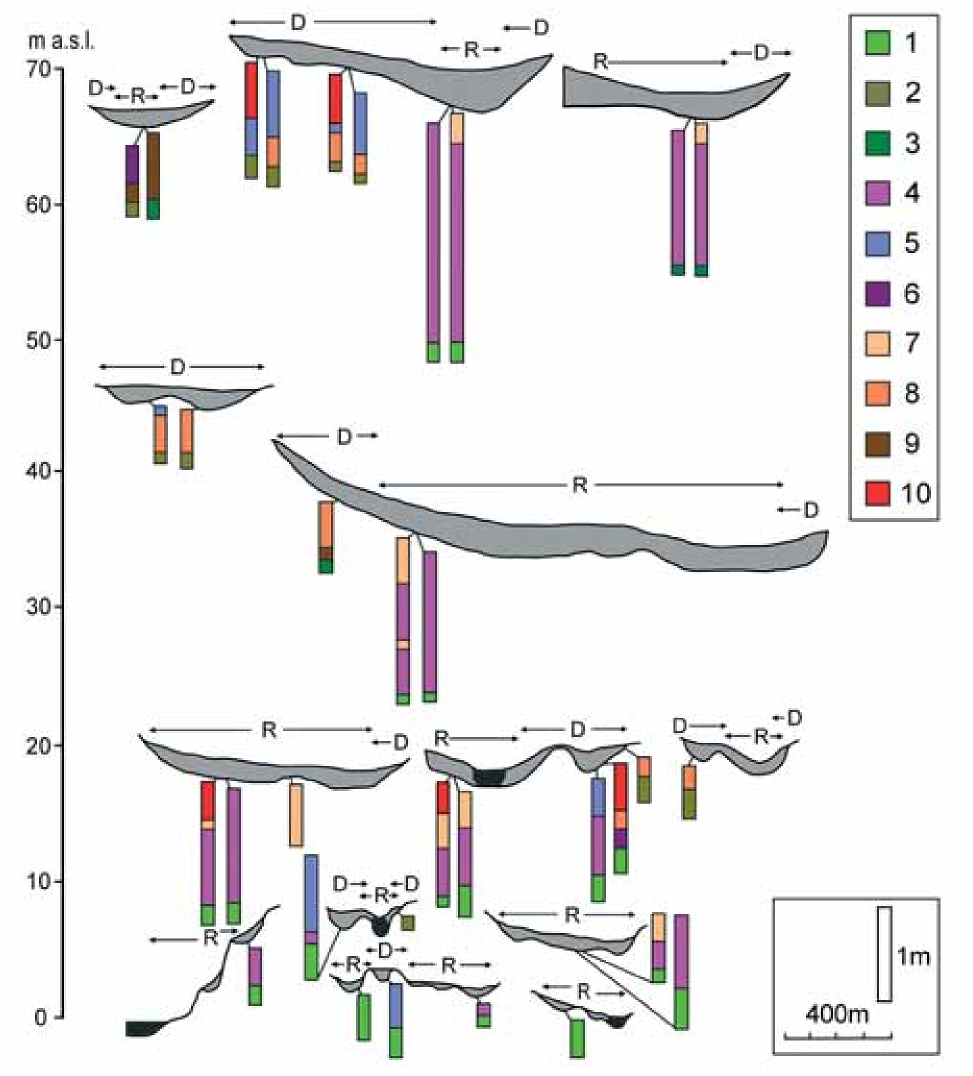

Figure 6. Peat profiles of lines studied at different elevations above sea level. Donor (D) and receiver (R) segments are shown above each profile. Laboratory-analysed peat samples are shown in colour (see Table 4 for sample classification).

terning on the receiver segments started to develop in a basin ~ 2 000 years old (17-20 m a.s.l.), where the large-scale profile of the mire had reached a sufficiently mature stage. Patterning is also clear for a basin 4 000 year old. The development of patterning on the donor segments seems to have started later, probably because the mires on donor segments had formed largely via paludification of heath forests (Rehell & al. 2010), and are thus "younger" than the central parts of the basins. Hence, the results support the presumption that internal factors can determine the forming of patterning (Foster & Fritz 1987, Foster & Jacobson 1990), although climate as a driving force cannot be confirmed with our results. The results also support the idea of strings and flarks forming together (Couwenberg & Joosten 2005), so that it could be concluded that typically regressive and progressive developments occur side by side.

The patterning starts to form in a similar way as reported for older aapa mires and bogs (Богдановская-Гиенеф 1936, Кузнецов 1982). The growth of lawn and hummock level patches on wetter surfaces begins to dam the water flow, and thus the patterns differentiate. On the receiver segment, the process works mainly on the wet tall-sedge level, where sedge (mainly *Carex lasiocarpa*) tussocks with mosses (mainly *Sphagnum papillosum*) on their roots form the starting points of a string. The same processes can also form patterning on donor segments and poorer parts of receiver segments, where water flow is limited. Under these conditions, the tussocks of *Eriophorum vaginatum* or *Scheuchzeria*, together with some sedges growing on lawn or carpet level, can start the process. Where the patterning develops on lawn level, the regressive formation of wet lags can be larger than in other cases.

The direction of water flow determines the direction of patterning and so an effect of water flow rate on the peat growth rate could explain the first stages of pattern forming. Evidently, the separate patches of lawn or hummock level can merge if the growth of peat-forming vegetation between the patches is stronger than on either side of them. Tussocks of sedges, with *Sphagnum* mosses on their roots, typically grow densely between larger patches of lawn level on the central parts young aapa mires (Fig 3A). The patterning could thus be said to be resultant of interaction of vascular plants and *Sphagnum* mosses (Malmer & al. 1994). The sedges and herbs can grow more vigorously when the water flow intensifies as it gushes through a narrower pathway. The *Sphagnum* mosses may then reach the elevated root sites of the vascular plants, and the formed obstacle with diplotelmic nature may cause wetting (Couwenberg & Joosten 2005) Briefly, if a stronger flow of water increases the peat growth locally, the growth must block the water pathways and thus create patterning.

The microtopographic patterning develops together with large-scale hydrotopography, and our studies of peat profiles support the idea that the large-scale division to donor and receiver segments is quite stable during the development of aapa mire systems (Rehell et al. 2010). Local shifts in water flowing pathways and lateral spreading of vegetation units, however, take place. In some profiles, it is possible to observe peat layers with typical characters of receiver segment changing into layers with characters of donor segment or vice versa. From this data it is, however, not possible to more closely assess how the relative areas of the two segments develop in time.

Patterning can develop in different hydrological situations of a mire system, ranging from bogs on the water divide to the strongly flowing central parts of aapa mires (Sjörs 1990). However, large parts of the mire remain unpatterned. These include large and monotonous lawn and hummock level lobes on the donor segments of aapa mire massifs, where wetter carpet level patches tend to form narrow soaks between the lobes (Laitinen & al. 2007). This might be due to the similar rate in growth in hummock-, lawn and carpet levels in these conditions, in spite of temporary waterlogged situations in the wetter parts (Sjörs 1990). It is also possible that the growth of sedges and other vascular plants on those *Sphagnum*-dominated carpets is too weak to start the formation of strings. Another, very different type of unpatterned mire can be found in the lowest parts of the older aapa mire massifs, the wet outlet fens (Laitinen & al. 2007), on which the structure resembles that of the wet tall-sedge level typical of the youngest mires. These fens are wet soaks with very lush sedge and herb vegetation and small, separate patches of lawn that do not form coherent strings. These are the parts of the mire system with the most intensified water flow, and typically also parts that retain a large amount of groundwater. The lack of patterning can be considered to be due to the percolation character (Couwenberg & Joosten 2005) with unclear acrotelm-catotelm boundary and also to a smaller water table fluctuation (Ivanov 1981, Belyea & Clymo 2001).

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The beginning of agriculture in Swedish Lapland

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Introduction

The purpose of this article is to understand the first argicultural settlers in Lapland: Where did they come from? What motivated them to start agriculture in Lapland? What was important when choosing more precisely where to settle? As we will see sedge hay from mires was one of the most important things (Fig. 1), and that makes this study relevant in the context of respecting and wanting to preserve the mires.

First some voices from the 1700s and 1800s concerning our questions. Linné (2004:47 [1732]) wrote: "Lapland is at many places inhabited by settlers, *they are Finns*, that here at the *King's command and allowance* settle, clearing fields and meadows, which give some taxes to the Crown, being besides that free from all extra expenses, like the Saamis, keeping neither soldier nor marine soldier, being just as content whether it is peace or war, because they don´t have to pay any extra taxes."

Laestadius (1981: 83 [1824]) wrote: "But what I wanted to say is that most settlers in Lapland are Swedes and descend in part from Väster- and Norrbotten, in part from Ångermanland, even from Småland. But in northern Lapland as in Enontekis, Juckasjerfvi, until *Jellivare*, settlers descend from Finland. Nonetheless I state, that many of the oldest dwelling sites have been chosen by the Sami. Because this is how it happens if a fisher Sami lives at the shore of a lake, then the closest settler asks which kind of fishing water there is, if there are possibilities for meadows and forests. And when the Sami openheartedly tells the circumstances, the settler is quickly ready to register the place."

Linné wrote his text as a description of one of his journeys and Laestadius wrote his text as an argument for more settlements in Lapland, calling for agricultural drainage of mires, which he considered wise land use. Both these writers had use of natural resources as an aim rather than conservation but that doesn´t make their testimony less valid to us. Both of them mention meadows as important for the early settlers.

For example Pettersson (1941, 1944, 1946) and Gustafson & Gustafson (2003) have made statements about the settlers. Are they both right when one says that the settlers were Finns and the other says that they were Swedes? If so, how is it possible? It is possible that Finns from eastern Finland can arrive before the local Swedes and Samis. I have even read overviews over Lapland's history were it is stated that the first agricultral settlers were Samis (Isaksson 2001). In this article I try to explore the

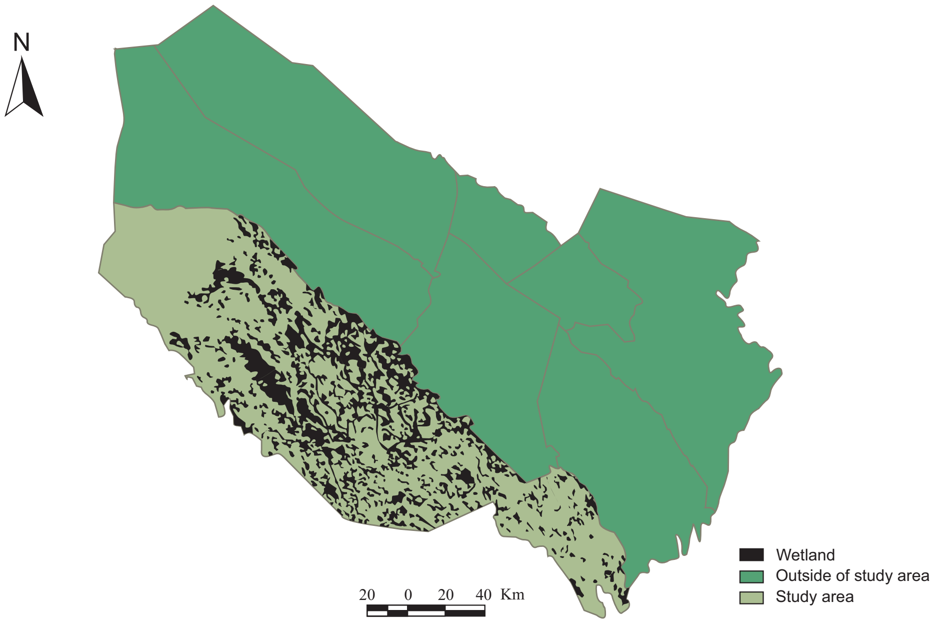

Figure 1. Distribution of mires (black) in the study area.

who, how and why of the settlers. Since the whole of Lapland is too much for the study, I have chosen a study area, originally for my master thesis in Physical Geography (Ingelsson 1999).

Åsele

According to Westerdahl (1986) the first three settlements in Åsele lappmark were in Gafsele (three farms), Hälla (two farms) and Noret (one farm, Saami settler) (For names of places see Fig. 2). Combining information given in Sjöberg (1999) and Gothe (1948) one can see that those in Gafsele and Hälla came from the same Finn family from the border area of the parish Ådal-liden and Anundsjö-villages Omsjö and Grundtjärn.

The Finns had already lived in Ångermanland during several generations (Gothe1948). The first settlers in what became Åsele parish were the finns Nils Andersson, his wife Ella Henriksdotter and their halfgrown children, five daughters and one son (Gavelin 1966). Gothe (1948) mentions four daughters and one son. They founded the village Gafsele. The son married a woman from a Finnish family, but all of the daughters who married, married Swedes. Some of the inmarried Swedes were quite successful. They became overseers (policemen), parlament repesentatives and judges for this new society, of course combining those jobs with the basic life-support from agriculture. The special career opportunities at those early times could indeed have been a motivation to immigrate to Lapland.

The most renowned son-in-law of the Gafsele Finns was Ingel Persson (b 1675). He became the first *länsman* (county constable). He and his wife Gertrud Nilsdotter took over the original estate number one from Gertruds parents. Their children were proud of coming from the first farm and chose themselves a new surname, Gavelin. One of the important tasks of the *länsman* was to coordinate the registrations of new

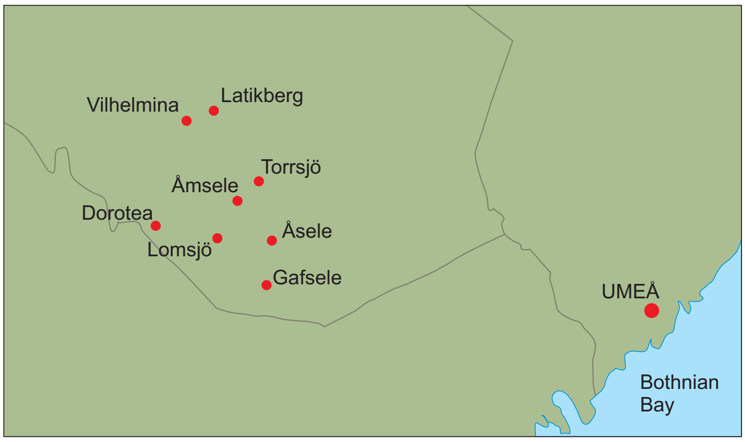

Figure 2. Names of places in the study area.

settlements. Per Ingelsson Gavelin who was the third *länsman* in the area received a medal for having checked on 60 settlements (Gothe 1948). When a new settler wanted to register a place, the sedge mires the family planned to use had to be registered too, in order to show that the attempt had a chance to succeed. And of course to avoid later uncertainty among the settlers, about which mires were whose (Lundkvist 1973).

Adam Kristofferson, the first Sami to become a settler had been taken from his family by force and put in school in Lycksele (Skytteanska skolan) (Lundkvist 1973). Probably the Swedes wanted him to become a priest or a missionary. However he became a parish clerk and settler (Westedahl 1986, Lundkvist1973).

Vilhelmina

Petterson (1941, 1944, 1946) described the oldest villages in Vilhelmina parish. For each village he lists the hay sources, often owned commonly by the village. Normally each village had 2-5 upland meadows and 11 sedge mires.

In order to understand my example from the Vilhelmina parish it´s necessary to first know something of how the Samis were organised. Laestadius (1981) divides the Sami into five categories.The Sami belonging to three of these categories, mountain Samis, half-mountain Samis and Forest Samis owned reindeer and had Lapp tax areas. The fourth category was the fisher Samis which lived from fishing and hunting. The fifth category was the poorest Samis, having nothing. The mountain Samis and the half-mountain Samis regularly travelled towards the coast to their winter pastures. The forest Samis mostly stayed in their own areas.

The legal status of the Lapp tax land was equivalent to ownership (Korpijaakko-Labba 1994).The Lapp tax lands were replaced by another system in 1886. The reform was inspired by the racistic argument that it was unnatural for the Samis to own land (Lundmark 1998).

We begin our story about the Vilhemina parish by getting acquinted with some of the forest Samis in the Åsele parish. Rissjölandet was a Lapp tax land situated between Åsele and Fredrika. Its inhabitants, the tax payer and his extended family were forest Samis. Their land contained a route on which the mountain Saami travelled with the reindeer to get to the winter pastures by the coast. The Sami word *rissnie* means moving route (Nilsson-Mankok 1981). The mountain Samis had to pay rent for passing. The first recorded owner of Rissjölandet (from the survey of 1695) had his name written as Jogell Jonsson but according to Westerdahl (1986) the name is probably Ingel Jonsson, because the next owner (assumed to be a son of the former) was Wanik Ingelsson Risberg. In the next generation, inheritance after Wanik was shifted by casting lots at Åsele court in 1748. Three sons wanted the land: Ingel, Arvid and Lars. Ingel got it. On maps from the 1770s one can see that Arvid too managed to get a smaller part, called Arvid Waniks land. In the 1770s we also find sons of Arvid and Lars moving away to become settlers. Most of them married women from agricultural background so that at least somebody in the family would have the "know-how" of this new lifestyle.

Let's follow Jon Larsson (b 1743) who founded a village called Latikberg. First he and his family tried to live as settlers in Bäsksele 1772-1779. They looked at a place to settle in what become Latikberg as early as 1777 but didn´t move in until 1780 (Gustafson & Gustafson 2003).

Jon Larsson had a neighbour in Bäsksele, Elias Hansson (b.1743). In Latikberg he eventually got another neighbour Mats Hansson (Gavelin 2001, Gustafson & Gustafson 2003.) The two men named Hansson were twins. They were farmer sons from Fjällsjö parish in the province of Ångermanland. Later in 1789 a Saami, Nils Andersson Bäsk in Bäsksele, who had half the Lapp tax land Bäsksjölandet sold it to eight settlers in three villages, Jon Larsson and the Hansson twins were among the buyers (Pettersson, 1941).

Already when getting his new neighbour, Jon Larsson wrote to the authorities about how to share the mires with his neighbour. After ten years they both signed a agreement of how to share. However, three years after the agreement, Mats in turn wrote to complain that the agreement had not been put fully in practice, adding that he didn´t want any court fight. It´s not known what happened in response to Mats Hansson´s letter (Gustafson & Gustafson 2003).

Lundkvist (1973) only mentioned one of the twins, Mats Hansson. Lundkvist also wrote that the father of Mats Hansson, Hans Matsson, was a Finn who had come travelling from Ragunda in Jämtland. I have noticed that Lundkvist elsewhere puts the label Finn also on part-Finns even after he himself has explained their ancestry. It is mentioned elsewhere (Olofsson 1990, Tillberg 2005) that Hans Matsson was born in Jämtland (but not in Ragunda parish) and that his paternal grandfather was a finn Mats Pålsson (b 1609), who arrived in Sweden 1635 or 1637 (Gothe 1948, Tillberg 2005). After that at least two of the inmarried women in that line were Swedish, from old farms. For example Maria Isaksdotter, mother of the twins, lived all her life at the same farm. She married when she was 15, which was early even with the culture of that time. At that time her father was old, he lived to the age 86 years, and needed help with the farm. Maria was the youngest child of her father. The farm was taken care of at that time by Maria´s cousin Erik Eliasson (b 1699) and his wife and their children. Maria married Erik, and his family had to move and become settlers in Lapland. Their village was Lomsjön in Åsele parish. Fortunately Erik´s wife was related to some Finnish settlers on her father's side so they probably had a support network (Gavelin 1966). Mats Hansson´s wife was his second cousin, Susanna Ersdotter from Lomsjön. She had an interesting long life. After Mats died she was married once more, then in old age she lived in the household of a granddaugher, who was noted to have married a Russian (Gustafson &Gustafson 2003).

Latikberg and other names of places.

In the name Latikberg, the part Latik is clearly of Sami origin. But what does it mean? Gustafson & Gustafson (2001) think that is means cloudberry (*Rubus chamaemorus*). Petterson (1946) was of the same opinion. The Sami word for cloudberries is *lattegeh* (Wiinka 1980). Wiinka &Wiinka (1999) give the name *luöttekevaarie* for northern, southern and central Latikberg. The first part of the name comes from Luöttet: to divide. Their commentary to the name: the mountain is divided (Wiinka & Wiinka 1999). Collinder has a similar word in his dictionary of Lappish place names in Sweden. I think that for moving Samis, toponyms describing landmarks are the most useful. Which perspective did Jon Larsson have? Two more reasons to trust the Wiinka couple, first BertilWiinka has Ume Saami as his mother-tongue and he learned most of the place names from his grandparents. Second reason in their book, they have many more examples of names being mistranslated by people who only know a few words of Sami language.

Another interesting place name in the region is Torvsjö, in Åsele parish. It looks like a Swedish name meaning "Peat lake". But the priest Jonas Nensén wrote in his notes that the original Saami name was *Tervetsjaurie*. Nenséns notes are at Uppsala university library, but I have seen copies at the DAUM archive in Umeå. Westerdahl (1986) has added the comment that *Tervetsjaurie* could mean 'tar lake'.

In order to show that changes of meaning "in translation" not always go from something unrelated to mires to concepts connected with mires, I give an example which I personally learned from Bertil Wiinka. In the name Arjeplog (Arjeplog is a town further north in Lapland) the end part is not Swedish *plog* meaning 'plough' but Sami *pluövie* meaning ' wet mire". Most Sami dictionaries I have looked at have *pluövie* as similar with that meaning.

Dorotea

The first settler in what later became the Dorotea parish was the Sweden-born Finn, Jon Ersson Kiervel from the province of Jämtland. His last name Kiervel is a swedification of the family name Kervelainen. His wife had the Finnish family name Hokkinen. The village they founded was Svanaby, also called Svanvattnet. Usually the Finnish family names where not registered on the Swedish side, but this and a few others names in the Dorotea parish and in Jämtland are exceptions (Gothe 1948, Sundström 1977). Choosing a place, only a small stony farm was possible in 1713. Sedge meadows in mires within appropriate distance were the most important thing (Sundström 1977, Sandqvist 1995).

Two of the Samis, Thomas Jacobsson and Olof Sakrisson, of the area complained at the court in Åsele already in 1715. They didn't want a settler, because their Lapp tax land was so small (Sundström 1977). The court tried to be neutral which in pratice turned out to be of advantage for Kiervel.

Twenty years later the Samis complained again that the Finnish settler in Svanavattnet took too much fish from that lake not leaving them their share (Gothe 1948). One reason for the Sami to complain is that their reindeer also needed the mires as summer pasture. One common trouble was that the reindeer tore the drying hay in search for fodder (Gothe 1948).

Ormsjön is a village founded by the Carolin soldier Johan Olofsson Nyberg from Hammerdal in Jämtland. One of his grandchildren told the local history researching priest Jonas Nensén that his grandfather knew Finnish magic. (Sundström 1977).One can wonder if there are more reasons for giving him the Finn label he often has in historical literature (Sundström 1977, Gothe 1948). Johan Olofsson Nyberg survived the 1718 home-march from Norway through the mountains. His friend drummer Samuel Turunen Mört (b 1693) from Raahe, Finland, also survived but froze his feet badly (Sundström 1977). Turunen stayed the rest of his live in Hammerdal, Jämtland. But his sons having already gotten their soldiers' surnames, decided that it was better to escape the fate of becoming soldiers. They moved to Ormsjön where they married daughters of Johan Olofsson Nyberg. Jon Larsson's cousin Sjul Arvidsson married a girl from Ormsjön, probably also a daughter of Johan Olofsson Nyberg (Gavelin 2001, Sundström 1977).

Genetics and ethnicity.

Using seven indicators found in blood samples, and comparing with reference samples from "central" Sweden, a Sami centre of education in Jokkmokk, and a Finnish reference sample from Oulu, Nylander (1992) estimates the degree of Finnish origin in the study area to be 20%. Both investigation areas in Åsele: Dorotea and Fredrika parishes (as one area) and Vilhelmina parish get the same low degree for Sami origin, 1-2 %. Interestingly, the neighbouring river valley with Lycksele, Stensele and Sorsele parishes gets only 0-3% Finnish origins is his estimates, in spite of the fact that the inhabitants of Lycksele are proud of their Finnish ancestor Hilduinen, (there is a statue of the Hilduinen family in the town of Lycksele). However, making such a study reliable is difficult. The first problem is the representativity of the reference samples; Nylander (1992) admits that Finnish influence in central Sweden is historically known, and, on the other hand, the Oulu Finns might have Sami ancestors too.

But the main conclusion is that in the whole of Lapland there is a mixture of Swedish, Finnish and Sami ancestry, and that the measured frequencies of indicators vary depending on which river valley is studied.

The personal feeling of ethnicity the historical persons had, we can never determine. However, in my study area the Finn label stayed long. Villages started by Finns were referred to as Finn villages despite some generations of marrying Swedes (Lundkvist 1973, Gothe 1948).

Samis on the other hand were accepted as Swedes as soon as they where successful with their agriculture. Pettersson (printed 1999, manuscript from 1930s) describes with diary details a settler couple of Sami origin. He describes them helping migrant Samis and the migrant Samis returning the favour by taking efforts to avoid the reindeers getting near the settlers' hay mires. Petterson's choice of words is interesting:"The Sami asked the Swedes on which side they were harvesting hay this year?"

Sjaggo (2003) and Mikaelsson & Hanes (2005) show a different picture for Samis in agriculture in their region Jokkmokk and Överluleå parishes. There the settled Samis apparently preferred to intermarry, for up to five generations, despite having other agricultural youth to choose among.

Source criticism

When reading about history, it is important to critcize the sources. When two books give oppostive views, which one would you trust or maybe trust none? Wedin (2001) writes that one of the early Finns in the Province of Medelpad, (at Kölsjön, Hassela parish) Per Andersson Tarvainen has been traced thanks to his surname to Muhluniemi farm near the Finnish town Äänekoski. The farm was owned 1553-1590 by Antti Antinpoika Tarvainen and 1591-1597 by Pekka Antinpoika Tarvainen, who probably is the settler at Kölsjön. Evidence of the name Tarvainen near Kölsjön is plentiful.

Sjöberg (1999) on the other hand hints that the first Finnish settler in Omsjön (Anders Andersson, arrived 1590), Ångermanland could be also from Äänekoski.

Rut Gavelin (1966) I´d like to criticize in another way, I think that she, when writing of Gafsele, is too favourable towards her ancestor Ingel Persson (b1675). Lundkvist (1973) displays the Gavelin family in a different light.

I too have mainly written positive things about my ancestors on my paternal grandfather's side. I do think however that the lifestyle factor is general for the whole of Lapland, because of the environment. My main concern was to understand the history of a region I discovered on a mire exploring journey.

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Moss diversity in the mires of the Maanselkä water divide

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Introduction

The aim of the present study is to investigate the diversity of mosses in mires situated in the central part of the Maanselkä ridge, which basically straddles the Finnish-Russian Karelian border. Bryological surveys were carried out on both sides of the ridge, in the protected areas of Karelia (Kalevala National Park and Kostomuksha Strict Nature Reserve) and Finland (Juortanansalo-Lapinsuo Mire Reserve and Elimyssalo Nature Reserve) (Fig. 1). Surveys in Karelia were done in the Kpoc (Karelia pomorica occidentalis) biogeographic province, and in Finland in the Ok (Ostrobottnia kajanensis) province (Mela & Cajander 1906). The dominant type of terrain in Maanselkä is north-taiga, hilly-ridge, moderately paludified, where tectonic denudation genesis has given rise to complexes of glacial formations and prevalent pine habitats (Gromtsev et al. 1997, 2002). The natural setting in Finland and Karelia are similar, namely, the degree of paludification is about the same (30%), mires of different types are found in both areas, an essential component of most of them is mosses.

Study area

The Maanselkä ridge extends from the north-east of Finland to the south of the Republic of Karelia; the middle of the ridge runs along the border with Russia and a spur of Maanselkä in the West Karelian upland, stretches in a NW–SE direction. The highest point of Maanselkä (577 m) is situated in the north-west of Karelia, where the absolute elevations of the ridge's central and southern parts reach 200–300 m and 200 m respectively. The Maanselkä ridge is a water divide because it stands in between the White and Baltic seas (Fig. 1).

The Kalevala National Park, 74 400 ha in total area, was designated in 2006 after 11 years of assuming the status of a planned protected area. The mission of the park is to conserve large areas of unique pine forests, as well as the surviving fragments of the natural and cultural landscapes in the park that memorialize and celebrate the Kalevala epic. A significant proportion of the territory is made up of mires and wetlands (20–30% in the eastern and 40–60% in the western portions of the park). Mesotrophic and meso-oligotrophic herb-Sphagnum massifs prevail within the mire complex systems. Oligotrophic bogs occupy minor areas, and hardly any aapa mires with a distinct pattern of string-flark complexes and moss-free flarks are present (Kuznetsov et al. 2000).

Figure1. Outline map of the investigated protected areas. 1 = Kalevala National Park;2 = Friendship Nature Reserve: 2a = Kostomuksha Strict Nature Reserve, 2b = Juortanansalo-Lapinsuo Mire Reserve, 2c = Iso-Palonen and Maariansärkät Nature Reserve, 2d = Lentua Nature Reserve, 2e = Elimyssalo Nature Reserve, 2f = Ulvinsalo Strict Nature Reserve.

Kostomuksha Strict Nature Reserve, 47 569 ha in size, was founded in 1983 to conserve a model area of the European Russian northern taiga (Хохлова и др., 2000). Approximately 20% of the territory consists of mires: Karelian concentric aapa mires, mesotrophic dwarf shrub-herb-Sphagnum mires, oligotrophic Sphagnum-dominated string-flark and pine-dwarf shrub-Sphagnum mires (Kolomytsev & Kuznetsov 1997). There are very few classic aapa mires with well-developed string-flark complexes in the reserve.

The Friendship Nature Reserve established in 1990. It consists of the Kostomuksha Strict Nature Reserve on the Russian side of the border, and five Nature Reserves on the Finnish side of the border (Fig.1): Juortanansalo-Lapinsuo Mire Reserve (3 700 ha), Iso-Palonen and Maariansärkät Nature Reserve (4 000 ha), Lentua Nature Reserve (5 100 ha), Elimyssalo Nature Reserve (7 300 ha), and Ulvinsalo Strict Nature Reserve (2 500 ha).

Juortanansalo-Lapinsuo Mire Reserve was established in 1988. It comprises a large mire complex system made up of poor aapamires and ombrotrophic bogs, and pristine forests on mineral soil islands (Кузнецов и др., 1999; Heikkila & Lindholm 2003). Elimyssalo Nature Reserve, established in 1990, contains old-growth forests, numerous small lakes and a large diversity of small mires – ombrotrophic, oligotrophic, meso-eutrophic, and aapamires (Heikkilä et al. 1997; Heikkilä & Lindholm 2003; Tahvanainen et al. 2002).

Materials and methods

Sampling was carried out by the author in Kalevala National Park, Kostomukshsky Strict Nature Reserve, Juortanansalo-Lapinsuo Mire Reserve and Elimyssalo Nature Reserve in the years1995–1998. Moss flora was studied by the route method, where the samples were treated using the comparative anatomical-morphological method. The species composition of moss flora originating from mires located at the centre of the Maanselkä ridge was chiefly determined using the author's own data (Бойчук, 1998, 2001; Boychuk 2003), complemented by other published sources (Кузнецов и др., 1999; Heikkilä et al. 1997; Tahvanainen et al. 2002). The taxonomy used follows Hill et al. 2006. All moss samples are stored at the Karelian Research Centre Herbarium (PTZ).

Results and discussion

The moss flora of Karelian mires comprises 133 species (Кузнецов, Максимов, 2005), i.e. 28.3% of the total number of moss species found in Karelia (470: after Максимов, 2006). The mire moss flora in Finland, according to Eurola & Huttunen (2006), is made up of 130 species, i.e. 19.7% of Finland's total moss flora (661: after Ulvinen et al. 2002). It can be concluded that the mire moss floras of Karelia and Finland are quite alike (113 shared species), probably due to the similarity of the natural settings and mire types.

The number of moss species recorded for mires within Kalevala National Park, Kostomuksha Strict Nature Reserve, Juortanansalo-Lapinsuo Mire Reserve and Elimyssalo Nature Reserve is 83, 87, 65 and 62, respectively (Table 1).

The combined number of moss species in the mires of the four protected areas at the centre of the Maanselkä ridge is 93, of which 90 are present within Kalevala National Park and Kostomuksha Strict Nature Reserve, and 78 within Juortanansalo-Lapinsuo Mire Reserve and Elimyssalo Nature Reserve. The number of shared species is 75. Only three of the species (*Dicranum leioneuron, Pseudocalliergon trifarium* and *Sphagnum annulatum*) known to occur on the Finnish side of the border have not been found in Russian Karelia. *Dicranum leioneuron*, a rare (regionally threatened) species in Finland (Ulvinen et al. 2002), has not yet been detected in Karelia, but records of the species are known for the north-western Russia (Ignatov et al. 2006). *Pseudocalliergon trifarium* prefers rich eutrophic fens (Härkösuo in Elimyssalo Nature Reserve), of which there are very few in Kalevala National Park and Kostomuksha Strict Nature Reserve. *Sphagnum annulatum* was once found to occur in northern Karelia (Максимов, 2003). Surveys conducted on the Finnish side of the border have not detected 15 of the species known to occur in Russian Karelia, but almost all of them with two exceptions (*Pohlia bulbifera* and *Splachnum rubrum*) are known to occur in the mires of Finland, as well (Eurola & Huttunen 2006; Heikkilä 2006).

Because the bedrock and soils in the four protected areas are rather poor, there prevail ombrotrophic and oligotrophic mires. Frequently occurring *Sphagnum angustifolium, S. balticum, S. fuscum, S. lindbergii, S. magellanicum* and *S. majus*, and less frequently occurring *S. compactum, S. rubellum* and *S. tenellum* have been spotted in all four protected areas. *Sphagnum cuspidatum* has so far been recorded only for the Kostomuksha Strict Nature Reserve. In contrast to the investigated Karelian protected areas, the Finnish protected areas have a significantly greater number of aapa mires, although they are mostly poor, without a distinct pattern of strings and flarks. Compared to the Finnish protected areas, the Karelian protected areas more commonly feature meso-oligotrophic and mesotrophic mires dominated by *Sphagnum fallax* and *S. papillosum*.

Meso-eutrophic mire sites occupied by herb-moss communities occur in mires of the surveyed areas on both sides of the Maanselkä ridge. Typical species recorded for these sites consist of *Sphagnum flexuosum, S. obtusum, S. platyphyllum, S. riparium, S. subsecundum, S. teres, S. warnstorfii, Calliergon giganteum, Warnstorfia exannulata, Scorpidium scorpioides, Cinclidium stygium* and *Campylium stellatum* Sites with groundwater discharge are inhabited by *Brachythecium rivulare, Bryum pseudotriquetrum, B. weigelii, Rhizomnium magnifolium, Philonotis fontana, Calliergonella cuspidata, Paludella squarrosa* and *Tomentypnum nitens*.

Two rare moss species,*Sphagnum auriculatum* and *S. subnitens*, from the mires of investigated Karelian protected areas are listed in the Red Data Book of Karelia (Ивантер & Кузнецов, 1995) and Red Data Book of East Fennoscandia (Kotiranta et al. 1998).

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Table 1
Distribution of moss species within four protected areas: Kalevala National Park (Kal), Kostomuksha Strict Nature Reserve (Kos), Juortanansalo-Lapinsuo Mire Reserve (Juo) and Elimyssalo Nature Reserve (Eli). C = common, s = sparse, r = rare.

Species	Kal	Kos	Juo	Eli
Aulacomnium palustre (Hedw.) Schwägr.	c	c	c	c
Brachythecium rivulare Schimp.	s	r		s
Bryum pseudotriquetrum (Hedw.) P.Gaertn. et al.	s	s	r	
Bryum weigelii Spreng.	s	r	r	s
Calliergon cordifolium (Hedw.) Kindb.	c	c	s	
Calliergon giganteum (Schimp.) Kindb.	r	r	r	
Calliergon richardsonii (Mitt.) Kindb.	r	r	r	
Calliergonella cuspidata (Hedw.) Loeske		r		s
Calliergonella lindbergii (Mitt.) Hedenäs	s	s		
Campylium stellatum (Hedw.) Lange & C.E.O.Jensen	s	s	r	s
Cinclidium stygium Sw.	r		r	r
Climacium dendroides (Hedw.) F.Weber & D.Mohr.	c	c		
Dicranella cerviculata (Hedw.) Schimp.	r	r	r	
Dicranum angustum Lindb.		r		
Dicranum bonjeanii De Not.	s	r	r	s
Dicranum fuscescens Sm.	s	s	s	
Dicranum leioneuron Kindb.			r	s
Dicranum majus Sm.	s	s	s	s
Dicranum polysetum Sw.	c	c	c	c
Dicranum scoparium Hedw.	c	c	c	c
Dicranum undulatum Schrad. ex Brid.	c	c	c	c
Drepanocladus aduncus (Hedw.) Warnst.		r		
Hamatocaulis vernicosus (Mitt.) Hedenäs	r			
Helodium blandowii (F.Weber & D.Mohr) Warnst.	s	s	r	s
Hylocomiastrum umbratum (Hedw.) M.Fleisch.	r			s
Hylocomium splendens (Hedw.) Schimp.	c	c	c	c
Loeskypnum badium (Hartm.) H.K.G.Paul	s	s	s	s
Meesia triquetra (L. ex Jolycl.) Ångstr.	s	r		
Paludella squarrosa (Hedw.) Brid.	s	s	s	s
Philonotis fontana (Hedw.) Brid.	s	s	r	s
Plagiomnium ellipticum (Brid.) T.J.Kop.	c	c	s	c
Plagiothecium laetum Schimp.	s	s	s	
Pleurozium schreberi (Willd. Ex Brid.) Mitt.	c	c	c	c
Pohlia bulbifera (Warnst.) Warnst.	r	r		
Pohlia nutans (Hedw.) Lindb.	c	c	c	c
Polytrichastrum longisetum (Sw. ex Brid.) G.L.Sm.	s	s		
Polytrichum commune Hedw.	c	c	c	c
Polytrichum strictum Menzies ex Brid.	c	c	c	c
Polytrichum swartzii Hartm.	s	s	s	
Pseudobryum cinclidioides (Huebener) T.J.Kop.	s	s	s	
Pseudocalliergon trifarium (F.Weber & D.Mohr) Loeske				s
Rhizomnium magnifolium (Horik.) T.J.Kop.	s	s		s
Rhizomnium pseudopunctatum (Bruch & Schimp.) T.J.Kop.	s	s	s	s
Rhizomnium punctatum (Hedw.) T.J.Kop.	r	s		
Rhytidiadelphus subpinnatus (Lindb.) T.J.Kop.		r		s
Rhytidiadelphus triquetrus (Hedw.) Warnst.	s	s	s	s

Sanionia uncinata (Hedw.) Loeske	c	c	c	
Scorpidium revolvens (Sw. ex anon.) Rubers	s	s	s	s
Scorpidium scorpioides (Hedw.) Limpr.	s	r		s
Sphagnum angustifolium (C.E.O.Jensen ex Russow) C.E.O.Jensen	c	c	c	c
Sphagnum annulatum H.Lindb. ex Warnst.				r
Sphagnum aongstroemii C.Hartm.	s	s	s	s
Sphagnum auriculatum Schimp.	r	r		
Sphagnum balticum (Russow) C.E.O.Jensen	c	c	c	c
Sphagnum capillifolium (Ehrh.) Hedw.	c	c	c	
Sphagnum centrale C.E.O.Jensen	c	c	s	c
Sphagnum compactum Lam. & DC.	s	s	s	s
Sphagnum contortum Schultz	r	r		s
Sphagnum cuspidatum Ehrh. ex Hoffm.		r		
Sphagnum fallax (H.Klinggr.)H.Klinggr.	c	c	c	c
Sphagnum fimbriatum Wilson	s	s	s	
Sphagnum flexuosum Dozy & Molk.	s	s	s	s
Sphagnum fuscum (Schimp.) H.Klinggr.	c	c	c	c
Sphagnum girgensohnii Russow	c	c	c	c
Sphagnum inundatum Russow	r	r		
Sphagnum jensenii H.Lindb.	s	s	s	s
Sphagnum lindbergii Schimp.	s	s	s	s
Sphagnum magellanicum Brid.	c	c	c	c
Sphagnum majus (Russow) C.E.O.Jensen	c	c	c	c
Sphagnum obtusum Warnst.	s	r	r	
Sphagnum papillosum Lindb.	c	c	s	c
Sphagnum platyphyllum (Lindb. ex Braithw.) Warnst.	s	s		s
Sphagnum pulchrum (Lindb. ex Braithw.) Warnst.	s	s		s
Sphagnum riparium Ångstr.	c	c	s	c
Sphagnum rubellum Wilson	r	r	s	s
Sphagnum russowii Warnst.	c	c	c	c
Sphagnum squarrosum Crome	c	c	s	
Sphagnum subfulvum Sjors	s	s	s	s
Sphagnum subnitens Russow & Warnst.		r		
Sphagnum subsecundum Nees	s	s	s	s
Sphagnum tenellum (Brid.) Pers. ex Brid.	s	r	r	r
Sphagnum teres (Schimp.) Ångstr.	s	s	s	s
Sphagnum warnstorfii Russow	c	s	s	c
Sphagnum wulfianum Girg.	r	s		
Splachnum ampullaceum Hedw.		r	r	
Splachnum rubrum Hedw.	r	r		
Splacnum luteum Hedw.	r	r	r	
Straminergon stramineum (Dicks. ex Brid.) Hedenäs	c	c	c	c
Tomentypnum nitens (Hedw.) Loeske	s	s	s	c
Warnstorfia exannulata (Schimp.) Loeske	c	c	c	c
Warnstorfia fluitans (Hedw.) Loeske	c	c	c	c
Warnstorfia procera (Renauld & Arnell) Tuom.	s	s		s
Warnstorfia sarmentosa (Wahlenb.) Hedenäs	s	s		s
Totally: 93	83	87	65	62

Vegetation studies and mapping in Juortanansalo mire reserve, eastern Finland

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Introduction

A project initiated with funding from the Academy of Finland was aimed to support mapping methods and help to harmonize approaches used in Russia and Finland. Earlier an article about the comparison of mapping methods in a small aapamire with highly diverse vegetation in Elimyssalo nature reserve in Kuhmo, eastern Finland was published (Galanina & Heikkilä 2007). This work is focused on a typical aapamire area in Juortanansalo mire reserve.

Juortanansalo-Lapinsuo mire reserve in Kuhmo (5436 ha), Eastern Finland, adjacent to the Finnish-Russian border, is a part of the Friendship Park nature reserve, created in 1990 (Fig. 1). This important mire and forest area belongs to the Natura 2000 network. In accordance with the Natura 2000 programme a plan for the extension of the reserve was made.

Figure 1. Location of the Juortanansalo-Lapinsuo mire reserve in the Nature Reserve Friendship.

Hilly landscapes with crystalline rocks of denudation-tectonic origin are typical for the whole region. Juortanansalo area is dominated by tonalites and migmatites (Gorkovets & Raevskaya, 2003). Fedorets and Morozova (2003) did soil studies: they recorded their spatial variation in Friendship Park. The soil fertility is low determinated by poor silicate bedrocks.

Juortanansalo mire reserve contains numerous relatively small mire massifs, which form a mosaic landscape pattern with mineral soil islands and ponds. Due to the varying hydrological conditions, different mire massif types and mire site type combinations have developed in the area.

The study area lies in the zone of Pohjanmaa aapa mires in the section of Kainuu (Ruuhijärvi 1960). It belongs to the middle boreal zone (Ahti et al. 1968). According to Russian literary sources (Юрковская & Паянская-Гвоздева, 1993) northern taiga forests are common for this latitude (64°N). Probably, the misunderstanding partly was caused by lack of data from Russian Karelia in 1970s, when most small-scale vegetation maps were prepared (T. Yurkovskaya, pers. comm.).

Three mires in Elimyssalo Nature Reserve, Friendship Park nearby Juortanansalo were studied earlier (Heikkilä et al. 1997). Comparison of their development and vegetation structure was made. Studied mires were two small aapa mires, typical of the region and a small eccentric bog. Both large bogs and aapamires are lacking in Kainuu region.

Mires and paludified forests of Kostomuksha Nature reserve, the Russian part of Friendship Park, were studied by Kolomytsev & Kuznetsov (1997). They describe different paludified landscape types and their mires. Thus, pine-dominated small-ridge-hilly landscape of intensively paludified crystalline basement terrains includes numerous mires in inter-hill depressions. They are aapamires, mesotrophic herb-sphagnum and dwarf-shrub bog complexes. Mires occur at absolute altitude of 195-200 m, relative altitude between mineral and paludified lands varying from 10-20 m. Mires originated from the small relic postglacial lakes.

It seems that Juortanansalo study area is similar to this landscape variation type. Difference between height level of relic mire lakes and hilltops is about 10-20 m. Relic lakes lie as high as Arolampi 236,9 m, Frederikinlampi 225,9 and Lampolampi 227,3 m. Common elevation is 240-250 m above sea level.

N. Katz (1948) described a province of mixed mires in Karelia. Swedish specialists used term "mixed mires" as well (Sjörs et al. 1965, Rydin et al. 1999). It is understandable, as we have to deal with heterogeneous complex mires which are small, numerous and diverse.

T. Yurkovskaya (1974) has studied neighbouring area on Russian side nearby Kontokkijarvi. A large-scale vegetation map covering36, 5 km^2 was made. Following mire types are recognized on Kontokkijarvi surroundings: eutrophic aapa, sedge mesotrophic mires, oligotrophic pine bogs, oligotrophic raised bogs with hummock-hollow complexes. Aapamires prevail; bogs occupy small limited area.

The purpose of this study was aimed to explore the landscape diversity and natural ecosystem mosaic on borderlands. The regular spatial structure of forests and mires was investigated. Nature regularities and landscape structure of border areas were recorded and confirmed by cartographic method. Mire types of the Juortanansalo nature reserve were studied and inventoried.

Materials and methods

Juortanansalo reserve preserves mainly mires and old-growth spruce forests on mineral soil islets. The diversity of mires can be analyzed and shown by cartographic methods. False colour infrared aerial photos and field work were used for mapping. Four mire massifs were investigated and mapped in scale 1: 20 000: the Arolampi mire massif (including a joint non-named mire) and three others: Lotvonsuo, Lamposuo and Frederikinlampi which are grouped together and form a mire system (Fig. 2). The mapping was made according to Russian mire research tradition, but in the final map the vegetation patterns were classified and named in the map legend according to Finnish school (See Galanina & Heikkilä 2007 for detailed description of methods).

Study sites for mapping purposes were chosen taking into account their site type diversity value. In a typical eastern Finnish mosaic landscape, like in Juortanansalo nature reserve, it is difficult to separate mire massifs and distinguish their borders. All the structural features can be seen on aerial photos and space images, so they are essential tools for the successful mapping.

Visual and field instrumental methods as well as GIS-technologies were used for distinguishing the patterns and calculating their areas. Arc GIS 9 program was used for the GIS analysis of the vegetation patterns. Making study profiles on Juortanansalo mires started the field work. Vegetation patterns distinguished from aerial photos were verified in the field and their limits were drawn in final place on the basis of field observations. Detailed studies were carried out by the method of geobotanic profiles from the mire margins to the remnant lakes and across the mires. 85 vegetation relevés (size 1m x 1 m) were prepared.

The mire site classification of Eurola and Kaakinen (1979) was used as a guide to Finnish mire type system as well as Eurola et al. (1994) and Laine & Vasander (2005). The nomenclature of vascular plants follows Hämet-Ahti & al. (1998) and that of bryophytes Ulvinen & al. (2002).

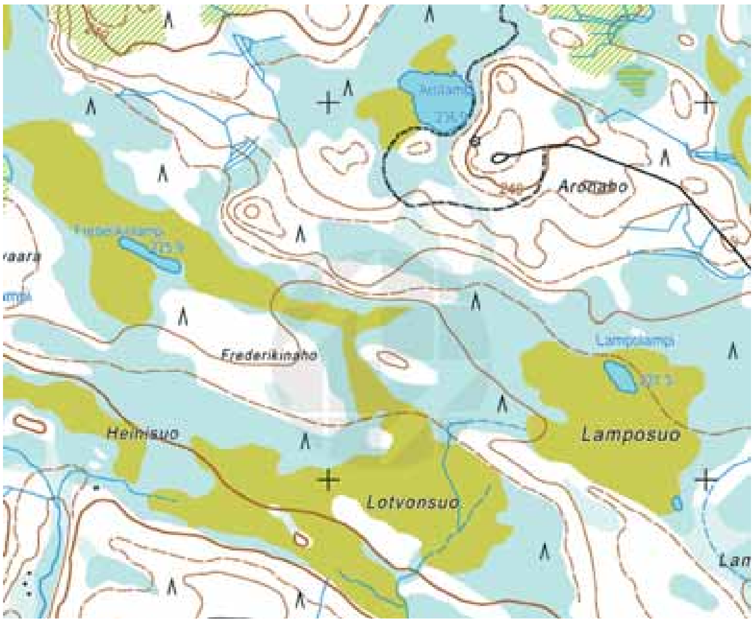


Figure 2. Topographic map of the study area showing names of places mentioned in the text. © Karttakeskus Oy, Lupa L 4659.

Results and discussion

The landscape of the study area in Juortanansalo was mapped focused on mires and their vegetation around the ponds Frederikinlampi and Lampolampi as well as in Lotvonsuo mire according to Finnish concept (Eurola et al. 1994) (Fig. 3). In the mapped area 22 different mire types were separated in the legend (Table 1). Aapamire complexes, intermediate fens, poor fens and pine mires occur in the study area. Old-growth spruce forests grow in the mineral soil islets.

Pine bogs with dwarf shrubs dominate in mire margins. There are narrow strips of spruce mires along the margins as well. Poor fens are widespread in the central parts of mire massifs. Intermediate flark fens and sedge fens can be found, too. Ombrotrophic carpets, lawns and hummocks that represent bog vegetation have a limited distribution. Bog hollows are not typical for the area.

Common bog species are pine, dwarf shrubs, *Eriophorum vaginatum* and *Trichophorum cespitosum*, and in wet places *Scheuchzeria palustris* and *Rhynchospora alba*. The only *Carex* species found in bogs is *C. limosa*, and in transitions to fen also *C. pauciflora* and *C. magellanica*. Боч & Смагин (1993) consider *Trichophorum cespitosum* to be an oligo-mesotrophic species as when going south, but in NW Russia this species becomes rare and seems to require more rich conditions. In Finland it is regarded as a bog species (Eurola & al. 1994).Bog vegetation was observed on Lamposuo (Fig. 4) and Frederikinlampi and Lotvonsuo margins (Table 1, legend numbers 5a, 6).

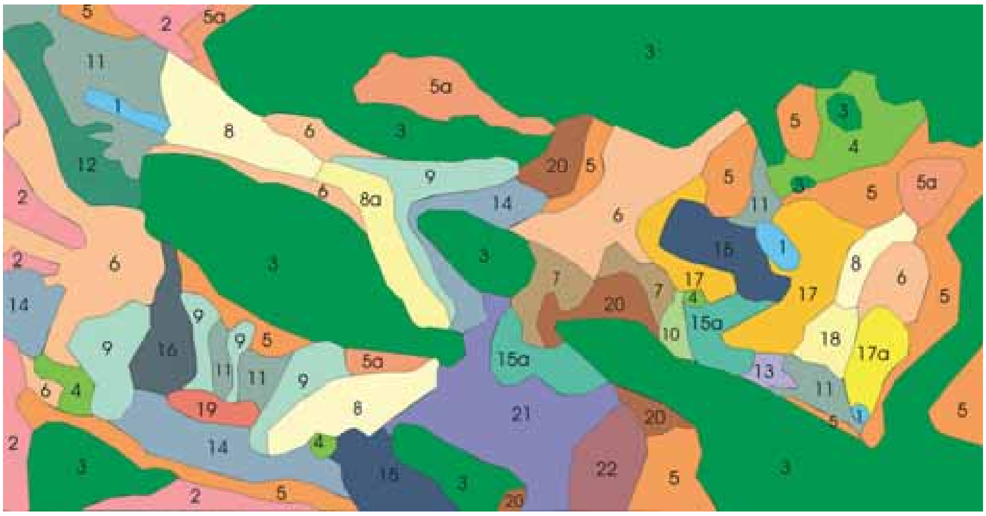
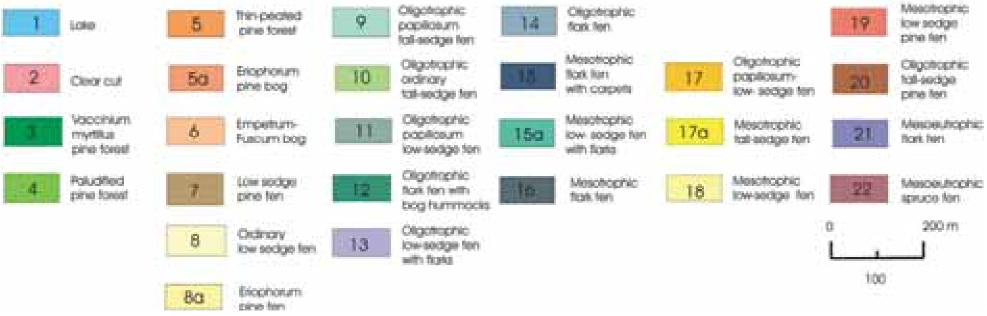


Figure 3. Vegetation map of the study area.

Table1. The legend of the vegetation map. Mapping units according to Eurola & al. (1994) and corresponding communities according to Russian vegetation classification school are presented. The area of each unit is given in hectares.



1	Lake
2	Clear cut
3	Vaccinium myrtillus pine forest
4	Paludified pine forest
5	Thin-peated pine forest
5a	Eriophorum pine bog
6	Empetrum-Fuscum bog
7	Low sedge pine fen
8	Ordinary low sedge fen
8a	Eriophorum pine fen
9	Oligotrophic papillosum tall-sedge fen
10	Oligotrophic ordinary tall-sedge fen
11	Oligotrophic papillosum low-sedge fen
12	Oligotrophic flark fen with bog hummocks
13	Oligotrophic low-sedge fen with flarks
14	Oligotrophic flark fen
15	Mesotrophic flark fen with carpets
15a	Mesotrophic low sedge fen with flarks
16	Mesotrophic flark fen
17	Oligotrophic papillosum-low-sedge fen
17a	Mesotrophic tall-sedge fen
18	Mesotrophic low-sedge fen
19	Mesotrophic low sedge pine fen
20	Oligotrophic tall-sedge pine fen
21	Mesoeutrophic flark fen
22	Mesoeutrophic spruce fen

Figure 4. Eriophorum pine bog. Lamposuo mire (Photos Olga Galanina).

Differentiation between fen and bog along the poor-rich gradient was given by Rydin et al. (1999). Following species are fen limit indicators: *Carex lasiocarpa*, *C. rostrata*, *Eriophorum angustifolium, Menyanthes trifoliata* and *Sphagnum fallax*. They can grow up to the border to the bog.

Poor fen vegetation is widespread in Juortanansalo reserve (Table 1, legend numbers 7, 8, 11, 14). Fen elements are similar to these in bogs. There are hummocks, lawns and carpets (Table 1, legend numbers 12, 13, 15 etc.).

The high hummocks occurring in some fens share many species with the bog hummocks. Examples are *Sphagnum fuscum*, *Dicranum bergeri* and *Polytrichum strictum* (Table 1, legend 15b). Typical of fen lawns are *Eriophorum vaginatum*, *Trichophorum cespitosum*, *Molinia caerulea* and several *Carex* species. In poor fens *Sphagnum compactum* and particularly *S. papillosum* in the lawns can be found most frequently (Table 1, legend numbers 11, 17). Lawns formed by *Eriophorum vaginatum* are most common (Fig. 5), those dominated by *Trichophorum cespitosum* have developed around Lampolampi lake in Lamposuo (Fig. 6). Wet carpets appear in a transitional site between Frederikinsuo and Lamposuo mires (Table 1, legend number 14) (Fig. 7).

Mud-bottom flarks have developed in wet sites of Lotvonsuo and Lamposuo mires (Table 1, legend number 15).

Oligotrophic fen communities are often characterized by dominance of tall sedges such as *Carex lasiocarpa* and *C. rostrata*. (Rydin et al., 1999). (Table 1, legend numbers 9, 10).

Intermediate fen communities are present in Juortanansalo as small patches dependent on small watercourses and spring influence (inside the legend number 19) and as a separete big pattern (21). Typical intermediate fen species recorded in Lotvonsuo are *Trichophorum alpinum*, *Parnassia palustris*, *Selaginella selaginoides*, *Juncus stygius*,

Figure 5. Poor low sedge fen by the pond Frederikinlampi.

Figure 6. Poor papillosum low-sedge fen by Lampolampi lake.

Figure 7. Poor flark fen. Frederikinlampi.

Tofieldia pusilla and bryophytes such as *Warnstorfia sarmentosa*, *Loeskypnum badium*, *Scorpidium revolvens*, *Paludella squarrosa* and *Sphagnum warnstorfii*. They grow together with common poor fen species. *S. subnitens* and *S. subfulvum* can be found in the lawns of intermediate fens (21).

In addition, there is more tall-growing vegetation (Table 1, legend number 20) and there are a few types of woody sites (numbers 19, 22), and a special flora around springs which cannot be shown on the map in this scale.

Studied mires are relatively small and their expansion is broken by a number of mineral islands. Mire plant communities often include the species such as *Maianthemum bifolium*, *Trientalis europaea*, *Equisetum sylvaticum*, *Carex nigra* and *C. globularis.* Woody species *Picea abies*, *Juniperus communis* and *Sorbus aucuparia* extend into open minerotrophic mires. The so-called mire margin – mire expanse gradient was observed (Sjörs, 1948).

As a result of the study, an original large-scale map with a number of vegetation patterns was prepared. The vegetation map shows the habitat diversity and it reflects the vegetation structure and spatial distribution of communities. The total mapped area was 122,8 hectares, 51,3 hectares of which was pine forests (including clear cuts 4,4 ha) and 0,8 ha water. Mires, which cover 70,7 ha, are represented by 19 mire types (Table 1). That means 3 mire site types per hectare in average. The most widespread mire vegetation types were thin-peated pine mires and Empetrum-fuscum bogs. Also low-sedge fens, oligotrophic papillosum tall-sedge fens, oligotrophic papillosum low-sedge fens, oligotrophic flark fens and meso-eutrophic flark fens covered almost 5 hectares each (Table 1). This kind of distribution and a list of prevailing sites are rather typical of Kainuu aapamires (Ruuhijärvi 1960). Oligotrophic raised bogs with a presence of hummock-hollow complexes were not recorded from Juortanansalo.

Conclusions

The studied area in Juortanansalo reveals a richness of mire site types on a relatively small territory. Different types of fens (mainly poor and intermediate sites) are the most common. Intermediate spruce and flark fens as well as small springs contribute to the total site diversity of the borderlands.

The vegetation map and particularly its legend based on Russian and Finnish traditions form a kind of "a bridge" between the different scientific schools of vegetation classification. The legend consists of mapping units that are mire sites after Eurola et al. (1994). Their interpretation according to Russian dominant vegetation classification approach is given. The presented table is a key for the understanding of the regularities of neighbouring territories of Finnish and Russian Karelia.

The studied mires have no evidences of forestry drainage; they are well preserved and representative for conservation and research purposes. The mires in Juortanansalo-Lapinsuo mire reserve are popular study sites of Finnish-Russian research cooperation; their official recognition as a part of the Friendship Park framework would be an important contribution to landscape and biodiversity preservation in Eastern Kainuu. The future attachment of this area to the Friendship Park increases the biodiversity for intermediate fens and their species in the Park.

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Holocene vegetation dynamics and carbon accumulation of two mires in Friendship Park, eastern Finland

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Introduction

The development of mires in the Finnish-Russian boundary zone has been thoroughly studied on the Russian side of the border in Kostomuksha town and its surrounding areas, as early as in the 1970s (Елина & Кузнецов 1977), and again in the 1990s (Kolomytsev & Kuznetsov 1997; Kuznetsov 2000). Additionally, at these times, Holocene vegetation dynamics was studied (Елина 1981). For the Finnish side of the boundary zone, published results on mire development have been very few (Heikkilä et al. 1997). Given that the only studies carried out so far were performed prior to radiocarbon dating (Kilpi 1937; Kanerva 1956), it is therefore important to augment the existing body of information on the Holocene development of mire and forest vegetation in the eastern Kainuu region. The biodiversity of this region is a direct consequence of the area's environmental history; the region's oldest mires, easterly located where the ice sheets first began to melt, hold the longest archive of natural history in Finland.

The boundary region gives unique possibilities for the comparison of Finnish and Russian mire research approaches. Studies in the region contribute to the work that is being done to enhance understanding of and planning efforts related to the Fennoscandian Green Belt along the Finnish-Russian border (Hokkanen et al. 2007), and are principal tasks of Friendship Park Research Centre.

Study area

The Finnish-Russian Friendship Nature Reserve includes Kostomuksha Strict Nature Reserve (*zapovednik*) on the Russian side of the border, and Friendship Park, consisting of five separate nature reserves, on the Finnish side (Fig. 1). It is located in the central part of the Maanselkä watershed area, a dissected tectonic denudation terrain; the numerous depressions in this terrain are filled with small mires, giving the effect of a mosaic of mires, watercourses and mineral soil forests.

The study area is situated in the middle boreal climatic-phytogeographical zone (Ahti et al. 1968; Tuhkanen 1984; Lindholm & Heikkilä 2006) and in the Archaean Karelian province of the Fennoscandian bedrock shield. Granite and gneiss form the bedrock (Luukkonen 1992; Gorkovets & Rayevskaya 2003). The mean annual rainfall is 600 mm and the mean annual temperature 1.2°C (Alalammi 1987). The mires are surrounded by drumlin formations oriented from NW to SE. On till soil there are

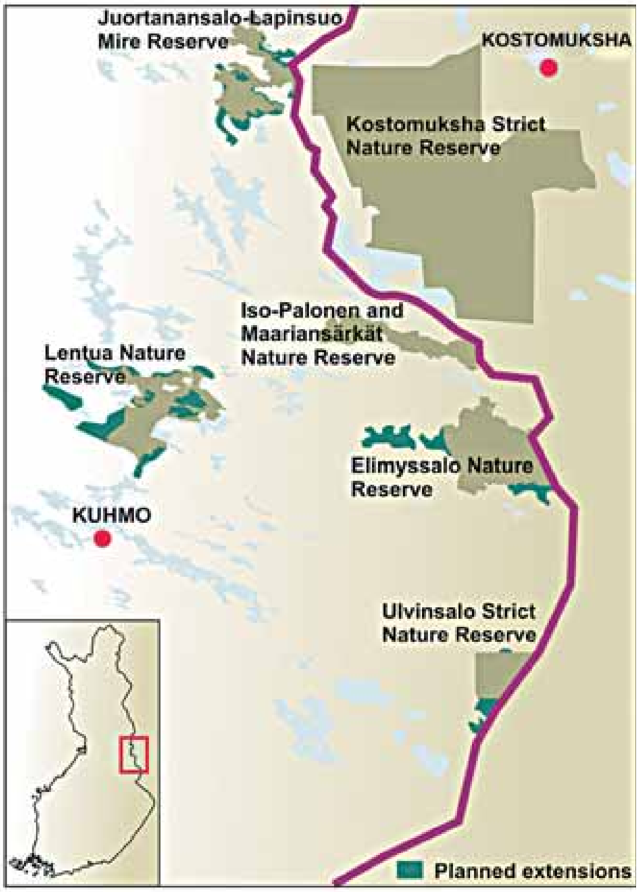

Figure 1. The location of the general study area and study sites within Friendship Park.

spruce-dominated forests of Myrtillus type, where the proportion of pine is 20%–30% of the canopy cover.

According to Katz's (Кац 1971) map of European mire provinces, the study area belongs to the Karelian-Finnish province of the middle taiga vegetation zone, where the mires are of mixed type. This kind of landscape was earlier described as a mire massif type, or the so-called Karelian mire complex (Auer 1922); however, the landscape is not comparable to the zones of bogs and aapa mires, because it is not climatic, being connected mainly with the relief. According to current mire zoning for Finland, the area belongs to the southern aapa mire zone (Ruuhijärvi 1988). In contrast, forest zoning in Russia fixes the study area in the northern taiga sector (Александрова & Юрковская 1989; Юрковская & Паянская-Гвоздева 1993), while mire zoning for Karelia defines it as lying within the district of Fennoscandian aapa mires of northern and central Karelia. (Kuznetsov 2003).

Härkösuo Mire

Härkösuo Mire, covering 20 ha, is located in the Elimyssalo Nature Reserve (64°12′N, 30°26′E; 235 m a.s.l.), in the municipality of Kuhmo (Fig. 1). The length of the mire, from east to west, is 1 000 m, and its mean width, from north to south, is 200 m. A small primary lake is located in the mire western end (Fig.2). The mire gently slopes and is mostly soligenous, and ground water influence is clear in the western part of the mire, in the southern margin. The opposite characterizes the south-eastern part

Figure 2. A view over Härkösuo Mire from the west (Photo: Suomen Ilmakuva Oy).

of the mire, where ground water flow is weak (Tahvanainen et al. 2002). The highly variable ecological conditions cause the mire vegetation to be very diverse (Fig. 2). Tahvanainen et al. (2002) divide Härkösuo Mire into five main vegetation classes (four types of fens, ranging from extremely poor to rich, and marginal pine bogs, containing a lot of internal variability), whereas Galanina and Heikkilä (2007) define 21 different mire site types for the same. A string-flark pattern is found in the central part of the mire, where strings rise to only 10–20 cm above the flark level, a phenomenon typical for southern aapa mires (Ruuhijärvi 1960). Situated in a tectonic depression, the mire has a thick peat layer, to a maximum depth of 805 cm.

Isosuo Mire

Located on the outskirts of Kuhmo, the Juortanansalo Mire Reserve (64°34'N, 29°51'E; 250 m a.s.l.) (Fig. 1) encloses Isosuo Mire, a typical aapa mire. As the mire forms a complex with other mires in the mosaic landscape, no exact boundaries can be defined for it. The mire gently slopes in a SW direction, is slightly concave in surface and has an area of approximately 250 ha (Fig. 3). In the central part of the mire, there is distinct string-flark patterning, and numerous open water flarks (Fig. 4). The mire vegetation consists mostly of the poor fen type, and in the southwest portion of the mire, where there is abundant water flow, there thrives vegetation characteristic of an intermediate fen. On the margins of the mire, pine bogs are found. The mire's centre is located in a tectonic depression, where the maximum peat depth is 620 cm.

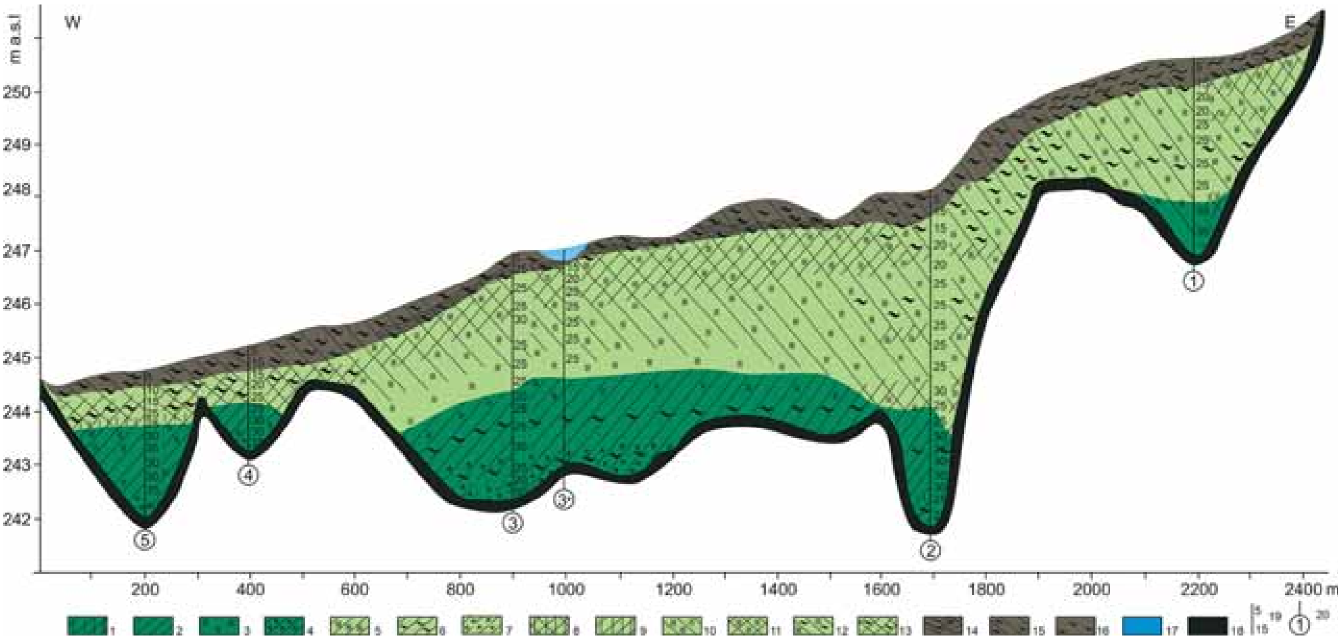

Figure 3. Isosuo Mire cross-section. Abbreviations: W, west; E, east. Following the Russian classification system, the peat types are: RICH: 1. woody-sedge, 2. sedge, 3. Scheuchzeria, 4. Equisetum-sedge, 5. Scheuchzeria-sedge, 6-7. Bryales-sedge; INTERMEDIATE: 8. woody-sedge-Sphagnum, 9. woody-sedge, 10. Scheuchzeria, 11. Scheuchzeria-sedge, 12. Scheuchzeria- Sphagnum, 13. Sphagnum-sedge; POOR: 14. cotton grass-Sphagnum, 15. Sphagnum, 16. hollow Sphagnum; 17. Water, 18. Till, 19. Degree of decomposition (%), 20. Coring point number.

Figure 4. A view over Isosuo Mire from the east (Photo: Suomen Ilmakuva Oy).

Materials and methods

Peat sampling

Peat cores were collected from the deepest sections of the mires, using either an 8 cm-diameter and 20 cm-long volumetric piston sampler or a standard Russian peat corer (500 x 50 mm). Peat layers (thickness to 5–25 cm) were visually identified and described in the field. Samples were obtained for the following: stratigraphic profiling (from eight peat cores, two from the Härkösuo Mire and six from the Isosuo Mire); thin stratigraphic layer (5–25 cm) profiling (one sample taken from the middle section of the layer); pollen analysis and radiocarbon dating (a total of 17 deep core samples taken from both mires); and macrofossil and pollen analyses (from approximately 100 g of fresh peat)

Peat analyses

Samples were microscopically (5% precision) analyzed to determine the degree of decomposition (Минкина & Варлыгин 1939). After this, the samples were rinsed with distilled water and separated from the humus, using a 0.25 mm mesh sieve. Next, the samples were microscopically (5% precision) analyzed and identified for botanical macrosubfossils (Короткина 1939). The macrofossil atlas (Кац и др. 1977) was used in species identification. Peat types were determined according to the Russian system of classification (Тюремнов 1976), which contains some distinctive features for Karelia (Елина и др. 1984; Heikkilä et al. 2001).

Once the analyses were completed, macrofossil percentage diagrams were prepared to portray mire vegetation dynamics. In the diagrams, species appear inversely, starting with those from the bottom layers and ending with those from the surface layers. Palaeocommunities were determined on the basis of the dominant species in each layer, and their ages through radiocarbon dating and pollen diagram zones.

Pollen analyses, diagrams and palaeovegetation reconstruction

Peat samples for pollen analyses were treated using the von Post method (consisting of a short period of boiling with 10% KOH) and the standard Erdtman acetolysis technique (Покровская 1950). Minerogenic samples from bottom layers were separated according to Grichuk's methods (Гричук & Заклинская 1948) using $KJ + CdJ_2 + H_2O$ heavy liquid (density = 2.25). Pollen keys and illustrations (Куприянова & Алешина 1972, 1978; Бобров et al. 1983; Moore et al. 1991) in combination with a reference collection of modern material (available at the Laboratory of Mire Ecosystems, Karelian Research Centre) were used in pollen identification.

Pollen diagrams were constructed using the programs TILIA and TILIA GRAPH (Grimm 1992). The percent ratio of four groups of microfossils (trees, shrubs and dwarf shrubs, herbs and cryptogams) was determined for each pollen spectrum. Then, total pollen for woody plants (AP) was equated to 100%, and taxa proportions (%) were calculated. The content (%) of identified herb pollen was calculated from the sum of woody and herbaceous pollen (AP + G). Spore content was calculated from the sum of microfossils of woody and cryptogamous plants (AP + S). This method of calculation reduced the effect of local factors (high content of Cyperaceae and Poaceae pollen and spores in some strata) in the Härkösuo and Isosuo pollen diagrams. In the pollen diagrams, black-filled shapes represent the content (%) of identified taxa, and grey-filled curves show 10x magnification.

Sum of squares cluster analysis was performed (Grimm 1987) to identify significant changes in the pollen stratigraphy. Based on these data, the pollen diagrams were divided into local pollen assemblage zones and subzones. These are distinguished in two pollen diagrams that were compared and subsequently correlated with known Late Glacial and Holocene time scales (Mangerud et al. 1974; Хотинский 1987; Елина и др. 2000). Conjugate palynological analysis and 17 radiocarbon ages were used in determining pollen spectra age, which was calculated with the aid of TILIA software.

The local pollen assemblage zones are not described in the present paper. Even so, Holocene periods and phases, the calibrated age of which was used in calculating peat increment and the age of mire palaeocommunities, are shown in the Härkösuo and Isosuo pollen diagrams. Also available is a reconstruction of the regional vegetation dynamics for the individual Holocene phases; the reconstruction includes an identification of the dominant tundra and forest palaeocommunities, along with their ages.

Radiocarbon ages

The ^{14}C samples generally represented a peat layer with a vertical thickness of 2–6 cm. Radiocarbon dating was carried out at the ^{14}C laboratory (Su) the Geological Survey of Finland, and at the Poznan Radiocarbon Laboratory (Poz). Thoroughly cleaned of rootlets and other possible organic impurities, the samples were analyzed as bulk sediment. The measuring technique involved proportional counting of CO_2 and the application of pulse-shape discrimination, as described in Äikää et al. (1992). The ^{14}C ages obtained from the samples were then converted to calendar years by the program CALIB REV 4.0 (Stuiver & Reimer 1993). The age–depth model was obtained using a method similar to that described by Goslar et al. (2005).

A Leco CHN 600 analyzer was used to determine the carbon content as a percentage of the total dry matter. The long-term (apparent) rate of carbon accumulation (g C m^{-2} yr^{-1}) was calculated using peat cores of known bulk density and age (see Tolonen & Turunen 1996). For the calculation of carbon accumulation rates, the following equation was used:

$$A^c = r \bullet \rho \bullet C \bullet 1000$$

A^c = apparent carbon accumulation rate (g C m^{-2} yr^{-1}); r = rate of vertical peat growth (mm yr^{-1}); ρ = dry bulk density (g cm^{-3}); C = carbon content as a proportion of the dry bulk density.

Peat increment and carbon accumulation

Peat increment was calculated in two ways. Firstly, palaeocommunities were identified in peat botanical composition diagrams. This was followed by the determination of the time intervals of their existence through calibrated radiocarbon dating and pollen diagram zoning, and the calculation of peat increment for each palaeocommunity. Secondly, Holocene phases were identified in the pollen diagrams, accompanied by the determination of their calibrated ages and calculation of peat increment per phase.

The temperature corrected electrical conductivity of peat layers was was examined by using conductivity and temperature probing (see Puranen et al. 1997, 1999).

Nomenclature

Nomenclature follows Hämet-Ahti et al. (1998) for vascular plants, and Ulvinen et al. (2002) for bryophytes.

Results

Dating of the mires

Radiocarbon dates for peat samples taken from the deepest-extracted cores (Härkösuo: 11 datings; Isosuo: 6 datings) indicate active peat accumulation in the mires throughout the Holocene (Table 1). The dates correspond well to the palynological analysis results reported below. The age of individual peat layers in the mires, to a depth of 4 m, is quite similar, whereas differences in the age of lower layers of the deposits are significant. Peat accumulation in the deeper Härkösuo Mire commenced 500 years later than in the Isosuo Mire.

Dynamics of Härkösuo Mire

Härkösuo Mire started to develop in terrestrial conditions. There is no gyttja on the bottom of the mire. In the first short stage of the mire's development, starting 10 240 yr. cal. B.P. (Table 1), the mire vegetation was dominated by a near mesotrophic *(Calliergon+Warnstorfii)* fen-like community (Table 2, Fig. 5). Peat increment was very quick, amounting to 1.67 mm yr^{-1}. This was followed by another short stage (600

Table 1. Radiocarbon dating results

Mire	Sample Peat type/ Humification	Depth (cm)	Lab no.	δ^{13}C (o/ oo	^{14}C age (yr BP)	Cal. Date Range (yr cal BP)	Most probable date (yr cal. BP)
Härkösuo	S/H3	20-21	Poz-9071		55±10	50-55	20
	ErS/H2	60-61	Poz-9138		830±30	700-740	730
	TrSC/H4	105-110	Su-3366	-28,3	1650±60	1620-1480	1540
	C/H4	208-213	Su-3367	-27,8	3290±70	3600-3440	3500
	EqCS/H4	290-295	Su-3368	-28,2	4420±50	5060-4880	5000
	CS/H3	365-365,5	Poz- 9069		5440±40	6210-6250	6220
	CS/H3	407-412	Su-3369	-28,1	6000±70	6910-6740	6800
	NCS/H4	579-584	Su-3370	-28,4	7620±80	8480-8340	8400
	MnSC/H5	671-676	Su-3371	-28,5	8240±60	9300-9100	9240
	MnSC/H5	715-715,5	Poz-9070		8750±50	9660-9800	9720
	MnEqCS/H6	775-780	Su-3372	-27,3	9110±80	10370-10190	10240
Isosuo	SHS/H2	70-75	Su-3360	-25,4	450±60	540-470	510
	ErNCS/H4	145-150	Su-3361	-27	2030±60	2050-1910	1980
	EqSC/H4	265-270	Su-3362	-28,4	4400±70	5070-4860	4950
	EqC/H5	375-380	Su-3363	-27,9	6120±60	7130-6890	6980
	EqPrC/H6	545-550	Su-3364	-28,5	8370±60	9470-9330	9440
	EqB/H4	615-620	Su-3365	-30,1	9500±70	11060-10960	10720

Table 2. Palaeocommunities and peat increment in Härkösuo Mire

Depth (cm)	Palaeocommunity	Age (yr. cal. B.P.)	Peat increment (mm yr^{-1})
0-60	Intermediate *Carex lasiocarpa* + *Eriophorum sp.* + *Trichophorum sp.* – *Sphagnum warnstorfii*	0-850	0.71
60-135	Intermediate *Carex rostrata* – *Sphagnum warnstorfii*	850-1900	0.71
135-220	Intermediate *Carex lasiocarpa* + *C. rostrata* + *Scheuchzeria* – *Scorpidium scorpioides*	1900-3950	0.42
220-280	Poor *Carex lasiocarpa* + *Eriophorum sp.* – *Sphagnum fuscum*	3950-5000	0.57
280-550	Rich *Carex lasiocarpa* – *Sphagnum warnstorfii* + *S. fuscum, C. lasiocarpa* - *Scorpidium scorpioides*	5000-8100	0.87
550-680	Intermediate *Carex lasiocarpa* – *Sphagnum teres*	8100-9300	1.08
680-715	Intermediate *Carex lasiocarpa* – *Calliergon sp.*	9300-9900	0.58
715-765	Poor *Carex rostrata* +*Equisetum sp.* – *Sphagnum riparium*	9900-10200	1.67

Figure 5. Härkösuo Mire macrosubfossil diagram. For a list of palaeocommunities, see Table 2. Abbreviations: BO, Boreal; AT, Atlantic; SB, Subboreal; SA, Subatlantic.

years) of poor fen community dominated by brown mosses, with a clearly lower peat increment of 0.58 mm yr^{-1}. A period of change lasting for more than 1 000 years then took place. Sedges and *Sphagnum teres* became dominant and peat increment was again on the increase (1.08 mm yr^{-1}). Subsequently, a rich fen period with a string-flark pattern established for 4 000 years (Palaeocommunities 4 and 5, Table 2). Vegetation in this period was very similar to modern variants. Then, a wet period began, about 4 000 years ago, marked by low peat increment (0.42 mm yr^{-1}) and a predominance of sedges and *Scheuchzeria* in the plant cover. The site became rich once more 1 900 years ago, with *Sphagnum warnstorfii* and *Scorpidium scorpioides* present and *Trichophorum* on the rise. In the last 850 years, a rich fen community prevailed, with mounting peat increment yet again.

Dynamics of Isosuo Mire

Isosuo Mire has a complex genesis and a peat deposit that is substantially varied in depth and stratigraphy. Mire vegetation dynamics was reconstructed using material from the deepest-extracted core (Core 2, Fig. 3).

In the beginning of the development of Isosuo Mire, there was a short stage (800 years) of rich flark level fen with many herbs and sedges and brown mosses (Table 3; Fig. 6). The bottom layer (10 720 years B.P.) belongs to the oldest terrestrial peat layers found in Finland. Peat accumulation began very quickly after the end of glaciation in this area. In the first stage, peat increment was rather low, at 0.50 mm yr^{-1}. Subsequently, for 600 years, an intermediate fen dominated by *Sphagnum teres* established. Then, there was a long period (2 500 years) of an intermediate flark fen dominated by sedges and *Sphagnum* sect. Subsecunda. Peat increment in this stage was somewhat higher, at 0.70 mm yr^{-1}. In the following 2 600 years, the mire turned into a poor flark fen with *Scheuchzeria* and *Sphagnum* sect. Subsecunda. A wet period ensued over the next 2 500 years , and poor wet fens prevailed, succeeded by an even wetter mire (likely with stagnant water) dominated by *Sphagnum lindbergii, S. majus* and *S. balticum*. In the last 850 years, there occurred a clear dominance of the mire surface by *Sphagnum papillosum*. The coring point was in a string, surrounded by wet flarks with *Sphagnum lindbergii* and *S. majus*. Overall, in the last 6 800 years, peat increment was relatively stable, at 0.50-0.59 mm yr^{-1}.

Peat increment and peat property statistics

The Härkösuo and Isosuo mires have respective average peat increments of 0.76 mm yr^{-1} and 0.58 mm yr^{-1}. In that order, the average carbon content of peat deposit is 53.2% and 54.6% of dry weight, and average dry bulk density is 66.6 kg m^{-3} and 61.0 kg m^{-3}. Mean ash content is 2.9% and 4.6% of dry weight, and mean sulphur content is 0.55% and 0.26% of dry weight.

Peat increment varied significantly over the lifetime of different palaeocommunities in the mires. The range in Härkösuo Mire was from 0.42 mm yr^{-1} in a very wet sedge-Bryales community to 1.67 mm yr^{-1} in a sedge-*Sphagnum* community in the early stages of paludification (Fig. 5, Table. 2). In the Isosuo Mire, peat increment fluctuations during the Holocene were minor – from 0.50 mm yr^{-1} in a *Scheuchzeria-Sphagnum* and a *Menyanthes*-Bryales community to 0.70 mm yr^{-1} in a sedge-*Sphagnum* (with *Sphagnum subsecundum*) community (Fig. 6, Table. 3).

Table 3. Palaeocommunities and peat increment in Isosuo Mire.

Depth cm	Palaeocommunity	Age yr. cal. B.P.	Peat increment mm yr^{-1}
0-50	Poor *Scheuchzeria – Sphagnum papillosum* + *S. balticum*	0-850	0.59
50-100	Poor *Scheuchzeria* + *Carex rostrata* + *C. limosa – Sphagnum lindbergii*	850-1700	0.59
100-225	Poor *Scheuchzeria –Sphagnum papillosum*	1700-4200	0.50
225-365	Poor *Scheuchzeria* + *Carex limosa – Sphagnum sect. Subsecunda*	4200-6800	0.54
365-540	Intermediate *Carex lasiocarpa* + *Equisetum sp. – Sphagnum sect. Subsecunda*	6800-9300	0.70
540-580	Intermediate *Carex lasiocarpa* + *Menyanthes – Sphagnum teres*	9300-9900	0.67
580-620	Rich *Menyanthes trifoliata – Scorpidium scorpidioides*	9900-10700	0.50

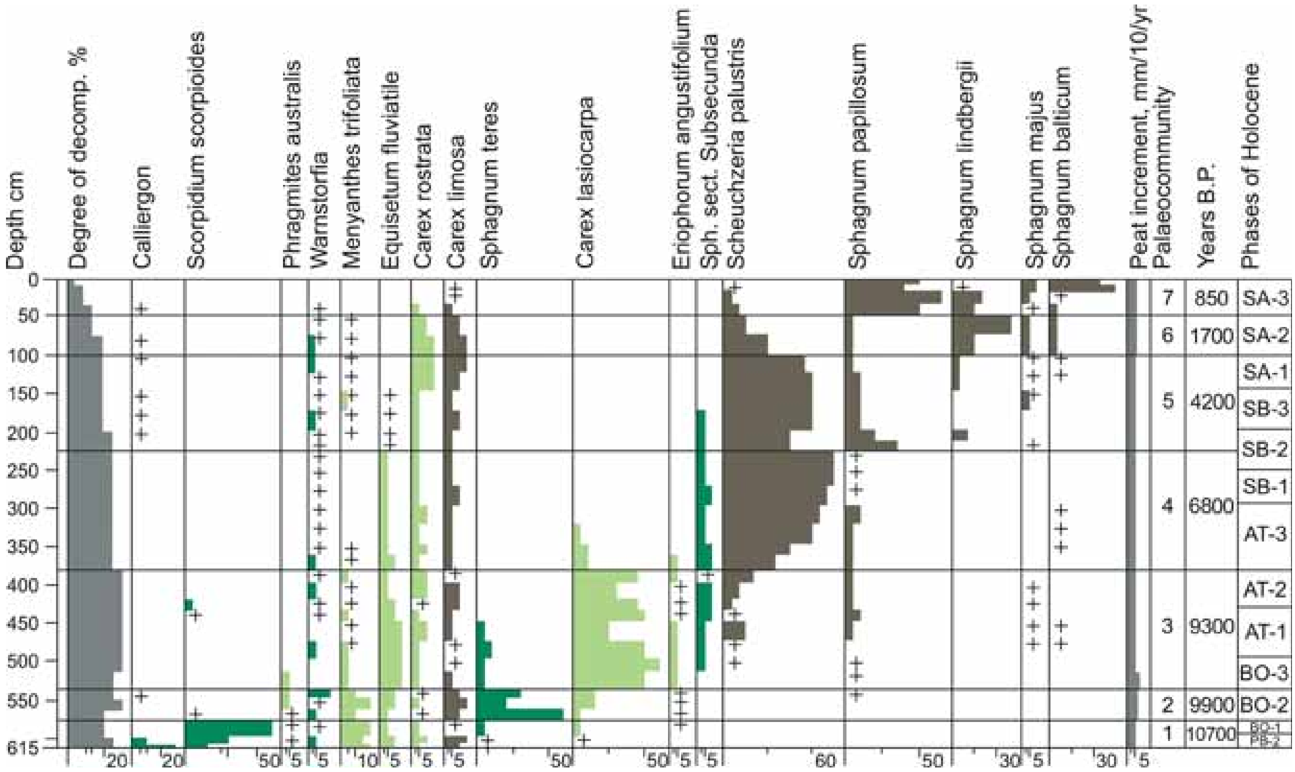

Figure 6. Isosuo Mire macrosubfossil diagram. For a list of palaeocommunities, see Table 3. Abbreviations: BO, Boreal; AT, Atlantic; SB, Subboreal; SA, Subatlantic. The oldest phase of the Holocene is the Preboreal (PB).

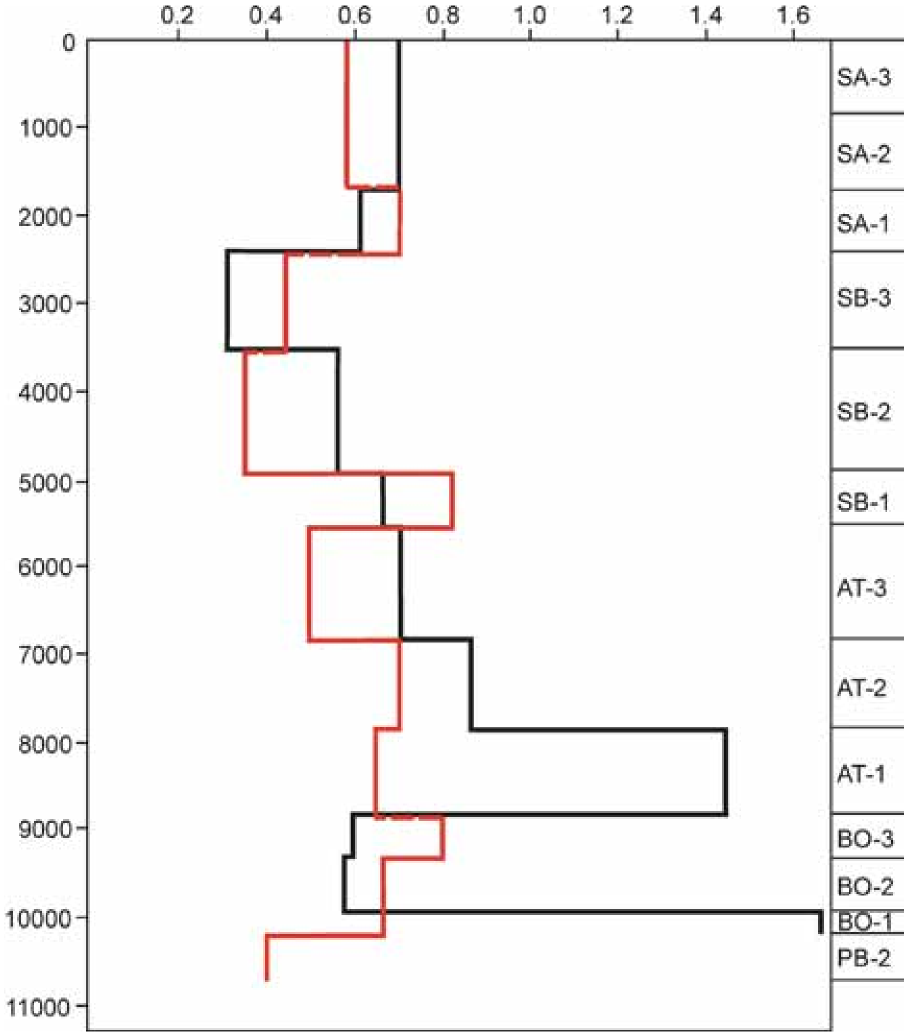

Figure 7. Peat increment in Härkösuo (black) and Isosuo (red) mires during the Holocene. Y-axis values represent peat layer ages (calibrated years B.P.), while x-axis values show peat increment (mm yr-1).

Peat increment values calculated against the Holocene phases (with calibrated ages) were somewhat different (Fig. 7). A finer division of stratigraphic sections in the pollen diagram enabled identification of sharper peat increment fluctuations in some Holocene phases.

In Härkösuo mire, the range was from 0.32 mm yr^{-1} in SB-3 to 1.67 mm yr^{-1} in BO-1, with mean peat increment over the Holocene being 0.75 mm yr^{-1}. In the Isosuo Mire, peat increment fluctuations in different Holocene phases were less pronounced 1, from 0.36 mm yr^{-1} in SB-2 to 0.83 mm yr^{-1} in SB-3 (Fig. 7), with mean peat increment over the Holocene being 0.58 mm yr^{-1}. In nearly all the Holocene phases, peat increment was higher in Härkösuo Mire than in Isosuo Mire. The periods of maximum and minimum peat increment in the mires are different, however. They depend on local hydrological conditions and palaeocommunity composition. Because the spectrum of palaeocommunities in the mires differed in composition and trophic status throughout the Holocene, no comparison can be drawn.

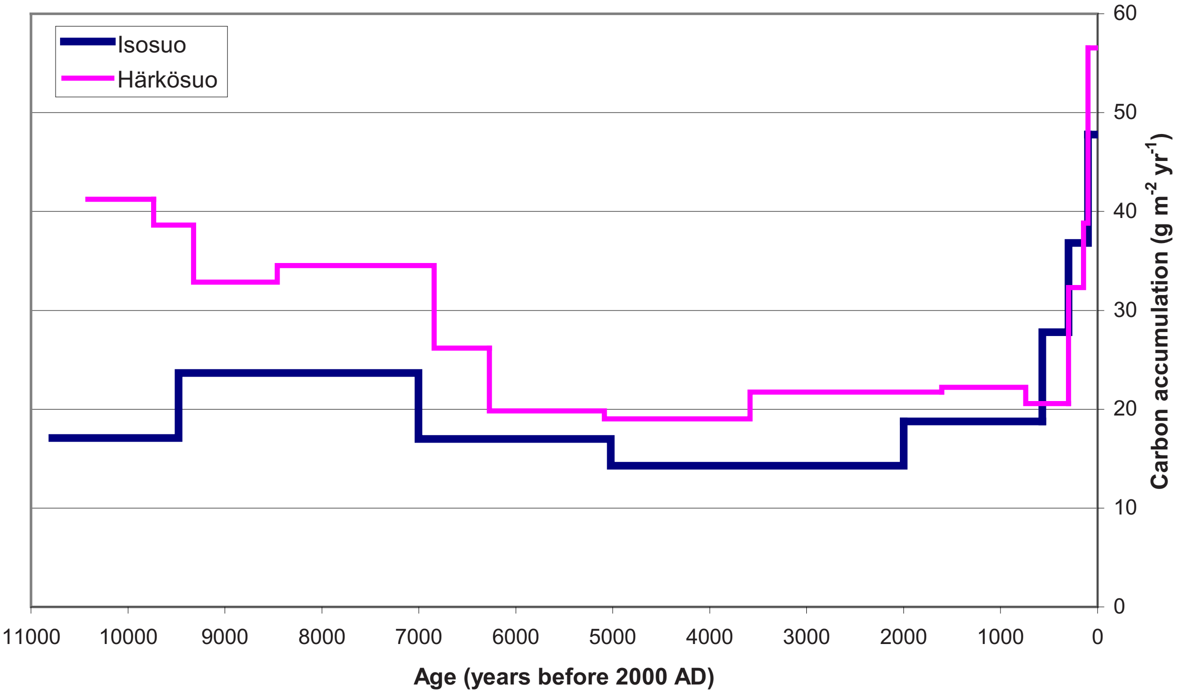

Figure 8. Carbon accumulation rates for the Härkösuo and Isosuo mires during the Holocene.

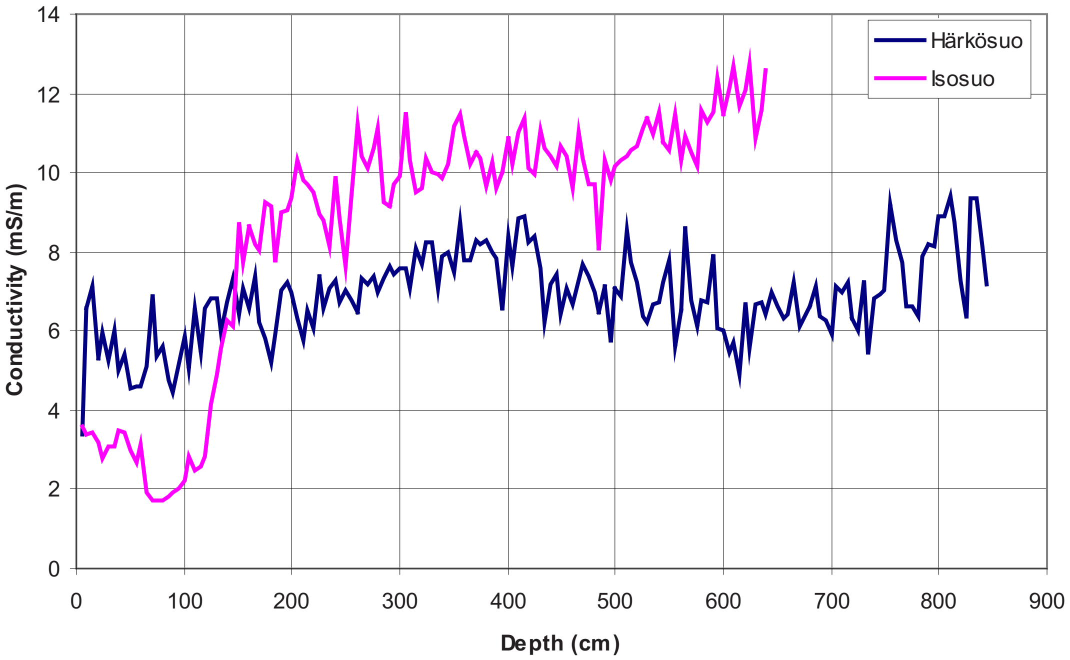

Figure 9. Temperature corrected electrical conductivity values of peat in the Härkösuo and Isosuo mires.

Carbon accumulation

The average carbon accumulation has been 26.7 g m^{-2} yr^{-1} and 18.9 g m^{-2} yr^{-1} in Härkösuo and Isosuo mires, respectively. The carbon accumulation dynamics in both mires is very similar (Fig. 8). However, carbon accumulation is somewhat higher in Härkösuo Mire, correlating well with the mire's higher peat increment. The most significant decrease of carbon accumulation in both mires occurred approximately 7 000 years ago. After that, the accumulation rates were very stable. The much higher carbon accumulation values over the last 300–500 years point to unceasing effective decomposition of plant remnants in the top 30–50 cm layer (corresponding to the acrotelm).

Electrical conductivity of peat

In Härkösuo Mire, peat electrical conductivity is rather stable (Fig. 9), unlike in Isosuo Mire, where there is a clear decreasing trend in the upper 150 cm of peat. This is due to the natural acidification of the mire, and is well connected with the mire's oligotrophic stage (see Table 3).

Reconstruction of landscape vegetation dynamics in the study area

The data obtained suggest that the study area had already emerged from under the ice by the middle of the Preboreal (PB) period (~ 9 600 yrs BP, 10 800 yrs cal. BP). This fact is evidenced by a radiocarbon date of 9 500±70 yrs BP (10 720 yrs cal. BP, Table 1) for the layer which directly overlies till and contains plant remains and sand impurities (see Fig. 10). Similar sediments in the Härkösuo test pit have an age of 9 110±80 yrs BP (Fig. 11). In both cases, the sediments underlie basal peat layers with minor sand impurities, which indicates that mire formation and peat deposition in the basins commenced in the second half of the PB-period.

According to the data (Figs. 10, 11), following the retreat of the glacier and decrease in the level of periglacial water-bodies, much of the study area was dominated by sedge-grass, dwarf birch-true moss and herb-dwarf shrub-true moss tundras with a significant proportion of Ericales in the plant communities. Tundra vegetation gradually lost its significance by the end of the PB-period, and open birch woodland was superseded by sparse birch and pine-birch forests of Northern Taiga appearance, still widespread in the area early in the Boreal period (BO), and appears to have had a dominating role near Härkösuo Mire approximately 8 800 yrs BP (9750 yrs cal. BP). A notable rise in pine contribution to the plant cover was observed in the BO from 8 750±50 yrs BP to a maximum in BO-3 (8 300–8 000 yrs BP, 9 300–9 000 yrs cal. BP), as corroborated by a radiocarbon date of 8 240±60 yrs BP (9 240 yrs cal. BP, Fig. 11, Table 1).

In the Atlantic period (AT), especially in AT-1 (8 000–7 000 yrs BP, 8 800–7 800 yrs cal. BP), there still existed dwarf shrub-true moss and dwarf shrub-lichen pine forests, sometimes mixed with birch. Forest fires in this period are evidenced by a rise in the amount of *Betula pubescens* pollen and the presence of *Epilobium angustifolium* pollen in sediments. *Ulmus, Quercus, Tilia, Acer* and *Corylus* pollen identified in samples are most probably exogenous. Study data suggest that spruce began spreading in the area in AT-3 (immediately after 5 440±40 yrs BP, 6 220 yrs cal. BP, Fig. 11 &Table 1). This process intensified in the Subboreal period, especially in the late chronozone SB-2 (see Figs 10, 11), as supported by a date of 3 290±70 yrs BP (3 500 yrs cal. BP, Fig. 10 & Table 1). Herb-true moss spruce and pine-spruce forests became increasingly widespread in SB-3 (3 200–2 500 yrs BP, 3 400–2 400 yrs cal. BP). In the Subatlantic period (SA) (2 500 yrs BP – present time), spruce contribution to the plant cover decreased somewhat, and the proportion of pine and birch continued to increase.

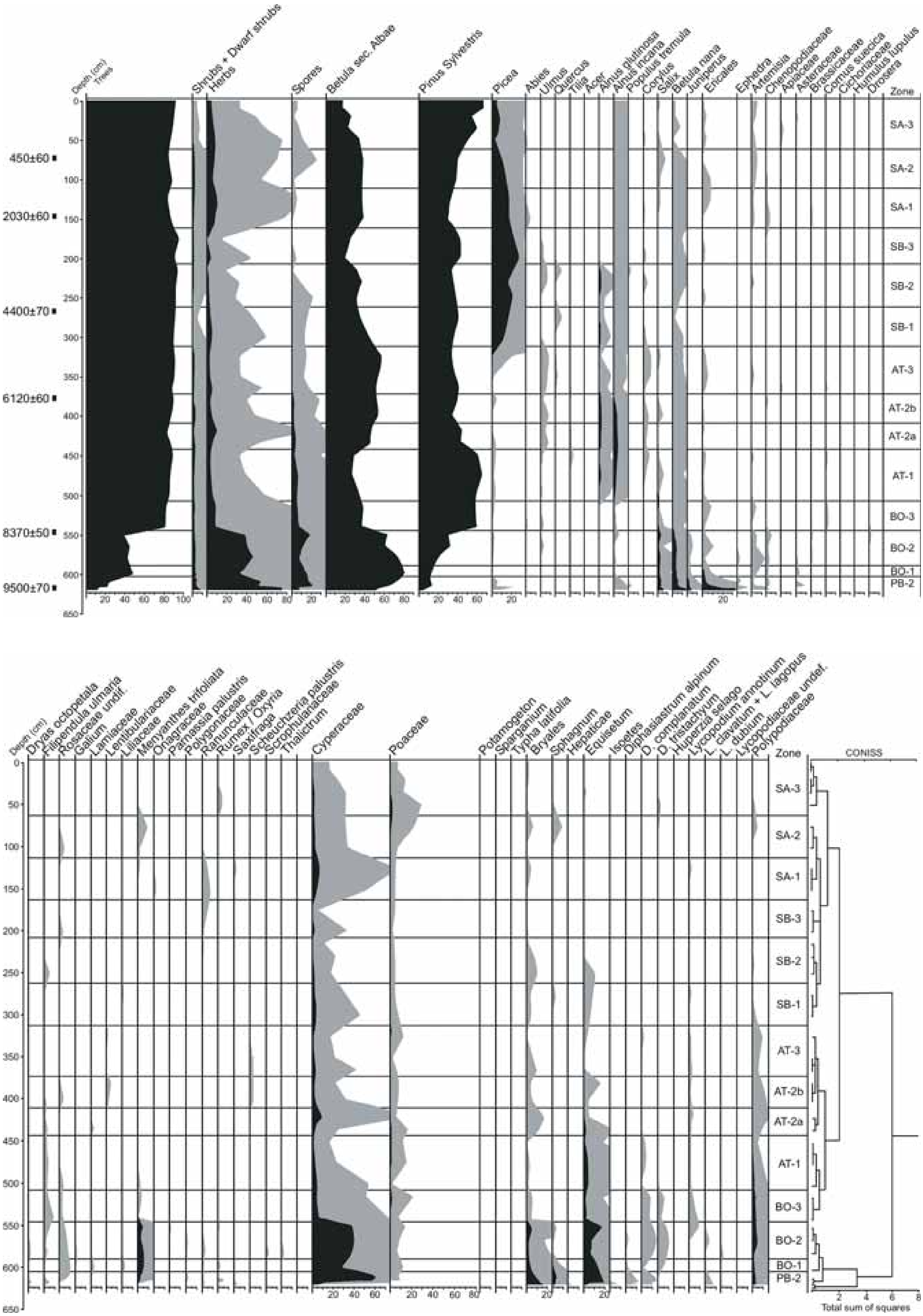

Figure 10. Isosuo Mire pollen diagram. Contours in grey have a magnification of x 10. Abbreviations: PB, Preboreal; BO, Boreal; AT, Atlantic; SB, Subboreal; SA, Subatlantic.

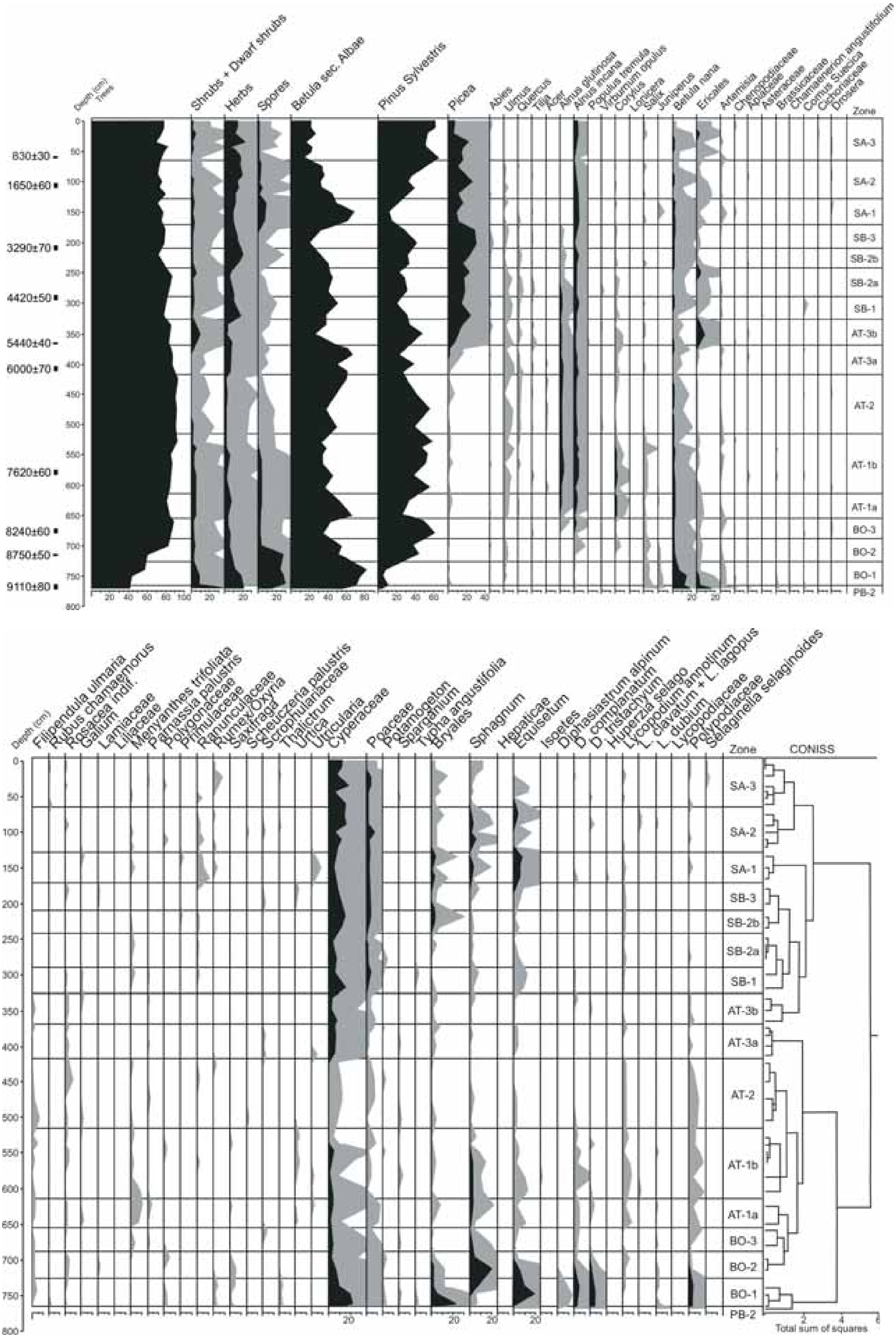

Figure 11. Härkösuo Mire pollen diagram. Contours in grey have a magnification of x 10. Abbreviations: PB, Preboreal; BO, Boreal; AT, Atlantic; SB, Subboreal; SA, Subatlantic.

Discussion

Deglaciation

In the study area, deglaciation began relatively late, some 10 400–10 300 varve years ago (see Lundqvist, 1991; Tikkanen, 2006). Our data suggests that the area emerged from under the ice by the mid-Preboreal period at the latest. This fact is evidenced by a radiocarbon date of 9 500±70 yrs BP (10 720 cal yr BP, Table 1) for the peat layer, directly overlying till and containing plant remains and sand impurities (see Fig. 10). By comparison, the Bryales peat between two layers of gyttja found in Parkusuo Mire in Ilomantsi, one of the first areas in Finland to undergo deglaciation, has been dated between 11 140 cal BP (9 700 ± 50 BP) – 11 570 cal BP (10 070 ± 80 BP). Hence, the Parkusuo Mire may be said to contain the oldest postglacial peat in Finland. (Mäkilä et al. 2006).

Development of mires

In comparison to other mires, the mires in the study area are close to a watershed area, where the emergence of land occurred early. There are old, deep mires in tectonic depressions. In flatter terrain within the study area, peat layers are much more shallow (Heikkilä et al. 1997), and peat increment rates lower. In the Kostomuksha region, while deep mires in tectonic depressions exist, many have gyttja layers on the bottom. These mires contain peat at an age of under 7 000-8 000 calibrated years, and gyttja at an age of greater than 10 000–9 000 years (Елина & Кузнецов 1977; Елина 1981; Kolomytsev & Kuznetsov 1997). The stratigraphy of peat deposits in the area is very diverse. Mires demonstrate numerous successions of the plant cover and frequent shifts in peat layers, like in the mires we have surveyed. This situation is due both to local geomorphological and hydrological conditions in which specific mires developed, and to global changes in natural conditions during the Holocene. A general temporal trend from rich to poor vegetation was evident in Isosuo Mire, which is comparable to that recorded for numerous other mires (e.g., Tolonen 1967). Interestingly this feature is not observable in Härkösuo Mire, which has a strong ground water influence (Tahvanainen et al. 2002).

Development of vegetation in the landscape

Two earlier pollen diagrams, assembled by Hyvärinen (1972), are available for Kuhmo region: Sydänmaanlampi (64°07′ N, 29°40′ E) and Joutenlampi (64°05′ N, 30°29′ E). The latter yielded a radiocarbon date of 8 390±290 yrs BP (Hel-185) for the lower (early) Pine-birch zone, which portrays a sharp rise in the *Pinus* pollen curve, indicating active expansion of pine in the area. According to Hyvärinen (1972), the generalized regional pollen-assemblage zoning for eastern Finland is: Birch (9 700–8 500 yrs BP), Pine-Birch-Alder (8 500–5 000 yrs BP), Pine-Spruce (5 000 yrs BP–present). Löytösuo Mire pollen diagram (Heikkila et al. 1997), dated to the end of Boreal period, has not as yet undergone radiocarbon dating.

Closely located to the study area is the western margin of Russian Karelia, for which the following pollen diagrams are available: Nosuo, Posledneye, Zayachje, and Nikolsuo in Kostomuksha area (Елина 1981). A radiocarbon date of 6 800±140 yrs BP (TA-581) is only available for the gyttja layer of Nosuo. The dating corresponds to a slight rise in the total deciduous (mainly *Ulmus*) pollen curve with the content of *Betula* pollen still being high. In overlying layers of gyttja and peat, the share of the latter

Figure 12. Pristine pine fen in Härkösuo mire showing a natural process: antlers of wild forest reindeer, which had been killed and eaten by a bear in 1994. The young boy with antlers is Tuomo Lindholm. Photo Tapio Lindholm.

decreased and a rise in the *Picea* and *Pinus* pollen curves was observed. This pollen diagramof Nosuo has a PB age, with two others dated to BO-2, and one to AT-1. The proportion of *Picea* pollen increased in the second half of the AT period and reached a maximum in SB (Елина 1981).

Our data show that the study area plant cover, in the middle boreal zone, started developing much later (in PB-2) than in the south boreal zone of Karelia (Елина 1981, Елина и др. 2000) Elina et al. 2010 and Finland (Vasari et al.1996). This may be due to a late deglaciation, which could not have taken place prior to 10 000 yrs BP (11 000 cal yrs BP).

History of spruce

Much attention has been paid to the dispersal of spruce forests in the Holocene. For most of north-western Europe, the post-boreal general spreading or "movement" of spruce has been presented cartographically in the form of isochrones (Aario 1965; Aartolahti 1966; Серебрянный 1971; Tallantire 1972; Tolonen & Ruuhijärvi 1976; Елина 1981;Tolonen 1983; Giesecke & Bennett 2004; Савельева 2007). In view of this, the study area is situated between the time contours of 6 000–5 000 yrs BP (Елина 1981), or 5 500–5 000 yrs BP (Tolonen 1983).

According to Hyvärinen (1972) the boundary between pine-birch and pine-spruce pollen assemblage zones in eastern Finland is ~ 5 000 yrs BP. Near Pappilanlampi in Finnish North Karelia, the abrupt increase in *Picea* began 5 300 yrs BP (Vuorinen & Tolonen 1975). In the Riisitunturi area, some 200 km north of our study area, spruce appeared 5 700 cal. years B.P. (Huttunen 2007). Our data shows that spruce started spreading in the study area immediately after 5 440±40 yrs BP up to the maximum in SB-3 (3 200–2 500 yrs BP). The reduction in *Picea* pollen content in the pollen diagram profiles of Isosuo and Härkösuo mires has been occurring (according to available radiocarbon dates) since about 300 yrs BP. The decrease in spruce contribution to forest structure is likely due to human activity, mainly slash-and-burn cultivation (Heikinheimo 1915), which served to increase the incidence of forest fires (e.g. Pitkänen et al. 1999, 2003, Tolonen & Pitkänen 2006, Wallenius 2008).

By the end of the Subatlantic period, when North Taiga spruce and pine forests still prevailed, the role of secondary forests began to increase in significance. This was due to the emergent agricultural utilization of the area. Human impact appears to have had local scope, mainly related to slash-and-burn agriculture. People practiced selective fellings, produced tar, and cleared areas for hay meadows and arable fields. The activities resulted in a change in the composition and ratio of primary forest types, expansion of secondary forests and meadows. Post-fire successions were represented by birch and birch-pine forests with a relatively poor dwarf shrub-herb ground cover. All these factors, including pine and birch participation in the forestation of mires, are mirrored in the decline of *Picea* pollen curves in the Isosuo and Härkösuo pollen diagrams throughout the SA period (see Figs. 10, 11).

Similar data were obtained for the Paanajärvi area (Елина и др. 1994; Huttunen et al. 1999; Jankovska et al. 1999). Huttunen et al. (1999) pointed to the spread of spruce that took place about 5 400 yrs BP (6 200 cal yrs BP). The change in the general landscape, emphasized by a decrease of *Picea*, over the past 300 years (according to available radiocarbon dates) has been primarily triggered by human settlement. The Paanajärvi region was first settled by Finnish farming families in the 18th century (Kettunen 1993).

It should be borne in mind that even more important than the history of spruce as a species is the history of spruce forest ecosystems, embodying the numerous plant, animal and fungus species that interconnect with the habitat. Indeed, the high biodiversity observed in the old-growth spruce forests along the Finnish-Russian border can be attributed to minimal human influence in the area (e.g. Heikkilä & Lindholm 2003; Isokääntä 2006; Fig. 12).

Peat increment and carbon accumulation

Peat increment and age values for the mires surveyed match those for mires developing in deep depressions, both in Finland (Mäkilä & Toivonen 2004) and Karelia (Кузнецов & Мякиля 2007). In Karelia, peat deposits thicker than 6 m have an age of 10 600-7 600 yrs, and a peat increment of 0.69–1.01 mm yr^{-1} (Кузнецов & Мякиля 2007). In Finland, in the case of the Isosuo Mire (which is a typical poor aapamire), the peat increment general trend through the Holocene follows the pattern described for the mires in eastern Finland, namely high values for the early Holocene, low values for the middle Holocene and a clear rise in values for the Subatlantic Chronozone (Tolonen and Ruuhijärvi 1976).

Carbon accumulation in the mires of the study area is slightly higher than average for aapa mires in Finland (Tolonen & Turunen 1996). The reason for this is a higher peat increment in deep and narrow depressions. The trend of carbon accumulation over the Holocene, however, is quite typical of aapa mires (Mäkilä et al. 2001, Mäkilä & Moisanen 2007), displaying the natural dynamics of these mires.

As discussed by many authors, the general trends of carbon accumulation are due to climatic changes in the past, though it should be acknowledged that the autogenic factors of mires have an important role in carbon accumulation. A lag in the decomposition phase is the key factor and not the high primary production in peat accumulation; moisture, oxygen, nutrient-cycling and most notably, nitrogen, are important factors (e.g. Tolonen 1979, Ikonen 1993, Damman 1996).

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Vegetation dynamics of the Ileksa-Vodlozero aapa mires

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Introduction

In the taiga zone of European Russia, Sphagnum communities with *Molinia caerulea* are found in the Karelian type aapa mires only (Юрковская 1987). The Karelian aapa mires are a specific type of mire that widely occurs in Karelia. The eastern boundary of the aapa mire range runs along the River Vyg, Lake Vygozero and Lake Onega. The same line is the western boundary of the range of Onega-Pechora aapa mires, the eastern limit of which runs along the Urals (Юрковская 1980, 1992). The surface of the aapa mires is concave, and wet string-flark and string-pool mire sites prevail at the centres of the mires.

The most widespread and characteristic associations in the Karelian aapa mires are Molinia caerulea + Carex lasiocarpa - Sphagnum papillosum and Molinia caerulea + Carex lasiocarpa - Sphagnum warnstorfii. They form the plant cover of strings, hummocks and Sphagnum carpets. Herb-sedge and herb-sedge-Hypnum communities with *Carex chordorrhiza, C. limosa, C. livida, Menyanthes trifoliata, Scorpidium scorpioides* and *Loeskypnum badium* dominate in flarks. In terms of the structure of their plant cover, Karelian aapa mires resemble the aapa mires of Finland (Ruuhijärvi 1960, 1983; Tolonen 1963, 1967).

Strings and hummocks of the Onega-Pechora aapa mires are occupied by plant communities of the associations Baeothryon caespitosum - Sphagnum papillosum, Andromeda polifolia + Menyanthes trifoliata - Sphagnum magellanicum, and Betula nana + Carex lasiocarpa - Sphagnum magellanicum. The plant cover of flarks is usually formed of *Sphagnum* communities of the Sphagneta jensenii formation and herbaceous communities of the Carex limosa + Menyanthes trifoliata association (Юрковская 1992).

Material

The study area is situated in the south-east margin of the Fennoscandian shield, forming a part of the Ileksa and Kozha river catchments. It includes the western part of the range of Onega-Pechora aapa mires, which dominate in the area alongside the Pechora-Onega raised bogs (Антипин и др. 1996). While past descriptions have held that the area has no aapa mires with *Molinia caerulea* communities (Юрковская 1980), our study confirms that these communities are indeed present in the area.

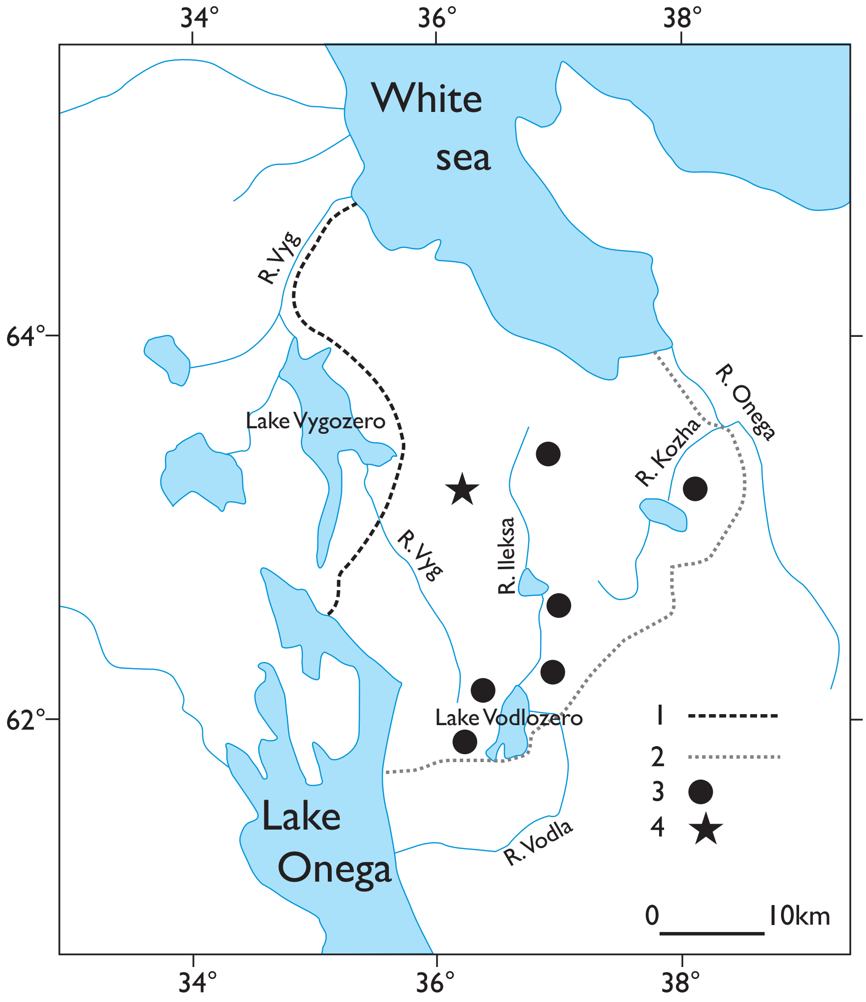

Figure 1. Location of the mires with Molinia caerulea. 1: The eastern boundary of the Karelian aapa mires type; 2: The eastern boundary of the Ileksa-Vodlozero mires type, 3: Studied mires, 4: Saimokh mire

Molinia caerulea is in fact a fairly common species in the flora of the study area. It mainly occurs in the northern part and less frequently in the southern part of the study area, and occupies moist habitats on watersides (Кравченко 2001). We detected *Sphagnum* communities with *Molinia caerulea* during field surveys to document the flora and vegetation of the mire ecosystems within Vodlozerskiy National Park (NP) and Kozhozerskiy Nature Park (Антипин и др. 1996). These mires have also been termed Ileksa-Vodlozero aapa mires (Антипин и др. 2001).

In the study period 1992 – 2002, we found 7 mires where communities with *Molinia caerulea* were detected and examined (Fig. 1). Mire sites with *Molinia caerulea* are situated on the periphery (margins or close to margins) and occupy not more than 5–10% of the mire area.

An exemplary model of Ileksa-Vodlozero aapa mires is the Saimokh mire we discovered in 1998 and examined thoroughly in 2003 (Fig. 2). It lies in the western margin of the Arkhangelsk Region in the north-western part of Vodlozerskiy National Park. The Saimokh mire stretches SE – NW for more than 3 km. Its width ranges from 0.5 km in the north to 1 km in the south. The area of the mire is over 400 ha.

Figure 2. Mire site Molinieto-Sphagneta papillosi + Herbeta + pools in the Saimokh mire (Photo Vladimir Antipin).

Results

Two mire sites with *Molinia caerulea* are situated in the southern part of the Saimokh mire: Molinieto-Sphagneta papillosi + Herbeta + pools and Pineto-Molinieto-Sphagneta. The first site is a flowing-water swamp made up of *Sphagnum* strings, carpets, herb-rich flarks and secondary pools. They occupy 25%, 30%, 35% and 10% of the site's area, respectively. The features alternate, generating a patterned string-flark-pool surface characteristic of aapa mires. Strings are 2–4 m wide and 0.3 m high. Flarks and pools are 1–4 m wide, with the water column from the surface to the peaty bottom of the pools locally reaching 2 m and the total thickness of the peat deposit being 4 m. Carex lasiocarpa + Molinia caerulea - Sphagnum papillosum communities cover the strings. Nearly pure *Rhynchospora alba* stands form chains of strings along margins with flarks. The margins also contain *Molinia caerulea, Carex limosa, Sphagnum papillosum, S. subfulvum,* and some *Betula nana, Andromeda polifolia* and *Carex lasiocarpa*. Small hummocks with Andromeda polifolia + Molinia caerulea - Sphagnum fuscum communities and flarks with Eriophorum polystachion + Menyanthes trifoliata occur on strings. The vegetation of carpets buffering strings and flarks is made up of Rhynchospora alba - S. papillosum communities. *Carex limosa* and *C. rostrata* grow in flarks, and singular *Equisetum fluviatile, Menyanthes trifoliata, Utricularia intermedia, Carex limosa* and *C. rostrata* specimens occur in pools.

The second site adjoins a flark. Its surface consists of hummocks and carpets with small flarks (hollows). Hummocks surrounding tree trunks and flarks occupy up to 30% each of the peatland area, while *Sphagnum* lawns (carpets) account for 40% of the area. The plant cover of hummocks surrounding tree trunks is comprised of Pinus sylvestris - Empetrum nigrum + Menyanthes trifoliata - Sphagnum magellanicum + S. angustifolium communities. Carex lasiocarpa + Molinia caerulea + Menyanthes trifoliata - Sphagnum fallax communities dominate on *Sphagnum* carpets. Menyanthes trifoliata + Carex lasiocarpa communities are common in swampy flarks.

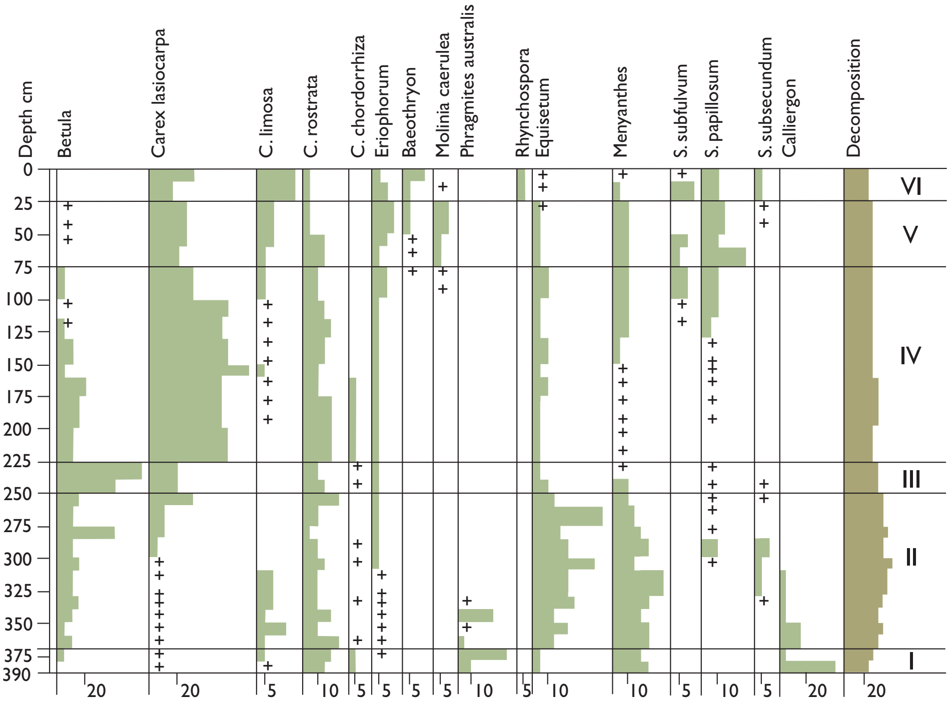

Figure 3. Diagram of the botanical composition and degree of peat decomposition in the mire site Molinieto-Sphagneta papillosi + Herbeta + pools. Herb flark with Carex limosa and C. rostrata. I-VI: Palaeocommunities and their hydrological conditions: I: Phragmites australis + Menyanthes trifoliata – Hypnum sp., flark, II: Equisetum fluviatile + Menyanthes trifoliata with birch, hummock-flark, III: Betula pubescens – Carex lasiocarpa + C. rostrata, hummock-flark, IV: Sedge (Carex lasiocarpa) with birch, hummock-flark, V: Sedge-Sphagnum (Carex lasiocarpa – Sphagnum papillosum + S. subfulvum), with Molinia caerulea, carpet, VI – sedge (Carex lasiocarpa + C. limosa), flark.

We studied the development of Ileksa-Vodlozero aapa mires by analyzing the dynamics of their plant cover in their most typical mire site: Molinieto-Sphagneta papillosi + Herbeta + pools. The peat deposit in the site is 3.9 m thick, underlain by layers of sticky clay. Peat samples for botanical analysis and degree of decomposition assessment were taken from under a string and a flark. Additionally, a clay sample was taken from under a string to determine the composition of plant remains.

Drawing upon the data obtained, the model displaying the dynamics of the plant cover and hydrological conditions was produced for the mire site (Fig. 3, 4). The site started forming in a moderately moist, flowing-water basin (possibly of glaciokarst genesis) whose vegetation was made up of Equisetum sp. + Menyanthes trifoliata palaeocommunities. They were superseded by early mire palaeocommunities, which deposited layers of herb-*Hypnum* fen peat. Later on, birch and *Sphagnum* mosses appeared in these wet/swampy communities. They formed the vegetation of the hummocks surrounding tree trunks, whereas flarks were mostly occupied by *Menyanthes trifoliata* and *Equisetum* sp. In later times, birch turned into the main community-forming and peat-producing species (birch peat layer at a depth of 2.3–2.6 m under the string and 2.25–2.5 m under the flark, see Fig. 3, 4). Remains of the birch stand (roots, stumps, fallen tree trunks) were constantly recorded from the peat core at a depth of 1-3 m.

The birch palaeocommunities were rather short-lived, replaced by sedge communities, apparently as a result of an abrupt rise in the water level in the mire. Peat mosses

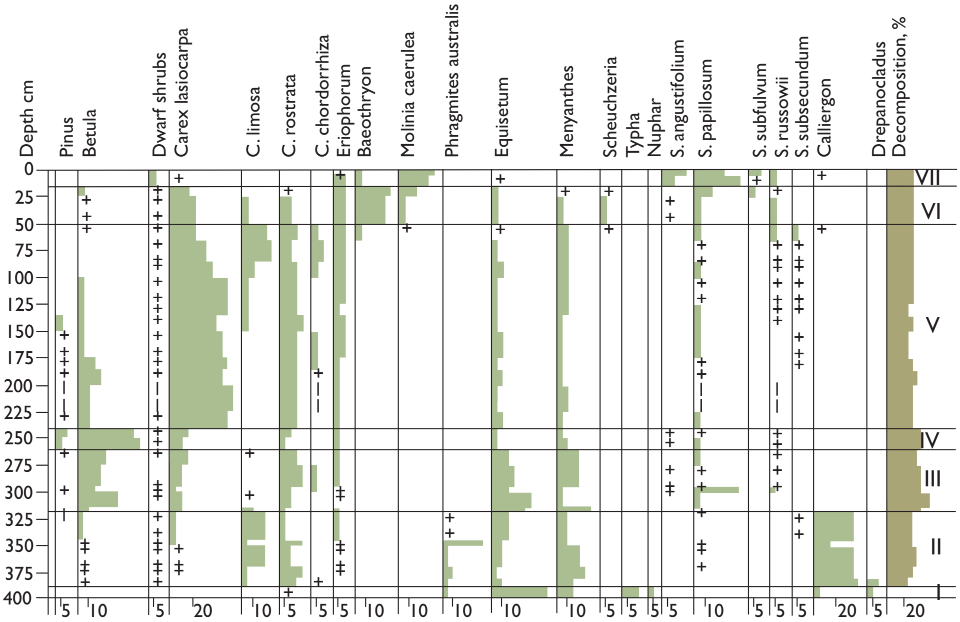

Figure 4. Diagram of the botanical composition and degree of peat decomposition in the mire site Molinieto-Sphagneta papillosi + Herbeta + pools. String Carex lasiocarpa + Molinia caerulea - Sphagnum papillosum community. I-VII: Palaeocommunities and their hydrological conditions: I: Equisetum fluviatile. + Menyanthes trifoliata , flark, II: Herb-Hypnum, flark, III: Betula pubescens – Equisetum fluviatile + Menyanthes trifoliata, hummock-flark, IV: birch, hummock, V: Sedge (Carex lasiocarpa), flark, VI: Baeothryon sp. + Carex lasiocarpa, hummock-flark, VII: Molinia caerulea - Sphagnum papillosum, hummock-string.

spread in the sedge flarks with a moderate flow rate, and sedge-*Sphagnum* palaeocommunities formed. It is likely that the site microrelief differentiated into strings, flarks and pools rather late, about 250–300 yrs. BP. At the same time, *Molinia caerulea* became widespread in the site. Its mass dispersal was promoted by a forest fire. Traces of the fire, charcoal particles, occur in the peat deposit at a depth of 0.1– 0.5 m. Communities with *Molinia caerulea* appeared there, probably, 300–400 yrs. BP, in conformance with the natural florogenesis of the species. Forest fires promoted a massive spread of the species in the habitat.

Discussion

We define Ileksa-Vodlozero mires as a geographic variant of aapa mires (Антипин et al. 2001). They lie in the area acting as a buffer between the Karelian and Onega-Pechora aapa mires. It used to be held that the area has no aapa mires with Molinia caerulea communities (Юрковская 1980). The eastern and southern boundaries of the Ileksa-Vodlozero aapa mire range run along rivers Onega, Kozha, Ileksa, Lake Vodlozero, and then further westwards, to the sources of River Vyg. Its western boundary is River Vyg, and the northern boundary runs along the southern foothills of the Vetrenyi Poyas mountain range (Антипин & Бойчук 2004). The mire flora comprises up to 40 higher plant species, including those characteristic of Karelian aapa mires: *Molinia caerulea, Juncus stygius, Baeothryon alpinum, Rhynchospora alba, Selaginella selaginoides, Trientalis europaea* and *Dactylorhiza maculata*. In Finnish North Karelia (63° N 31° W), Tolonen (1963, 1967) found *Molinia caerulea* to be quite common in an identical mire site type "Mesotrophe Sphagnum papillosum Weissmoore", where the total number of species was 42.

The emergence of communities with *Molinia caerulea* in the aapa mires of the region is due to natural florogenesis. This plant species colonises its favoured mesotrophic and mesoeutrophic habitats. In mire sites, *Molinia caerulea* mostly occupies strings and hummocks whose *Sphagnum* cover is made up of *Sphagnum fuscum, S. papillosum* or *S. warnstorfii*, moss species with low annual increment. The reason for this selectivity is that *Molinia caerulea* is a hemicryptophyte, the root system of which is not suited to ecotopes with rapidly growing *Sphagnum* sod. We believe that forest fires must have contributed to the emergence and spread of *Molinia caerulea* in the mires. Since about the second half of the Holocene, fires were one of the leading ecological factors determining the structure and dynamics of the plant cover in the taiga zone (Громцев 2000). Vegetation in paludified habitats was often burnt out, too. The territory still bears numerous traces of heavy fires that took place 100–300 years ago. Most of them broke out with people having a part to play in them, whether intentionally or not, evidenced by traces of the fires being most abundant near settlements.

In satellite images (Spot format, 20 m resolution) mire sites typical of the Ileksa-Vodlozero aapa mires appear as dark-emerald pixel spectra. This is the decoding trait for the plant cover of this type of mires, and can be used to select the mires to be surveyed in situ and to organize monitoring of the plant cover dynamics in the Ileksa-Vodlozero aapa mires of the region.

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Vegetation of forested mires in the middle boreal subzone of Karelia

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Introduction

The total area of forested mires in Karelia is ca. 10% of the total land area (Пьявченко & Коломыцев 1980). As an ecosystem, forested mires are a combination of of both dry forests and open mires, and due to different ecological influences on its flora, forested mires contain high species richness and coenotical diversity.

Forested mires play an important role in the conservation of diversity regionally as well as in the whole boreal forest landscape of Fennoscandia (e.g. Sjöberg & Ericson,1992; Ohlsson et al. 1997; Korpela 2004). In the latter half of the 20th century, mainly in southern Karelia, 18% of forested mires were drained for forestry purposes (acc. Саковец и др. 2000). However, many sites avoided being clear-felled and still remain in a pristine state.

To date relatively few studies have been carried out in Karelia on the community structure, ecology and classification of forested mires. In addition, detailed botanical reviews of forested mire sites are extremely rare (К.Солоневич & Н.Солоневич 1932; Цинзерлинг 1934), and if they have been completed standardization is problematic as the descriptions follow different classification systems (Юрковская 1959; Яковлев & Воронова 1959; Волков и др. 1990; Кузнецов 2005). This study was carried out for the purpose of describing and analyzing the vegetation diversity and structure of forested mires to define their main compositional gradients.

Materials and methods

The vegetation data of this study consist of 251 releves of sample plots 20x20 or 25x25m in size, collected in the middle boreal subzone of Karelia in 1999-2005. The vegetation data was supplemented with data on peat depth and microrelief structure. The nomenclature of vascular plants and mosses in the releves follows Черепанов (1995) and Ignatov & Afonina (1992).

The classification of sites in this study is mainly based on the "cross-table" method, assumed in Russian forest typology (Дыренков, Лешок 1988), consisting of two subdividing paths: the ecologo-phytocoenotical approach (Нешатаев 2001) to determine the floristic composition of understorey vegetation, and the dominance of tree species approach. The ecologo-phytocoenotical approach is based on determining the dominant species and prevailing eco-coenotical groups of species (Кузнецов 2005) in vegetation composition. This approach results in recognizing a series of associations with similar understorey vegetation. Subsequently, the series would be divided into associations according to dominant tree species with highly constant (classes IV-V after Braun-Blanquet 1964) species determined for each syntaxon.

The diversity pattern of forested mires was examined using the ordination (DCA) technique afforded by the PC-ORD program (McCune & Mefford 2006). The ordination was carried out by downweighing rare species and rescaling axes. To reduce noise, the coverage of species was converted into scores using the next percentage scale: 1, 5, 10, 20, 50 (after Работнов 1978). Environmental gradients (fertility, soil humidity, light factor, etc.) were calculated on the basis of ecoscales (Лопатин 1985; Цыганов 1983). The main compositional gradients were extracted using the Pearson and Kendall correlations of DCA axes and the obtained environmental gradients

Results and discussion

Vegetation associations

The sites of forested mires were divided into 4 formations, 9 series of associations and 17 associations (Table 1). A short description of each association is provided in this section.

1. Alnus glutinosa - Athyrium filix-femina association is dominated by black alder (*Alnus glutinosa*) in the tree stand and ferns (mainly *Athyrium filix-femina*, *Dryopteris expansa*, but also *Gymnocarpium dryopteris*, *Phegopteris connectilis*, sometimes *Dryopteris carthusiana* and *Matteuccia struthiopteris*) in the field layer (Fig. 1). The tree stands have a high coverage (50–90%) with the height of 18–22 m. The cover of the suppressed tree layer and shrub layer (*Alnus glutinosa*, *Padus avium*, *Sorbus aucuparia*, *Frangula*

Table 1. The forested mire vegetation associations for Russian Karelia

Series of associations	Formation			
	Alnus glutinosa	Betula pubescens	Picea x fennica	Pinus sylvestris
Athyrium filix-femina	A. g. – A. filix-femina			
Carex spp. - Menyanthes trifoliata	A. g. – Carex spp.	B. p. – M. trifoliata		
Filipendula ulmaria	A. g. – F. ulmaria – Calla palustris	B. p. – F. ulmaria	P. x f. – F. ulmaria	
Calamagrostis phragmitoides		B. p. – C. phragmitoides	P. x f. – C. phragmitoides	
Molinia caerulea - Sphagnum spp.		B. p. – M. caerulea – Sphagnum spp.	P.x f. – M. caerulea – Sphagnum spp.	P. s. – M. caerulea – S. angustifolium
Menyanthes trifoliata - Sphagnum spp.				P. s. – M. trifoliata – Sphagnum spp.
Equisetum sylvaticum - Sphagnum spp.			P. x f. – E. sylvaticum – Sphagnum spp.	P. s. – E. sylvaticum – Sphagnum spp.
Vaccinium myrtillus - Sphagnum spp.			P. x f. – V. myrtillus – Sphagnum spp.	P. s. – V. myrtillus – Sphagnum spp.
Ledum palustre - Sphagnum angustifolium				P. s. – L. palustre – S. angustifolium

Figure 1. Alnus glutinosa – Athyrium filix-femina site (*Dryopteris expansa* is dominant in field layer) (Photos Stanislav Kutenkov).

alnus, Viburnum opulus, Rosa acicularis, Rubus idaeus) is also high (covering up to 60%). Besides ferns in the field layer, there is a frequent occurrence of *Filipendula ulmaria, Calla palustris, Caltha palustris, Naumburgia thyrsiflora, Ranunculus repens* and *Viola epipsila*. Forest species, normal for hummocks in other forested mires are almost totally absent here, displaced by ferns and herbs. The cover of the moss layer is weak (up to 10%) and consists of eutrophic hygrophilous species (*Calliergon cordifolium, Climacium dendroides, Pseudobryum cinclidioides, Plagiomnium ellipticum*). The peat layer is rather shallow at a depth of 30–130 cm. In sum, the Alnus glutinosa - Athyrium filix-femina association is quite rare in Karelia.

2. Alnus glutinosa – Carex spp. association is dominated by black alder with a mixture of birch (*Betula pubescens*), spruce (*Picea* x *fennica*), grey alder (*Alnus incana*) and willow (*Salix* sp.). Pine (*Pinus sylvestris*) does form part of this composition, albeit rarely. The forest stand is high (16–20 m), with a high coverage (60%). The canopy cover of the suppressed tree layer (mostly saplings of black alder) is ca.10%. Sedges (*Carex cinerea, C. elongata, C. vesicaria, C. cespitosa* and *C. rostrata*) dominate in the field layer (10-60%). *Naumburgia thyrsiflora, Vaccinium vitis-idaea, Equisetum palustre, Dryopteris carthusiana, Calamagrostis* spp, and *Filipendula ulmaria* are common, but not abundant. The microrelief is clearly divided into wide wet flarks with sedges and separate hummocks with mosses, dwarf–shrubs and herbs near tree trunks. The average peat depth is 90 cm.

3. Betula pubescens – Menyanthes trifoliata association is characterized by a predominance of mesotrophic hydrophytes (*Menyanthes trifoliata, Comarum palustre, Equisetum fluviatile*) in the field layer. Birch is dominant in the tree stand layer, and pine and spruce to some extent. The tree stand is 14–18 m high, with an average canopy cover of 40%. *Equisetum palustre, Calla palustris, Caltha palustris, Carex cinerea, C. elongata, Naumburgia thyrsiflora, Calamagrostis phragmitoides, Filipendula ulmaria* and *Trientalis europaea* are typical non-dominant species in the field layer. The moss layer is rather diverse and mosaic-like, typically housing Sphagnum mosses (*Sphagnum centrale, S. warnstorfii, S. squarrosum*) on small lawns, forest species (*Pleurozium schreberi, Hylocomium splendens, Dicranum scoparium, Rhytidiadelphus triquetrus*) on hummocks, and *Climacium dendroides, Calliergon cordifolium* and *Pseudobryum cinclidioides* in flarks. The peat depth varies from 30 to 550 cm. Generally, the Betula pubescens – Menyanthes trifoliata association is typical of mire margins.

4. Picea x fennica – Filipendula ulmaria association is the most typical in the Filipendula ulmaria series and among the meso-eutrophic forested mires. The sites of this association are widespread in the boreal zone and well known in Fennoscandia as the typical spruce mire (e.g. Eurola et al. 1984 Laine & Vasander 1996). The tree stand, composed of spruce mixed with birch, is high (20–22 m) with canopy gaps. In the overtopped tree and shrub layers (covering 20% of projection) grow spruce, birch, *Padus avium, Sorbus aucuparia, Salix myrsinifolia* and *Rosa acicularis*. *Filipendula ulmaria* dominates (20–70%); in the field layer. Herbs such as *Geum rivale, Convallaria majalis, Athyrium filix-femina* and *Dryopteris carthusiana* are abundant. *Trientalis europaea, Maianthemum bifolium, Oxalis acetosella, Gymnocarpium dryopteris, Viola epipsila, Rubus saxatilis, Vaccinium vitis-idaea, V. myrtillus, Equisetum sylvaticum, E. palustre, Paris quadrifolia, Crepis paludosa, Calamagrostis phragmitoides* and *Carex cespitosa* are highlyconstant in this association as well as in the whole Filipendula series. The moss layer consists of a hummock forest species mosaic (*Pleurozium schreberi, Hylocomium splendens, Dicranum* spp.), and *Calliergon cordifolium, Climacium dendroides* and Mniaceae species in flarks. *Sphagnum warnstorfii* dominates in some of the sites. The peat, with a high (sometimes silted) content of wood, has a depth roughly varying from 0.2 to 3 m.

5. Betula pubescens – Filipendula ulmaria association has a plant species composition and site properties that are almost identical to the Picea x fennica – Filipendula ulmaria association. Notable exceptions in this association are the dominance of birch,a higher tree canopy coverage (up to 80%), and a decreased cover of *Oxalis acetosella, Orthilia secunda, Carex disperma, Athyrium filix-femina* and *Sphagnum* mosses.

6. Alnus glutinosa – Filipendula ulmaria – Calla palustris association has a tree stand that is mixed with black alder (prevailing), spruce and birch. Occasionally pine, grey alder and aspen (*Populus tremula*) are present. Tree height is 16–20 m, and the canopy coveragevaries from 30% to 90%. The mean age of alder is 80–90 years, and that of spruce and birch 90–150 years. The suppressed tree and shrub layer is rather dense, with 25–60% of it mainly consisting of *Alnus glutinosa, Padus avium* and *Frangula alnus*, and also spruce, birch, *Sorbus aucuparia, Viburnum opulus, Rosa acicularis*, and *Ribes nigrum*. The dense dominant and suppressed tree layers establish shaded conditions; the microrelief is rugged with hummocks on the base of tree trunks occupying 5-30% and low hummocks as well as flarks 25-70% of the projection. The species composition of the understorey level is similar to the whole Filipendula series, *with Calla palustris, Carex elongata*, occasionally *Equisetum fluviatile* and *Menyanthes trifoliata* added to the dominanting species. The moss coverage is lower than in a spruce series due to the shading and high amount of foliage litter. Species composition, as well as the microrelief, are more similar to forested spruce mires than true southern alder swamps

Figure 2. Picea x fennica – Calamagrostis phragmitoides site

(e.g. see Paal 1997; Сарычева 1998). The average peat depth is 120 cm, 350 cm being the deepest value recorded.

7. Picea x fennica – Calamagrostis phragmitoides association (Fig. 2) is characterized by a clear dominance of *Calamagrostis phragmitoides* and *C. canescens* in the grass layer (both species are frequently hybridized and it is hard to distinguish between them). In other respects, the Calamagrostis series is similar to the Filipendula series. Among the co-dominants are *Filipendula ulmaria, Equisetum sylvaticum, Carex cespitosa*; in the moss layer *Sphagnum warnstorfii, S. centrale* and *S. angustifolium*, dominate, although without creating dense carpets. *Trientalis europaea, Vaccinium myrtillus, V. vitis-idaea, Carex disperma, Carex vaginata, Maianthemum bifolium, Oxalis acetosella, Orthilia secunda, Linnaea borealis, Rubus saxatilis, R. arcticus, Dryopteris carthusiana, Equisetum palustre, Pleurozium schreberi, Hylocomium splendens, Rhytidiadelphus triquetrus, Calliergon cordifolium, Viola epipsila* and *Dicranum scoparium* are highly constant. The tree stand, dominated by spruce mixed with birch and rarely with pine and aspen, has a crown cover of 30–50%. The overtopped tree and shrub layer is sparse, usually formed by *Sorbus aucuparia, Alnus incana* and *Rosa acicularis*. The microrelief, although more smoothed out than in the Filipendula association, is still irregular. The average peat depth is 1 m, with 3 m being the deepest value recorded.

8. Betula pubescens – Calamagrostis phragmitoides association is quite similar in vegetation composition to the previous association; however, instead of spruce, birch is dominant in the tree stand, and as a result, has higher canopy coverage, up to 80%.

9. Picea x fennica – Molinia caerulea – Sphagnum spp. association is dominated by *Molinia caerulea* (20%) in the field layer and *Sphagnum* mosses (*Sphagnum warnstorfii, S. centrale*) in the bottom layer. The tree stand, formed of spruce mixed with birch and occasionally pine, has a crown cover of 30–70% and a tree height of 16–20 m. Besides *Molinia caerulea*, other characteristic species are *Juniperus communis, Frangula alnus, Potentilla erecta* and *Carex flava*. Highlyconstant for this association as well as the whole Molinia series are the different ecological group species: forest species– *Trientalis europaea, Maianthemum bifolium, Convallaria majalis, Vaccinium vitis-idaea, V. myrtillus, Linnaea borealis, Carex vaginata, Pleurozium schreberi, Hylocomium splendens* and *Dicranum scoparium*; indicators of flooded water *Filipendula ulmaria, Crepis paludosa, Viola epipsila, Calamagrostis* sp. and *Plagiomnium ellipticum*; oligotrophic dwarf-shrubs *Vaccinium uliginosum, Chamaedaphne calyculata* and *Ledum palustre*; and flark species *Equisetum fluviatile, Comarum palustre* and *Carex nigra*. In the shrub layer, *Rosa acicularis, Salix aurita* and *Sorbus aucuparia* dominate. The peat depth varies at 0.8–3.5 m, with a mean value of 1.9 m.

10. Betula pubescens – Molinia caerulea – Sphagnum spp. association has a tree stand dominated by birch, with pine and spruce rarely occurring. The crown cover is 40-80% and tree height is 16-20 m. The overtopped trees and shrubs cover 20-40% of the projection, which is twice as much as in the spruce and pine associations. *Molinia caerulea* cover on average 30% of the projection. In other respects, the plant species composition and site properties of this association are almost identical to the Picea x fennica – Molinia caerulea – Sphagnum sp. association.

11. Pinus sylvestris – Molinia caerulea – Sphagnum angustifolium is similar to the previous association, but less species rich. *Molinia caerulea, Juniperus communis, Frangula alnus, Potentilla erecta* and *Carex flava* are characteristic species. The dominant tree species is pine, with spruce and birch typically occurring albeit with a relatively low coverage. The canopy cover of the tree stand is low at 20–40%, and the tree height is 16–18 m. The mean age of pine and birch exceeds 100 years, and *Juniperus communis* can reach 25% of the cover projection. The microrelief is slightly rugged, consisting mainly of Sphagnum (*Sphagnum angustifolium, S. warnstorfii, S. centrale*) carpets. Hummocks are sparse, existing at the base of tree trunks. Characteristic species are similar to that for the whole Molinia series, though occurring at the frequency of bog species: *Oxycoccus palustris, Ledum palustre, Empetrum nigrum, Eriophorum vaginatum, Carex chordorrhiza, C. paupercula* and *C. globularis* is higher. The peat depth varies from 0.7 m to 6 m, usually exceeding 3 m.

12. Pinus sylvestris – Menyanthes trifoliata – Sphagnum spp. has a pine-dominated tree stand, where birch,spruce, and occasionally only pine are present. Tree height reaches14-16 m, with an average crown density of 0.5. The suppressed tree layer (grey alder, birch, spruce and pine) and shrub layer (*Sorbus aucuparia, Salix aurita, S. myrsinifolia*) are not abundant and cover an average12% of the projection. The microrelief is slightly rugged, consisting of hummocks and sphagnum carpets. The cover of the latter varies from 40% to 98%. Highly constant species consist of *Menyanthes trifoliata, Comarum palustre, Equisetum fluviatile, Sphagnum angustifolium, S. centrale,* and *S. warnstorfii*; some oligotrophic species such as *Oxycoccus palustris, Chamedaphne calyculata, Carex paupercula*; and species occurring in all types of forested mires such as *Calamagrostis phragmitoides, Vaccinium myrtillus, V. vitis-idaea* and *Pleurozium schreberi*.

Figure 3. Picea x fennica – Equisetum sylvaticum – Sphagnum girgensohnii site

Peat depth varies from 0.3 to 6 m, commonly exceeding 1.5 m. The type of vegetation communities present in the Pinus sylvestris – Menyanthes trifoliata – Sphagnum spp. association typically occur in mire margins.

13. Picea x fennica – Equisetum sylvaticum – Sphagnum spp. is characterized by a clear dominance of Equisetum sylvaticum, which covers 25–70% of the projection of the field layer (Fig. 3). The tree stands are mixed, with a dominance of spruce. The crown cover varies from 30% to 70% (at a mean of 50%), and the tree height reaches 18–20 m. The suppressed tree and shrub layer is relatively sparse, the mean cover projection being about 10%. Typical species in this association are spruce, birch, *Sorbus aucuparia, Rosa acicularis, Salix aurita*, and *S. myrsinifolia*. Other species occurring in the field layer are *Equisetum palustre, E. pratense, Dryopteris carthusiana, Vaccinium vitis-idaea, V. myrtillus, Rubus saxatilis, R. arcticus, Linnaea borealis, Orthilia secunda, Oxalis acetosella, Trientalis europaea, Maianthemum bifolium, Carex disperma, C. globularis* and *C. vaginata*. Sphagnum mosses (*Sphagnum angustifolium, S. girgensohnii, S. centrale, S. squarrosum, S. warnstorfii, S. wulfianum*) dominate in the bottom layer (40-90% of projection). Some Mniaceae species and *Calliergon cordifolium* are less abundant, while small patches of *Polytrichum commune* are typical. The peat depth is often lower than 60cm, but can reach 2m.

14. Pinus sylvestris– Equisetum sylvaticum – Sphagnum spp. is pine-dominated, with spruce, birch and occasionally aspen occurring in the tree stand. Pine height is 22–24 m, with a crown cover of 30-40% and big gaps in the canopy a typical feature. The overtopped tree and shrub layer is sparse, up to 10% of the canopy projection and consisting of spruce, birch, *Juniperus communis, Salix aurita* and *Sorbus aucuparia*. Pine saplings are rare, with the understorey vegetation composition similar to, but species number slightly lower than in a spruce association. The peat depth is usually lower than half a meter. The low abundance of pine in the suppressed tree layer, presence of *Chamaenerion angustifolium, Sphagnum wulfianum* and *S. girgensohnii* in the vegetation composition indicates a transitional state of association.

15. Picea x fennica – Vaccinium myrtillus – Sphagnum spp. is characterized by the dominance of *Vaccinium myrtillus* and *V. vitis-idaea*, which cover an average of 20% and 7% of the projection in field layer, and continuous Sphagnum (*Sphagnum girgensohnii, S. angustifolium, S. magellanicum*) carpets. *Rubus chamaemorus* is also relatively abundant. Other typical species are *Carex globularis, Chamaedaphne calyculata, Pleurozium schreberi* and *Polytrichum commune*. The forest stands are mixed, with a clear dominance of *Picea x fennica*. Spruce height is within the range of16–22 m and the crown cover is 40–70%. The suppressed tree layer consists of spruce (10% of the projection) and birch, and shrubs consist of *Sorbus aucuparia, Juniperus communis* and *Salix aurita*. The peat depth varies from 0.2m to 3 m, usually exceeding 1 m.

16. Pinus sylvestris – Vaccinium myrtillus – Sphagnum spp. has a pine-dominated tree stand, with an abundance of spruce in the suppressed tree layer (8–45% of the projection). The dominant species of the field layer are *Vaccinium myrtillus, V. vitis-idea* and *Rubus chamaemorus* (21%, 8%, and 12% of cover projection, respectively). The species composition and site properties are almost identical to spruce associations.

17. Pinus sylvestris – Ledum palustre – Sphagnum angustifolium has a pine-dominated tree stand. Tree height reaches 14–18 m, with a crown cover of 20–40%. Spruce and birch are rare in the intermediate tree layer. The suppressed tree and shrub layers are sparse and poor in species. The flora in this association is the poorest of all the studied associations. Highly constant species include *Eriophorum vaginatum, Ledum palustre, Chamedaphne calyculata, Oxycoccus palustris, Rubus chamaemorus, Vaccinium uliginosum, Sphagnum angustifolium, S. magellanicum* as well as typical forest species such as *Vaccinium myrtillus, V. vitis-idaea and Pleurozium schreberi. Carex lasiocarpa* and *Aulacomium palustre* are present in half of the sites, and the sphagnum moss cover is 80-95% of the bottom layer. The peat depth varies from 0.6 m to 5 m, usually exceeding 2 m.

Many of the associations or similar syntaxa were previously described for other regions of European Russia and Finland (Смирнова 1928; Василевич 1997, 2004; Василевич & Щукина. 2001; Eurola et al. 1984; Heikurainen 1978). The forested mires of eastern Fennoscandia demonstrate a unique combination of different sites. Classification is open-ended, and new syntaxa may still be added. It should be noted that several sample plots were excluded from the assemblage of the present associations and due to this, there is a lack of material that prevents the distinguishing of new associations.

Species richness

The forested mires in the middle boreal zone of Karelia have a rich, diverse vegetation. Most of the communities have a rugged microrelief, with a combination of hummocks at the base of tree trunks, low hummocks, lawns and flarks. This leads to a mosaic like vegetation structure and presence of species, indicating different ecological origins.

Dry forest species are found on hummocks at the base of tree trunks in all the forested mire associations. Species of paludifying forests dominate in the Equisetum–Sphagnum series and are frequent on low hummocks in sites of the Filipendula, Calamagrostis and Vaccinium–Sphagnum series. There is presence of some groups of species typical for herb-rich forests such as *Athyrium filix-femina, Dryopteris expansa, Geum rivale, Cirsium oleraceum, C. heterophyllum, Calamagrostis canescens, Filipendula ulmaria, Crepis paludosa, Viola epipsila, Sphagnum squarrosum*, and *Climacium dendroides*; this group is prominent and characteristic of low hummocks and intermediate level in the Athyrium, Filipendula and Calamagrostis series, but less abundant in the Carex–Menyanthes and Molinia–Sphagnum series. In contrast, species like *Calla palustris, Carex cinerea, C. elongata, C. disperma, Caltha palustris, Ranunculus repens, Naumburgia thyrsiflora, Calliergon cordifolium, Calliergonella cuspidata, Pseudobryum cinclidioides* and *Plagiomnium ellipticum* are abundant on flarks. Indicators of wet yet less fertile conditions, species of strings and lawns of meso- eutrophic mires dominate in the Carex–Menyanthes and Menyanthes–Sphagnum series but occur less abundantly on flarks within sites colonized by the Filipendula, Calamagrostis and Molinia–Sphagnum series. Bog species, indicating poor nutrient conditions, dominate the Pinus sylvestris – Ledum palustre – Sphagnum angustifolium association and also frequent hummocks in sites colonized by theVaccinium–Sphagnum, Molinia–Sphagnum and Menyanthes–Sphagnum series.

Table 2. Number of species by vegetation layer. n = number of plots; layers: A = tree, B = shrub, C = dwarf-shrub and grass, D = moss; H = number of highly constant species. Association ordering follows that in the main text.

Association	n	Number of species in association					Avgerage number of species per plot			
		Layers					Layers			
		A+B	C	D	Σ	H	A+B	C	D	Σ
1	7	16	69	32	117	26	9	28	10	47
2	13	18	70	38	126	28	8	24	12	44
3	16	24	93	38	155	17	8	25	12	43
4	34	25	106	51	182	30	9	28	11	48
5	25	27	114	46	187	36	8	33	12	53
6	28	28	112	55	195	28	9	28	11	48
7	14	25	105	37	167	29	7	32	12	51
8	12	16	74	32	122	27	6	25	10	41
9	5	15	63	20	98	39	8	30	9	47
10	5	15	61	30	106	31	8	26	11	45
11	6	13	65	161	104	31	6	30	10	46
12	14	18	72	31	121	14	6	19	8	33
13	18	17	81	35	133	18	6	20	10	36
14	10	16	61	26	103	22	8	18	11	37
15	20	9	37	22	68	8	3	9	7	19
16	7	6	18	16	40	13	3	9	6	18
17	11	8	29	17	54	15	3	12	6	21
Total	251	34	185	77	296	12				39

The mean number of vascular plants and mosses on the plot, as well as in the associations show significant variation. The total number of species in association is largest in the Filipendula series (Table 2) and lowest in the Vaccinium-Sphagnum and Ledum-Sphagnum series. The mean number of species per plot is highest in the Filipendula series, but also relatively high in the Calamagrostis, Athyrium and Molinia-Sphagnum series. Sites with the poorest species diversity are associated with locations colonized by the Vaccinium-Sphagnum and Ledum-Sphagnum series.

Main compositional gradients

Detrended Correspondence Analysis (DCA) was used to extract the main compositional gradients of the forested mire vegetation and to discover the distribution of the sample plots against the obtained vegetation compositional gradients. The correlation of certain environmental variables of the obtained gradients was tested to aid the ecological interpretation of the ordination results. Using a Jaccard distance measure, the coefficients of the first three axes were determined to be 0.60, 0.08, and 0.05 respectively.

While sample plots of the same associations were grouped together, no distinct clusters on the sample plot ordination space were observed (Fig. 4). The first DCA axis correlates significantly with moisture and runs parallel to the fertility gradient. The second axis has a relatively low correlation with the light factor (shading) and humidity, and the third axis correlates weakly with humidity. The increase in wetness is assumed to lead to a decrease of stand and shrub layer density, and in the case of wet communities the light factor and humidity can be said to be interrelated. The peat depth weakly correlates with the second axis.

The first axis clearly distinguishes the rich sites of the Athyrium and Filipendula series on the left from the poor Ledum- and Vaccinium–Sphagnum series on the right. The vertical gap seen near the center of the ordination is likely to reflect the boundary between meso-eutrophic and meso-oligotrophic communities (Fig. 4). In the former, in addition to the above-mentioned associations, are Calamagrostis, Menyanthes–Carex, and spruce and birch associations from the Molinia series. In the latter, the Pinus sylvestris–Molinia caerulea–Sphagnum angustifolium association and associations from the Equisetum– and Menyanthes–Sphagnum series prevails. The second axis distinguishes the wet Carex–Menyanthes and Menyanthes–Sphagnum series at the top from the drier and shaded Equisetum– and Vaccinium–Sphagnum series on the bottom. Other series remain in the centre of ordination spaces. Species richness is significantly correlated with the first axis (Fig. 4), thus indicating an increase in species richness along the fertility gradient, which was noted to be highest in the Filipendula series (see also Table 2).

The crucial influence of fertility and soil humidity on species composition of boreal forested mires has been argued by many authors (e.g., Сукачев 1928; Лопатин 1985; Eurola et al. 1984; Korpela & Reinikainen 1996); however, the importance of the light factor on species composition in forested mires requires further investigation.

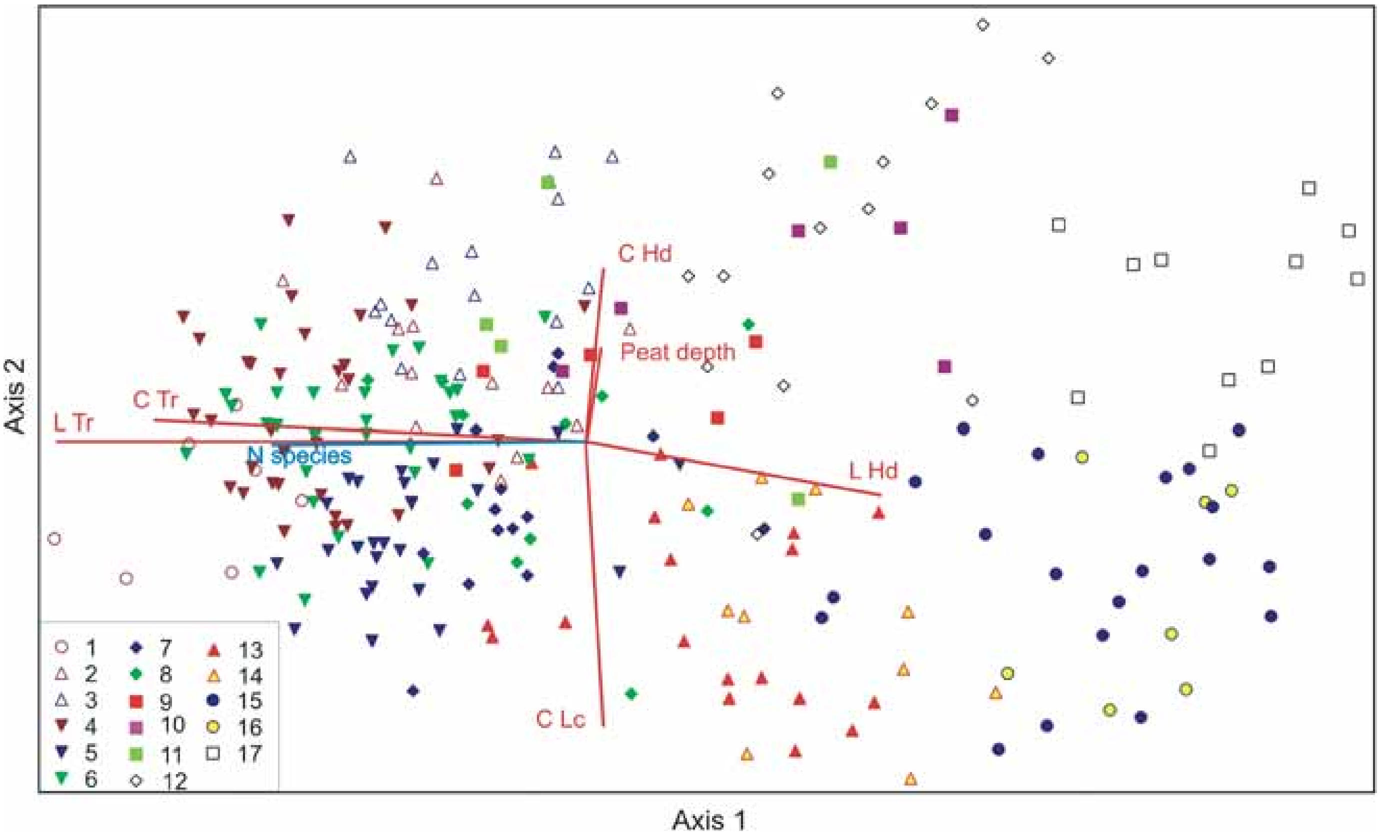

Figure 4. DCA ordination of the 251 forested mire sample plots for axes 1 and 2, with the vectors of passive explanatory variables. Association ordering follows that in the main text. The explanatory variables (gradients) are: L Tr and L Hd = trophy and humidity calculated by the ecoscales of Лопатин (1985); C Tr, C Hd and C Lc = trophy, humidity and light factor calculated by the ecoscales of Цыганов (1983). N species = number of species per plot.

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Mire flora and vegetation and their conservation in the Republic of Karelia, Russia

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Introduction

The Republic of Karelia (hereafter termed 'the Republic') is situated in the boreal zone, in East Fennoscandia, and is one of the most paludified regions of the world. Due to a peculiar combination of geomorphological and climatic factors, mires and paludified ecosystems occupy a third of its territory (5.4 million ha). High variation of natural settings in the region has resulted in the formation of mire ecosystems of various types. Most mires in Karelia have remained undisturbed, and only approximately 20% of them were drained during the 1960s-1980s for forestry and agricultural purposes. The paper briefly summarises the results of studies on the flora and classification of vegetation of undisturbed mires in the Republic, as well as on biodiversity conservation there.

Methods

The plant cover of mires was studied in situ, with the mapping of species distribution and identification of plant syntaxa. The topological-ecological classification of vegetation was developed using ecological groups of species (Kuznetsov 2003; Кузнецов 2005) and basic principles of classification of North European vegetation (Påhlsson 1994).

Results

Conservation of biodiversity at the species and community levels in any region should be based on the study of the floristic composition and classification of plant communities. Peculiar ecological conditions in mires are responsible for the specificity of their floristic composition and community structure.

Vascular plant flora in mires

We regard the flora of mires as that pertinent to a specific group of biotopes. Vascular plants in the mires of Karelia comprise 300 species belonging to 145 genera and 65 families. This represents 18% of the regional and 32% of the native flora, the latter of which comprises 926 species (Кравченко & Кузнецов 2005). This fact points to heavy biotopic selection of species during the formation of the mire flora and vegetation.

Variation of the species richness of mire flora among regions of the boreal zone is quite moderate – from 200 to 380 species, but differences in the taxonomic structure are significant. The mire flora most similar in species number and composition are those of Karelia (300 species) and Finland (287 species – Eurola *et al.* 1984). They share 262 species, the Jaccard similarity coefficient (Kj) being 0.81. The mire flora of Karelia and Northwest Russia (357 species – Боч & Смагин 1993) have a much lower similarity at the species level, sharing 216 species, with Kj equalling just 0.53. Significant differences between the mire flora of these two adjacent regions are due not only to the floristic and phytogeographic features of the regions, but also to the subjective interpretations of the authors of the mire flora checklists. Both checklists contain species present in mires of the adjacent region; however, the authors have not reported these species in their own studies.

Boreal mire flora has formed through migration of species from various habitats and their adaptation to harsh conditions. Its specificity is low – 128 species (43%) of the Karelian mire flora are classified as "exclusive" to mires, showing preference for such habitats (constancy classes III-V in Braun-Blanquet system). Many species in mires are facultative, often occurring in other habitats as well. Taxonomic spectra of the regional and mire floras of Karelia differ significantly (Table 1). Compared to the regional flora, mires have a greater proportion of the families *Cyperaceae, Orhidaceae, Salicaceae, Ericaceae, Equisetaceae* and *Onagraceae* in the cover, but a lower proportion of *Asteraceae, Brassicaceae, Caryophyllaceae* and *Ranunculaceae*. This proves that mire habitats are more hydrophilous but have a lower heat supply.

Table 1. Composition of the most abundant families in the regional and mire floras of Karelia and Finland. N refers to number of species,% indicates the abundance of species in each family, and R refers to the ranking of each family in the mire flora of Karelia (1) and Finland (2), and in the regional flora of Karelia (3). Free-standing dashes represent the position of the family in the spectrum as being lower than the 10th.

Family	1			2			3		
	N	%	R	N	%	R	N	%	R
Cyperaceae	61	20.3	1	68	23.7	1	96	10	1
Poaceae	25	8.3	2	24	8.3	2	85	8.9	2
Orchidaceae	18	6.0	3	13	4.5	4	33	3.4	8
Salicaceae	17	5.6	4	15	5.3	3	24	2.8	–
Asteraceae	12	4.0	5	10	3.5	5-7	70	7.3	3
Rosaceae	11	3.7	6	10	3.5	5–7	50	5.3	4
Ericaceae	9	3.0	7	10	3.5	5-7	–	–	–
Caryophyllaceae	8	2.7	8-10	7	2.5	8-10	46	4.8	5
Equisetaceae	8	2.7	8-10	7	2.5	8-10	–	–	–
Onagraceae	8	2.7	8-10	7	2.5	8-10	–	–	–
Ranunculaceae	–	–	–	–	–	–	40	4.2	6
Scrophulariaceae	–	–	–	–	–	–	35	3.8	7
Brassicaceae	–	–	–	–	–	–	30	3.1	9–10
Fabaceae							30	3.1	9–10
Summary	177	59.0		171	59.8		505	52.7	

A big group of species (69) with rare and sporadic occurrence has been identified in the mire flora of the Republic. A variety of factors are responsible for that: location at the margin of the distribution range, rarity of habitats, low competitive capacity in other communities, etc. (Кузнецов & Дьячкова 2005). They are all in need of certain protection and biological control at the regional level (Table 2). Nine species from the list are included in the Red Data Book of the Russian Federation (Тахтаджян 1988), 38 species in the Red Data Book of Karelia (Ивантер & Кузнецов 1995), and 43 species of the Karelian mire flora have different IUCN categories in the Red Data Book of East Fennoscandia (Kotiranta *et al.* 1998). These data prove that mires play an important role in maintaining the floristic diversity of the region, and that typical and unique mires should be protected. The established network of protected mires in the Republic as it exists today, cannot ensure adequate protection of the whole diversity of mire species and communities (Антипин & Кузнецов 1998) in the Republic.

Mire bryoflora

An essential component of mire communities is mosses. The bryoflora of Karelia's mires is known to comprise 133 species. They belong to 46 genera and 19 families (Кузнецов & Максимов 2005), accounting for 28% of Karelia's regional bryoflora (470 species – Максимов 2006). Very similar is the composition of mire bryoflora of Karelia and Finland, the latter made up of 129 species (Eurola *et al.* 1984). They share 111 species, Kj being 0.88. Mires of Northwest Russia harbour 127 moss species of 23 families (Боч & Смагин 1993), but the species composition of moss flora in Karelia

Table 2. Protected and threatened vascular plants in the mires of Karelia. Figures in brackets show the conservation status (IUCN category) in the Red Data Books of Karelia (Ивантер, Кузнецов 1995) and Russia (Тахтаджян1988); dashes refer to species not designated as red-listed in Russia. *Species without a red-list designation and recommended for inclusion in the new edition of the Red Data Book of Karelia.

Group	**Species**
I. Rare species (8)	Carex bergrothii (3,–); C. heleonastes*; C. laxa (2,3); C. jemtlandica (3,–); C. scandinavica, C. tenuiflora; Malaxis monophyllos (2,-), Stellaria fennica
II. Species of rare habitats (9)	Angelica archangelica (3,–); Carex appropinquata; C. capitata; Eleocharis quinqueflora; Equisetum variegatum; Eriophorum brachyantherum (4,–); Poa remota; Saxifraga hirculus; Schoenus ferrugineus (3,–)
III. Species at the margin of the distribution	
III.1. Northern margin (18)	Betula humilis (4,–); Carex acutiformis (3,–); C. disticha (4,–); C. pseudocyperus (3,–); C. riparia (3,–); C. vulpina (1,–); Dactylorhiza longifolia (4,2); Dryopteris cristata; Epipactis palustris (3,-); Glyceria lithuanica; Iris pseudacorus; Liparis loeselii (1,3); Lycopus europaeus; Ophrys insectifera (0,2); Rumex hydrolapathum; Stellaria uliginosa; Thelypteris palustris; Viola persicifolia (3,–)
III.2 Southern margin (17)	Carex adelostoma (3,–); C. livida (3,4); C. media (3,–); C. norvegica (1,–); Dactylorhiza lapponica; Epilobium alsinifolium (3,–); E. davuricum (3,–); E. hornemannii (3,–); E. lactiflorum; E. laestadii; Juncus triglumis (3,–); Pinguicula alpina (3,–); P. villosa; Ranunculus lapponicus; Sanguisorba polygama; Saxifraga aizoides (3,–); Stellaria calycantha (3,–)
III.3. Eastern margin (6)	Lycopodiella inundata; Myrica gale (1,2); Rhynchospora fusca(3,3); Salix repens (2,–); Utricularia stygia
III.4. Western margin (4)	Carex atherodes; Ligularia sibirica, Rubus humulifolius (3,–); Trisetum sibiricum (3,–)
IV. Slowly reproducing species (6)	Coeloglossum viride, Cypripedium calceolus (4,3); Dactylorhiza cruenta (3,–); D. incarnata; D. traunsteineri (4,2); Hammarbya Paludosa

and Northwest Russia differs significantly. They share 93 species, Kj of the bryofloras being as low as 0.58.

Spectra of the leading families by the number of species and their contributions to the regional and mire bryofloras of the Republic differ notably (Table 3). The most common family in the mire bryoflora is *Sphagnaceae*, although it exists as the third most common family in the regional flora. On the contrary, while *Dicranaceae* is only the third most common family in mires, it exists as the most common family in the regional bryoflora. The abundance of some moss families comprising hydrophilous species (*Mniaceae, Splachnaceae, Helodiaceae* and *Meesiaceae*) is much higher in mires. The spectra of the leading families in bryofloras of Karelia and Northwest Russia (Боч & Смагин 1993) are nearly identical (Table 3).

Species “exclusive ” to mire ecosystems prevail in the mire bryoflora, accounting for 74%. A significant contribution of 23% is made by indifferent species, whereas accidental species contribute only 3%. These figures show that mire bryoflora is more specific than the flora of vascular plants (42% of “loyal” species). Some moss species growing in mires are rare for the region, and 8 of them (*Sphagnum affine, S. denticulatum, S. molle, S. palustre, S. subnitens, Splachnum vasculosum, Tayloria lingulata* and *Cinclidium subrotundum*) are included in the Red Data Book of Karelia (Ивантер & Кузнецов 1995). For these species, mires are the key habitats, and it is only by conserving mires and pertinent populations that one can ensure preservation of the species. As with vascular plants, the list of moss species in need of protection in the Republic has to be revised and updated, and a new edition of the Red Data Book of Karelia should be prepared taking the new data into account.

Table 3. Abundance of families in the regional and mire bryoflora of Karelia and mire bryoflora of NW Russia. N refers to number of species,% indicates the abundance of species in each family, and R refers to the ranking of each family in the regional (1) and mire (2) bryoflora of Karelia and mire bryoflora of NW Russia (3). Free-standing dashes represent the position of the family in the spectrum as being lower than the 10th. * Figures in brackets indicate number of species in families below the ten most common families. ** Dashes indicate that no species of the family are present in the mire bryoflora.

Family	**1**			**2**			**3**		
	N	**%**	**R**	**N**	**%**	**R**	**N**	**%**	**R**
Dicranaceae	46	10	1	11	8	3	8	6	4
Amblystegiaceae	45	10	2	24	18	2	24	19	2
Sphagnaceae	39	9.0	3	37	28	1	35	27	1
Bryaceae	34	8.0	4	6	4	6-7	6	5	5-6
Grimmiaceae	29	6.5	5	-**	-	-	-	-	-
Brachytheciaceae	28	6.5	6	7	5	5	6	5	5-6
Hypnaceae	27	6.5	7	(3)		-	4	3	7-9
Mniaceae	20	4.5	8	9	7	4	13	10	3
Pottiaceae	19	4.0	9	-	-		-	-	-
Polytrichaceae	17	4.0	10-11	4	3	10-12	4	3	7-9
Orthotrichaceae	17	4.0	10-11	-	-	-		-	-
Splachnaceae	(10)*			6	4	6-7	(3)		
Meesiaceae	(5)			4	4	10-12	(3)		
Bartramiacea	(8)			5	4	8-9	(3)		
Hylocomiaceae	(7)			5	4	8-9	(3)		
Helodiaceae	(6)			4	3	10-12	(1)		

Mire vegetation

The plant cover of mire ecosystems has a complex structure, and is therefore studied at several (3 to 7) levels – from mire complex systems to mire communities. The latter is the most informative level in terms of the diversity of mire ecosystems of any large region. Specific methods of study and principles of classification are used for each level, and the main criteria for distinguishing between classification units are the composition and structure of the plant cover. The paper is limited to a brief review of the classification of Karelia's mire communities.

Methods of classifying vegetation have been discussed by phytocoenologists for over a hundred years. Some methods and principles of classification of communities have been developed. The main principles relate to dominant, floristic and topological-ecological features. Each method has its own syntaxonomic units and criteria for identifying them. The lowest units in most classifications are associations, their ranges varying substantially depending on author. Classification of mire communities of Russia and Scandinavia has been the subject of many papers. The classifications were developed using different methods, making comparisons problematic. Many publications lack tables showing complete species composition of the syntaxa described, which also hinders comparative work, especially for different regions.

In the mid-1980s, the Mire Ecosystems Lab started pooling geobotanical relevés for developing the classification of mire vegetation. The data bank now contains ca. 5000 relevés. After different options were considered, the topological-ecological approach, which is widely used in Scandinavia and Canada (Jeglum 1991, Påhlsson 1994) was chosen. Such classifications are based on the combination of the ecological features of habitats with phytocoenotic parameters of the communities themselves. In order to distinguish between the lowest ranking units of classification, dominant species and diagnostic groups of species are widely used. Based on the classification of vegetation compiled for Northern Europe a topological-ecological classification of Karelian mire vegetation was developed (Kuznetsov 2003; Кузнецов 2005). We established 12 ecological groups of species embracing the whole mire flora of the region (woody species excluded), which were used to differentiate syntaxa at different levels of the classification (Кузнецов 2005).

The classification consists of three steps. Syntaxa are distinguished during the various steps according to ecological, phytocoenotical and topological criteria (groundwater level and regime, pertinence to microrelief features). Various criteria and features are used in all methods of classifying vegetation. To make the application of the classification more convenient, each syntaxon is given a code with one digit for classes, two for groups, etc.
The highest units of the classification, classes, are singled out with regard to the level of water-mineral nutrition. There are four such classes: ombrotrophic, oligotrophic, mesotrophic and eutrophic (Table 4). The same types of mineral nutrition are distinguished for mires in Scandinavia (Eurola *et al.* 1984; Påhlsson 1994), the scope of which differs somewhat from mire types described in earlyRussian papers (e.g., Лопатин 1972, Пьявченко 1972). The ombrotrophic class corresponds to the oligotrophic class in Russian mire science and comprises communities fed by precipitation. The spectra of the eutrophic and mesotrophic classes are narrower than in Russian classifications, and the oligotrophic class corresponds to the meso-oligotrophic subtype distinguished by some Russian researchers (Лопатин 1972). Of primary importance in categorizing the relevés and placing syntaxa into a given class was the set of ecological groups of species within them.

Table 4. Topological-ecological classification of mire vegetation in Karelia

CLASS	**Group of associations**	**No of associations**
OMBROTROPHIC	Tree-Sphagnum	2
	Hummock	3
	Carpet	1
	Hollow	5
OLIGOTROPHIC	Tree-Sphagnum	2
	Hummock	1
	Carpet	2
	Flark	4
MESOTROPHIC	Tree-herb	4
	Carpet	1
	Flark	8
	Swamp	8
EUTROPHIC	Tree-moss	3
	Hummock	3
	Carpet	4
	Flark	3
	Hypnum spring	3
TOTAL		57

Within each class, four groups of associations are distinguished by virtue of their proximity to the main elements of microrelief which differ in terms of hydrological conditions.

Group 1 consists of forested communities characterized by highly variable hydrological conditions during the growing season, which support the existence of the tree storey made up of mesophilic tree species with no specialized morphological adaptations to life in mires. The flora of these communities contains a wide range of both mire- and forest-affiliated species. Communities which make up groups of forested associations have tree storeys with a canopy closure of at least 0.2.

Group 2 is formed by communities restricted to high Sphagnum hummocks (ridges) with groundwater levels which fall by 25-40 cm during the summer. Mire dwarf shrubs are quite abundant in all of the communities.
Group 3 comprises various herb-Sphagnum associations pertinent to lawns (carpets) under which the groundwater level falls by 10-20 cm during the growing season. Herb and herb-moss communities of hollows and flarks form Group 4. Even in summertime, the water there stays just several centimetres below the surface of mosses (or peat, where the moss layer is absent) or even covers it.

In the ombrotrophic, oligotrophic and eutrophic classes, all four groups are represented – from forested ones to those of hollows and flarks; the mesotrophic class lacks the hummock group. Being rather poorly studied so far, spring mire communities of Karelia are singled out into a special spring group within the eutrophic class, contrary to the systems of classification of Northern Europe (Påhlsson 1994) and Finland (Eurola et al. 1984), where they form a separate class. Their taxonomic status will be clarified as more materials become available.

The basic unit in this system of classification is the association. Associations were identified using a number of ecological criteria used both in the dominant and in the ecological-floristic methods of classification: presence and contribution of different ecological groups, ecological proximity of the dominants and co-dominants of the main community layers. Often, absence of species from certain ecological groups from the community is a more reliable diagnostic trait than the dominance of a certain species, since the latter may sometimes be accidental. For each association, diagnostic species have been identified which show average or high constancy there (or in one of its sub-associations), and most accurately reflect its appearance, structure and ecological properties. In many associations, and especially in the sub-associations and variants within them, these diagnostic species simultaneously dominate respective layers. This is true first of all for communities with few species, which develop under the most severe environmental conditions (e.g., *Eriophorum vaginatum, Scheuchzeria palustris* and *Sphagnum majus* in ombrotrophic hollows), as well as for the communities that formed when the coenosis was optimal for the species which was a powerful community-builder (e.g., sedge stands of *Carex lasiocarpa, C. cespitosa, C. diandra*). Some mesotrophic and eutrophic communities, especially forested ones, often lack distinct dominants of the herb-dwarf shrub layer, and only a large group of diagnostic species, each relatively unabundant, allows for such syntaxa to be distinguished. Diagnostic species of most associations belong to several ecological groups, some species being diagnostic for several associations when found in combination with various species, which may sometimes belong to different classes (e.g., *Carex lasiocarpa*).

Associations are assigned names according to 1 or 2 diagnostic species of each layer, the names including two to four scientific names of plant taxa written with intervening dashes. Some associations are split up into sub-associations and variants with respect to the species that dominate particular layers. In dwarf shrub-moss and herb-dwarf shrub-moss associations with the compositionally similar dwarf shrub-herb layer, sub-associations are distinguished with respect to dominant moss species with similar ecological ranges, which replace each other without any transformation of the community structure. Moss-free (herb) and herb-moss sub-associations are distinguished within some herb and herb-moss associations, the overall appearance and composition of the herb layer remaining unchanged. Variants of associations are distinguished according to the dominant dwarf shrub- or herb layer species, the general composition of the moss layer and structure of the communities remaining the same. When an association comprises several sub-associations, it is named after the most typical and widespread one. Species constancy, species richness, floral composition (number of vascular plant, moss and lichen species) and mean species saturation were determined for each association and the syntaxa distinguished within them (Кузнецов 2005). A sample summary table for one association in comparison with a similar syntaxon from adjacent regions is presented in Table 5. The association belongs to the flark group of the oligotrophic class.

Discussion

Comparison of different classifications

The associations of Karelian mire vegetation identified and described through this procedure correlate well with the syntaxa distinguished by supporters of the dominant and ecological-floristic methods both in Karelia and in neighbouring regions. Many of our associations correspond to groups of associations or, sometimes, to formations, and our sub-associations – to associations in classifications based on the dominant principle (Osvald 1923; Юрковская 1987). In turn, many of the associ-

Table 5. Association *Rhynchospora alba – Menyanthes trifoliata – Sphagnum papillosum* (**I**) and its sub-associations: **A** – *Rh. alba – M. trifoliata – S. papillosum*, **B** – *Rh. alba – M. trifoliata* **–** *S. pulchrum*, **C** – *Rh. alba – M. trifoliata* in Karelia and association *Menyantho–Rhynchosporetum albae*(**II**) (adapted from Смагин1999)

			I	**A**	**B**	**C**	**II**
Ecol.		No of relevés	25	9	7	9	12
group		Species richness	42	38	17	32	
		Average species density	12	14	10	9	
		No of species of constancy classes III-V	9	14	11	7	7
2		*Drosera rotundifolia*	II	II	V$_1$	–	–
3		*Betula nana*	II	III	–	–	II
		Andromeda polifolia	IV$_1$	V$_1$	V$_1$	II	V
		Oxycoccus palustris	III	IV$_1$	IV$_1$	I	IV
		Eriophorum vaginatum	II	II	III$_1$	I	+
		Carex pauciflora	II	III	r	–	–
4		*Carex limosa*	IV$_1$	IV$_1$	V$_1$	IV$_1$	V$_1$
	$\mathrm{D}^{\mathrm{I}*}$	*Scheuchzeria palustris*	IV$_1$	IV$_{1\ 1}$	V$_2$	IV$_1$	V$_1$
	D^{I}	*Rhynchospora alba*	V$_{2-3}$	V$_{2-3}$	V$_2$	V$_{2-3}$	V$_2$
		Drosera anglica	IV$_1$	IV$_1$	III$_1$	IV$_1$	II
5		*Carex lasiocarpa*	III$_1$	III$_1$	r	III$_1$	–
		C. rostrata	II	III$_1$	II	I	–
	D^{I}	*Sphagnum papillosum*	III$_{1-4}$	V$_4$	V$_{1-2}$	–	II
	D^{I}	*S. pulchrum*	II	–	V$_5$	–	–
		Molinia caerulea	I	III$_1$	–	–	–
	D^{I}	*Menyanthes trifoliate*	V$_1$	IV$_1$	V$_1$	V$_1$	V$_2$
		Eriophorum polystachion	II	II	–	I	I
		Equisetum fluviatile	II	II		II	II
		Utricularia intermedia	I	r	r	II	III$_1$
10		*Phragmites australis*	I	–	–	III	–

*D$^{\mathrm{I}}$ indicates the diagnostic species of Association I.

ations are close in scope or fully correspond to the associations distinguished by the ecological-floristic method (Dierssen 1982; Боч & Смагин 1993; Смагин 1999) (tab. 5).

The topological-ecological classification of Karelian mire vegetation was compared with that of Northern Europe (Påhlsson 1994). Compositionally and ecologically similar syntaxa of different ranks were selected from North European mires for almost every association identified (Кузнецов 2005). However, there are significant distinctions between the classifications in terms of the range of some classes and of some lowest-ranking units, such as "types" in the system of classification employed in Northern Europe and "associations" in our classification. Since the oligotrophic and mesotrophic herb and herb-moss communities of Karelian mires are subdivided into smaller units, a whole range of new associations were distinguished. On the one hand, Karelia lacks the mire communities characteristic of the nemoral, mountain and tundra areas of Scandinavia, and the coastal mires of Norway. On the other hand, some associations restricted to areas with a more continental climate occur in Karelia and eastern Finland at the western boundaries of their distribution ranges, and have not been reported from anywhere in Sweden or Norway. Examples include ombrotrophic dwarf shrub-*Sphagnum* communities with *Chamaedaphne calyculata*, and mesotrophic and eutrophic communities with *Carex omskiana, Bistorta major, Betula humilis* and *Ligularia sibirica.* Associations dominated by *Carex livida, Rhynchospora fusca* and *Schoenus ferrugineus,* communities with the moss layer dominated by *Sphagnum subfulvum, S. subnitens and S. pulchrum* reach the eastern boundaries of their distribution range in Karelia.

The classification is open-ended insofar as new syntaxa can be included and their ranks revised. As the study area is expanded, the distribution ranges of associations and sub-associations will be specified and their geographic variants identified. The classification is convenient for solving scientific and practical tasks as it allows many associations to be easily identified already in the field. Further research into the plant cover of mires in Karelia and adjacent parts of Fennoscandia will increase our knowledge of their diversity and enable adequate conservation measures to be taken.

Conservation of the biodiversity of Karelian mires

Establishment of the network of protected areas (PAs) of different ranks began in Karelia in the mid-1970s. At present the Republic has 264 PAs with a combined area of over 950,000 ha (Государственный доклад… 2006). Most PAs include mire ecosystems of some kind, and over 130,000 ha of mires are protected (Антипин & Кузнецов 1998). Quite a number of PAs have been designated specifically to conserve mires (4 mire reserves and 65 mire nature monuments). Substantial and highly diverse mire areas are protected within the national parks Vodlozerskiy, Paanajärvi, Kalevalskiy, strict nature reserves Kostomukshskiy and Kivach, as well as within a number of large landscape and zoological reserves (e.g., Sorokskiy, Tolvajärvi, Shaidomskiy, Olonetskiy, Kizhskiy, etc.). A majority of Karelian mire complexes and the main vegetation syntaxa, as well as rare plant species are represented in the PAs. In general, however, the network of protected mires in Karelia is insufficient (only 3% of mires in the Republic are protected), wherefore the programme has been worked out for optimizing the network (Антипин & Кузнецов 1998).

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Mire types of the southern part of Kenozero National Park, Arkhangelsk region, NW Russia

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Introduction

Variable types of mires and divers plant communities were studied in the southern part of Kenozero National Park. The most interesting type is aapamire. Earlier it was supposed that aapamires are azonal mire massif types spread only in Fennoscandia and Northern Ural. Later an idea about zonal distribution of aapamires in Russia was developed (Юрковская, 1992). However, considering aapamires as zonal types we must take into account the discrete character of their distribution. They occur in suitable geomorphological and hydrological conditions. Data about this mire type are not sufficient. In the territory of Russia, aapamires are divided into 3 groups: Forest-Tundra (Lapland), Karelia and Onega-Pechora mire massifs (Юрковская, 1992). Forest-Tundra aapa mire type is characterized by dwarf shrub – cloudberry - *Sphagnum fuscum* ridges and sedge-*Sphagnum* (*Carex rariflora, C. limosa, C. rotundata, C. aquatilis, Eriophorum polystachion, E. russeolum, Menyanthes trifoliata, Sphagnum lindbergii, S. jensenii, S. majus, S. riparium*) flarks. Dwarf shrub – cloudberry *Sphagnum* communities are found along the margins. Its western variant has *Molinia caerulea* and *Calluna vulgaris* on the ridges.

Karelian aapa mire type has typically dwarf shrub – *Molinia*-sedge-*Sphagnum* ridges (*Betula nana, Calluna vulgaris, Carex lasiocarpa, Trichophorum cespitosum, T. alpinum, Sphagnum papillosum, S. fuscum, S. warnstorfii*) with *Pinus sylvestris* and *Juniperus communis*, and sedge or sedge-*Hypnum* flarks (*Carex limosa, C. livida, C. chordorrhiza, C. lasiocarpa, Equisetum fluviatile, Menyanthes trifoliata, Utricularia intermedia, Scorpidium scorpioides*). Pine - dwarf shrub- sedge-Sphagnum mire sites are found in the margin parts.

Onega-Pechora aapa mire type has treeless sedge-*Sphagnum* ridges without *Molinia caerulea* and *Calluna vulgaris*, and sedge or sedge-*Sphagnum* flarks (*Carex limosa, C. lasiocarpa, Eriophorum polystachion, Scheuchzeria palustris, Menyanthes trifoliata, Sphagnum jensenii, S. majus*) without *Carex livida* and *Trichophorum alpinum* in the flarks. Dwarf shrub- sedge-*Sphagnum* mire sites are found in the margin parts. They are either treeless or have pine stands.

There are two reasons making the aapamires in the south-west part of Arkhangelsk region very interesting. For one thing, the aapamires of Kenozero National Park are situated near the southern border of their natural distribution. Secondly, they are located near the border of Onega-Pechora and Karelia aapa types. Here Onega-Pechora and Karelia mire massif types are overlapped. Due to such disposition, these mires have specific features as well in landscape as in plant communities. Longitudinal differences in species composition of plant communities can be distinguished even in the park territory. The aapamires, which are similar to the Karelia type are located to the west from Lekschmozero lake. There are dense stands of low pines growing on the ridges. The sedge layers are formed by *Carex lasiocarpa*, and the moss layer by *Sphagnum warnstorfii*. In the flarks there is a moss layer formed by *Scorpidium scorpioides*. These mires are different from Karelia aapa mires by the absence of *Calluna vulgaris* and *Molinia caerulea* on the ridges, and *Carex livida* in the flarks, and the constant and abundant presence of *Rhynchospora alba* in flarks. The massifs near the eastern border of the Park are similar to Onega-Pechora type. The regional features differing it from typical Onega-Pechora aapamires are the presence and domination of *Trichophorum alpinum* on the ridges and *Rhynchospora alba* in the flarks. A regional feature of aapa mires is the presence of Menyantho-Rhynchosporetum albae communities. Probably they spread on the aapamires only near the southern border of their natural distribution. The constancy and abundance of the eastern species *Sphagnum jensenii* is a regional feature in the aapamires of the National Park.

The nomenclature of vascular plants follows Черепанов (1995), and that of mosses Игнатов & Афонина (1992).

Vegetation and flora of the mires in the study area

Kenozero National Park is located in the south-western part of Arkhangelsk region (Fig. 1) near the Karelian Republic and Vologda region border. The Baltic – White Sea watershed runs across this territory. It belongs to the middle taiga zone. There are all forms of moraine relief here. Limestone and marble rock often appear on the surface. The spruce-*Sphagnum* and spruce-blackberry forests are dominant. There are different communities of pine forest. Mires of different types: bogs, aapamires, wooded fens and sedge fens occur around the lake Lekschmozero in the southern part of the park.

Bogs

Bogs are widely spread over the investigated territory. They are eccentric treeless ridge-hollow bogs and pine bogs. Pine bogs usually occupy small depressions. They are covered by monotonous pine - dwarf shrub - *Sphagnum* communities. Eccentric treeless ridge-hollow bogs with the presence of hummock-hollow complexes occupy large areas. Dwarf shrub-*Sphagnum fuscum* communities with low pines grow on hummocks. *Sphagnum*-cottongrass communities are typical for bog hollows. Vegetation changes from ridge-hollow complex to carpet hummock complex are the following: Ledo – Sphagnetum fusci + Eriophoro vaginati – Sphagnetum baltici or Scheuchzerietum palustris in hollow —> Scheuchzerietum palustris + Chamaedaphne – Sphagnetum magellanici. A regressive mud-bottom complex was recorded once, and it was covered by a regionally rare community Hepatico – Rhynchosporetum albae. The absence of *Empetrum nigrum* is a specific floristic feature of local treeless bogs.

Transitional mires

Transitional mires sites are situated along the bog or aapamire margins. The plant communities consist of very few species such as *Carex rostrata* (dominant species), and *Sphagnum fallax, S. papillosum* and *S. angustifolium,* which form the moss layer. Large transitional massifs were not found. However in the Park there are heterogenic massifs.

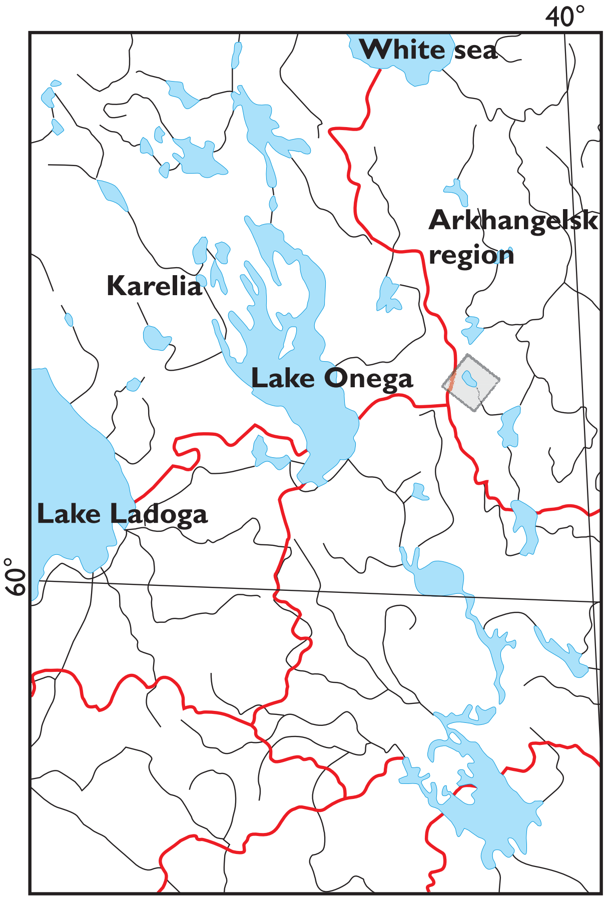

Figure 1. The investigated area around Lekschmozero lake.

Heterogenic massifs

A number of massifs consist of different types of mire sites. For example there are mire massifs with small aapa complexes in their centre surrounded by oligotrophic sites. Typical vegetation series from the bog margin to center is the following: pine - dwarf shrub - *Sphagnum* communities —> hummock carpet hollow oligotrophic complex (Ledo – Sphagnetum fusci + Andromedo polifolii – Sphagnum fusci-magellanici + Scheuchzerietum palustris) —> carpet string flark aapa complex (Menyantho-Baeothryetum cespitosae + Menyantho-Rhynchosporetum albae + Menyantho-Caricetum limosae). Another series is the following: margin fen forest (Pino sylvestris – Sphagnetum warnstorfii) —> wooded transitional bog (Pino betulo pubescentis – Sphagnetum fallacis) —> hummock carpet hollow complex (Ledo – Sphagnetum fusci + Eriophoro vaginati – Sphagnetum angustifolii + Scheuchzerietum palustris) or pine - dwarf shrub - *Sphagnum* communities —> lake.

Aapamires

Meso-eutrophic aapa mires are widespread. They are located in deep depressions and usually crossed by rivulets between Lekschmozero lake and Karelian border. They are characterized by a round structure of plant cover. Rich wooded fen sites appear along the margins. A ridge-flark aapa complex has developed in the central part of mire massifs. The width of the ring like ridges is 2 –5 meters. They are occupied by Menyantho-Sphagnetum fusci communities. Communities of Menyantho-Rhynchosporetum albae are placed in flarks. Another variant of this mire type is characterized by following series: margin slope —> Pino sylvestris – Sphagnetum warnstorfii —> Pino sylvestris – Sphagnetum warnstorfii Sphagnetosum angustifolii —> Pino betulo pubescentis – Sphagnetum fallacis —> ridge flark aapa complex Betulo nanae – Sphagnetum warnstorfii + Menyantho-Rhynchosporetum albae or Caricetum diandrae. The moss layer in Caricetum diandrae is often formed by Scorpidium scorpioides (Table 1, Table 2).

A large mire system consisting of different types of massifs occurs to the east from Lake Lekschmozero. There are bogs and aapamires. The aapamires cover most of the system. The largest aapa mires massifs are Chuchya glud′ and Sokolya glad′. The Chuchya glud′ mire massif is characterized by the following series: cottongrass-*Sphagnum* carpet along the margin (Eriophoro vaginati – Sphagnetum baltici) —> carpet mire site with Caricetum rostratae sphagnetosum papillosi —> ridge flark aapa complex (Menyantho – Caricetum limosae sphagnetosum papillosi + Menyantho – Caricetum limosae utricularietosum intermedii or Menyantho-Rhynchosporetum albae. The ridges are low and flat. The difference between ridge surface and water level in flarks is not more than 15 cm., usually 10 - 12 cm. In the southern part of this massif, the spatial vegetation series is shorter: carpet Caricetum rostratae sphagnetosum papillosi —> lawn site Menyantho – Caricetum limosae sphagnetosum majii —> ridge flark aapa complex Menyantho-Sphagnetum magellanici + Menyantho – Caricetum limosae utricularietosum intermedii or Menyantho-Rhynchosporetum albae. *Betula nana* and *Carex lasiocarpa* are abundant on the ridges. *Carex lasiocarpa* is not a typical species for this kind of mire system.

Sokolya glad′ is larger and its central part is occupied by spacious ridge carpet flark aapa complex. The mire water depth in flarks is above 20 cm. Flarks are covered by communities of Menyantho – Caricetum limosae which consist of only 3 – 4 species: *Carex limosa, Menyanthes trifoliata, Scheuchzeria palustris* and few *Sphagnum jensenii*. The ridges are occupied by communities of Menyantho-Sphagnetum magellanici. The carpets are located among ridges or they are patches inside of flarks. Carpets are covered by communities of Menyantho – Caricetum limosae sphagnetosum papillosi. Flarks with open water disappear gradually from centre to margins.

Further the complex consist of 2 components: ridges and hollows. Hollows are covered by the same communities as carpets in the previous complex. The only difference is that the dominant species of moss layer, *Sphagnum papillosum* is replaced by *S. jensenii*. This complex occupies a large area which is equal to the previous. Further this complex is changed into an oligotrophic ridge-hollow complex with untypical vegetation on the ridges. There are lots of *Eriophorum vaginatum* and a few dwarf shrubs. The ridges are very loose.

Ridge-hollow complex is characterized by the prevailing of *Eriophorum vaginatum* on the ridges. Hollows are covered by communities of Scheuchzerietum palustris sphagnetosum majii. Along the margin there is a carpet hummock complex with communities of Eriophoro vaginati – Sphagnetum angustifolii and Ledo – Sphagnetum fusci. This spacious mire is absolutely treeless. A dense net of narrow overgrown mire streams is a specific feature of this treeless mire.

Data on peat deposits shows that the aapa complex is very young. The depth of *Sphagnum* peat is only 0.5 m. The main part of peat body consist of sedge peat. The bottom layers are formed by *Equisetum* or reed remains.
To the west from Lake Lekschmozero, only two small mire sites were found. There are aapa complexes where ridges are covered by communities of Menyantho-Sphagnetum fusci and Betula nana – Sphagnetum warnstorfii.

Fens

Rich wooded fen, rich sedge-*Hypnum* or sedge-*Sphagnum* fens and sedge fens are common. Wooded fens are widespread. Their surface is almost totally covered by communities of Pino sylvestris – Sphagnetum warnstorfii. The tree layer consist of *Pinus sylvestris* with the presence of *Betula pubescens* and *Picea abies*. The field layer is formed by *Menyanthes trifoliata*. Typical species of this association are *Carex diandra, C. dioica, Bistorta major* and *Rumex acetosa*. *Betula nana* is abundant. *Betula humilis* is common in this community. *Sphagnum warnstorfii* dominates in moss layer. Such mires are located in depressions of varying depth.

Rich sedge-*Hypnum* or sedge-*Sphagnum* fens are located along Karelian border in moraine depressions. They are supplied by rich ground water. The pH is 6.8 – 8.2. These fens are covered by communities of following associations: Bistorto-Caricetum diandrae, Bistorto-Caricetum appropinquatae (on the slopes sites) and Carici rostratae-Poetum pratensis (at the springs and along cold-water rivulets). The floristic core of this associations are *Sphagnum warnstorfii, Aulacomnium palustre, Tomentypnum nitens, Paludella squarrosa, Angelica sylvestris, Carex dioica, Galium uliginosum, Bistorta major, Rumex acetosa, Poa pratensis, Plagiomnium ellipticum, Helodium blandowii, Stellaria crassifolia, Saxifraga hirculus* and *Luzula pilosa*. Associations differ one from other by sedge layer dominants. *Poa pratensis, Rumex acetosa and Carex rostrata* are dominant in the field layer of ass. Carici rostratae-Poetum pratensis. In this community there are not diagnostic species of the alliance Caricion davallianae. However, in these fens there are communities with *Eriophorum latifolium* as dominant. Along the streams occur rich fens communities with *Carex limosa* as the dominant species.

Sedge fens are rare mire types in this territory. Both known sites were found along rivulets. They are covered by communities of Caricetum diandrae and Caricetum lasiocarpae. *Juncus stygius* was often recorded in this community.

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Table 1. Communities of aapamire ridges.

Species	West from Lekschmozero			East from Lekschmozero		
	Covering %					
Menyanthes trifoliata	15	10	25	10	25	25
Betula nana	3	2	5	1	20	15
Andromeda polifolia	1	5	2	+	20	10
Oxycoccus palustris	3	3	3	1	3	2
Drosera rotundifolia	1	1	1	+	1	+
Dactylorhiza maculata	+	+	+	+	+	
Chamaedaphne calyculata	+		2		3	2
Sphagnum angustifolium		10	35		10	10
Sphagnum warnstorfii	15	85	50			
Pinus sylvestris	10	10	10			
Carex dioica	1	+	+			
C. diandra		1	8			
C. pauciflora	2	+	2			5
Trichophorum alpinum	15	5	12			
Dactylorhiza incarnata	+	+				
Aulacomnium palustre	2		1			
Comarum palustre		1	3			
Carex lasiocarpa	1	12			10	
Scheuchzeria palustris				3	+	3
Sphagnum papillosum				90		10
S. magellanicum	40				90	70
Sphagnum jensenii				5		
S. fallax				3		
S. fuscum	40			1		5
Polytrichum strictum	2					5
Carex rostrata	2	3		5		
C. limosa						+
Drosera anglica				1		
Rhynchospora alba				20		
Trichophorum cespitosum				1		
Salix myrtilloides					+	
Eriophorum vaginatum						5
E. gracile						+
E. polystachion			+			
Pedicularis sceptrum-carolinum	+					
P. palustris			+			
Melampyrum pratense	+	+				
Equisetum fluviatile			2			
Bistorta major			+			

Table 2. Communities of aapamire flarks.

Species/ pH	West from Lekschmozero			East from Lekschmozero		
	5.4-6.0			4.3-4.8		
	Covering %					
Menyanthes trifoliata	5	8	20	15	20	25
Carex limosa	8	20	20	10	15	10
Utricularia intermedia	20	20	15		20	5
Drosera anglica	8	+			2	3
Rhynchospora alba	12	5				15
Campylium stellatum	20	10				
Scorpidium scorpioides		45	50			
Hamatocaulis vernicosus		10	5			
Trichophorum alpinum	+	2				
Eriophorum polystachion	+	1	5		+	
Carex diandra			12			
Scheuchzeria palustris		3		5	3	2
Sphagnum jensenii				5		10
S. platyphyllum					5	10
Carex rostrata		3				
C. lasiocarpa		1				
C. chordorrhiza			1			
Equisetum fluviatile			1			1
Andromeda polifolia					+	+
Betula nana			+		+	
Oxycoccus palustris		+				+
Hammarbya paludosa					+	+
Pedicularis palustris		+	+			+
Juncus stygius			+			
Sphagnum majus					10	
S. papillosum					3	
S. balticum					5	
S. obtusum						10
S. fallax						5
S. contortum		5				10
S. subsecundum			5			
Calliergon stramineum						+
Cinclidium stygius		5				

Postdrainage vegetation dynamics in mesotrophic herb-Sphagnum mires of southern Karelia, Russia

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Introduction

Drainage-induced changes in the vegetation of mires and paludified forests have been considered in quite a number of publications both in Russia and in other countries. Successions of drainage in the conditions of Finland were investigated by Sarasto (1957). The effect of water level drawdown after drainage of mires for forestry was studied by comparing the vegetation on undrained pine-mire sites with that of sites drained 3-55 years earlier (Laine et al. 1995). Abolin and Bush reviewed the major regularities of drainage successions (Буш, Аболинь 1968; Буш 1970). Communities appeared as a result of drainage in herb-Sphagnum pine forests and similar communities were briefly characterized for Karelia (Юрковская 1963), Lithuania (Капустинскайте 1978). Neshataev (Нешатаев 1986; Нешатаев & Федорчук 1989) studied successions characteristics as a result of drainage of herb-Sphagnum pine forests in the Leningrad region. In the monograph by Fedorchuk, Neshataev & Kuznetsova (Федорчук, Нешатаев & Кузнецова, 2005), Neshataev presents data on biogeocoenoses variability of the main forest types, their dynamics in the process of age and regeneration changes in the tree stand composition on the drained lands.

Most researchers focus mainly on the effect of drainage on the tree layer. The Russian Academy of Science Silvics Laboratory conducts biogeocenological studies of peatland forests with experimental forest drainage at the Zapadno-Dvinskiy research station (Биогеоценологическое изучение болотных ... 1982). In Western Siberia, Efremov (Ефремов 1987) summarized the results of 20-year studies in permanent sample plots, which concentrated on comprehensive assessment of the formation process of pioneer tree stands in drained treeless and slightly treed mires.

In southern Karelia problems of natural forest regeneration in the first 10-15 years after drainage are studied by Medvedeva (Медведева 1989), Sakovets & Gavrilov (Саковец & Гаврилов 1994), Sakovets and others (Саковец и др. 2000).

A substantial part of the materials on changes in the plant cover of mires and paludified forests comes from one-time surveys done quite a long time after drainage. Fedorchuk et al. (Федорчук и др. 1981) note that relative stabilization of the plant cover usually takes place not earlier than 20-25 years after drainage. Finnish researchers Heikurainen (Хейкурайнен 1983) and Laine (1989) report that the ground cover in drained mires attains a stable plant community, different from the initial one, only 40 or more years after drainage.

The plant cover dynamics in its lower layers is considered in relatively few papers, mostly describing mires of European Russia (Ниценко 1951; Юрковская 1963; Гузлена 1963) and Western Siberia (Елисеева 1963, 1964; Платонов 1967). Much fewer are data gathered from permanent sample plots through repeated surveys in the first decades after drainage, which provide a deeper insight into the mechanism of the drainage effect not only on the tree layer, but also on the soil cover and ecological conditions in drained sites. According to Grabovik (Грабовик 1989, 2005), successional changes taking place in the plant cover of mesotrophic herb-Sphagnum mires during 30 years after drainage are directed towards more mesophytic communities than the initial ones. Changes in the moisture supply cause the most sensitive response among hyper-hygrophilous herb and Sphagnum species, which disappear from the plant cover in the very first years after drainage. The process of change includes also leveling out of the mire sites' microrelief.

The rate and intensity of natural forestation of mesotrophic herb-Sphagnum mires after drainage depend on the structure of their plant cover prior to drainage: in the sites that used to have suppressed woody plants, dense, high-productivity birch stands (canopy closure up to 1.3) form in 30 years, whereas natural forestation in formerly treeless sites is slower, and only a sparse woody layer would form in 30 years.

The main aim of the study is to analyze the results of 32-years research into postdrainage dynamics of species composition and plant cover structure in spatial and temporal aspect in mesotrophic herb-Sphagnum mires.

Material and methods

Scientific-research studies on the effect of drainage have been conducted in the mire tracts on the territory of the Kindasovo forest and mire research station, Karelian Research Centre, in the subzone of middle taiga in Koivu-Lambasuo nature reserve (61° 48′ N & 33° 35′ E) since 1970 year (Fig. 1). As to the climate, the territory of the station is characterized by the following average long-term data: the duration of vegetative period is 148 days, the air temperature during the vegetative period is 11,7° C; annual precipitation 565 mm, and that for the vegetative period 316 mm (Чесноков 1979).

Mire studies at the station were conducted in two stages. At the first stage, in the early 1970s, a series of permanent sample plots was laid in natural mires of different types. Data on the structure and productivity of the plant cover in natural mesotrophic mires are presented in papers by Elina (Елина 1977; Елина et al.1984).

In the following years some mires at the station were drained and we continued further studies on postdrainage dynamics of species composition and plant cover structure in the mires.

Research into the dynamics of the plant cover species composition and structure was conducted using earlier tested and modified techniques (Александрова 1964; Программа и методика... 1966). The horizontal structure of the plant cover was investigated by the large-scale mapping technique (Юнатов 1964).

Within the mire complexes studied, sites were chosen that were most typical for them (according to the form of microrelief and plant cover), i.e. permanent sample sites where constant observations were made during the following years. The sizes of the sample plots (from 50 to 150 m) were dependent on the complexity of the complex

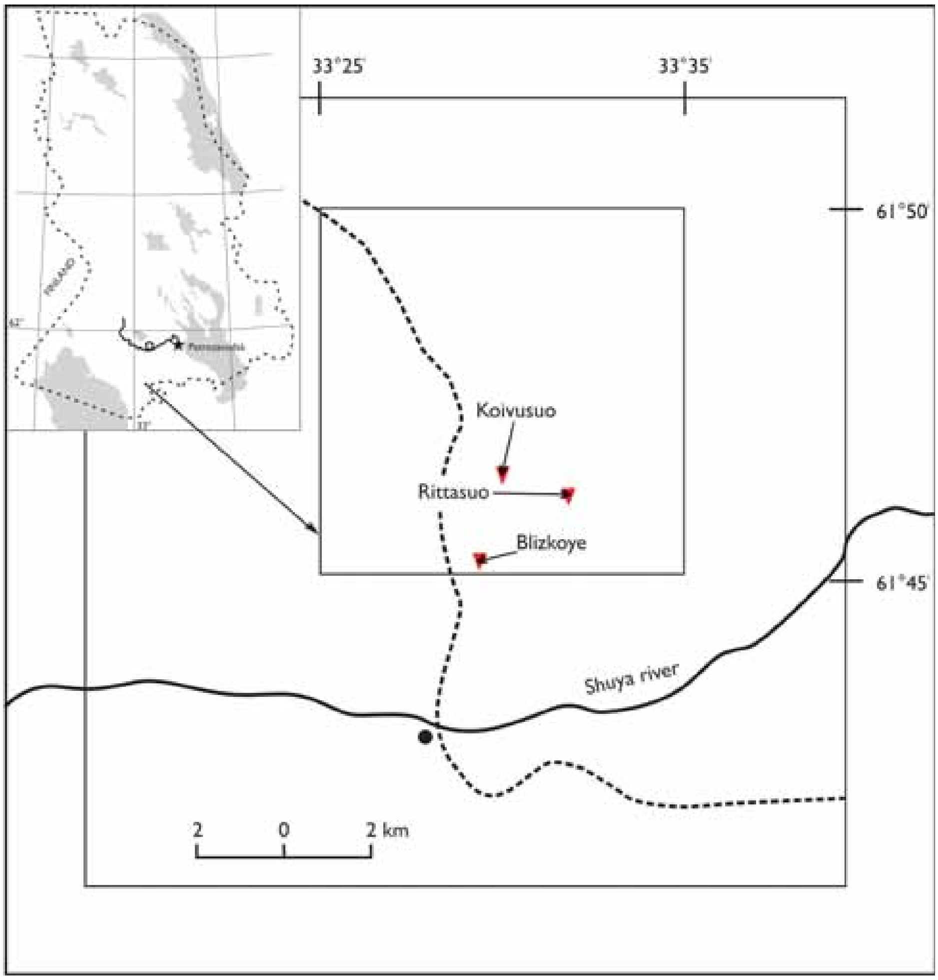

Figure 1. The location of the study sites.

structure and the number of individual elements in the microrelief. A total of 11 permanent sample plots were laid.

Observations over the dynamics of the plant cover species composition in drained mires were conducted within permanent sample plots in permanent 1-square-metre test sites situated at different distances from the drainage ditches. The community structure, floristic composition, contributions of individual species to the plant cover were analyzed within the study. Postdrainage dynamics of the species composition of the plant cover in special and temporal aspect was performed using the ecologo-coenotic species groups (ECG) distinguished in the classification of phytocoenoses dynamics developed for Karelia (Кузнецов 2002) Analysis of phytocoenoses dynamics was performed both in a more intensively drained part of the mire site, within a 30-m strip along the ditch, and in the middle of the strip between the ditches (160 m width) which was drained less intensively.

Nomenclature of vascular plants follows Черепанов (1995), and that of mosses follows Игнатов & Афонина (1992).

Basic stand quality parameters were determined by the methods applied in forest management valuation (Анучин 1971).

Sample plot 1 was established in the central, open part of the Blizkoye mire, in a string-flark *Sphagneta centrale+Herbeto-Sphagneta subsecundi* complex.

Sample plot 2 is situated in the Koivusuo mire margin, in a slightly treed string-flark *Sphagneta angustifolii+Herbeta* complex with rare *Betula pubescens* both on strings and in flarks. Tree and tree-*Sphagnum* mire sites are much more frequently found within other mire types, especially in their margins.

Results and discussion

Dynamics of the plant cover structure in mesotrophic herb-Sphagnum mires

Sample plot 1. Prior to drainage, the plant cover of the mesotrophic string-flark Sphagneta centrale+Herbeto-Sphagneta subsecundi complex was represented by communities of strings and flarks. Most of the string-flark complex (70%) was flark communities of Carex lasiocarpa-Menyanthes trifoliata. The plant cover of strings was represented by coenoses of the Chamaedaphne calyculata-Sphagnum centrale+S. angustifolium association (Table 1). Isolated Betula pubescens or Pinus sylvestris trees up to 2 m high grew on strings. The fen peat deposit was within 1 m thick, underlain by clay.

Sample plot 2. The main features of the mire before drainage were strings holding *Betula pubescens- Chamaedaphne calyculata- Pleurozium schreberi* and *Andromeda polifolia-Carex lasiocarpa-Sphagnum angustifolium* coenoses. Depressions were occupied by the *Phragmites australis-Carex lasiocarpa* coenosis (Table 1). Trees there were low (2-4 m), the tree stand had low canopy closure, 0.2. The fen peat deposit was 1.5 m thick, underlain by clay.

In 1970-1971 these mires were drained by a network of open ditches spaced 160 and 180 m, respectively, according to the parameters of the forest-drainage network in the conditions of Karelia (Пятецкий & Медведева 1971). At present the ditches do not practically function. For a period of 32-years observations the average values of GWL during the vegetative period varied in driest years reaching 40-45 cm in the middle of the strips between the ditches with their width of 160 m, and 36-55 cm beneath the surface of the *Sphagnum* carpet.

Long-term permanent-plot research into the plant cover dynamics in mesotrophic mires of mid-taiga Karelia upon drainage have shown the rates and directivity of successions to differ, and the plant cover structure to change greately in sample plots with a complex plant cover (Table 1; Грабовик 1989, 2007).

5 years after drainage

Sample plot 1. The following plant coenoses and their fragments have been identified through analysis of large-scale maps and geobotanical descriptions of the plot. In the string-carpet complex formed in place of the string -flark one, string s grew to occupy 20% of the area, with birch and pine now growing on some of them. Fragments of various plant coenoses were present on the strings. Their more elevated parts by tree trunks carried *Betula pubescens-Chamaedaphne calyculata-Sphagnum cen-*

trale, lower strings – *Andromeda polifolia-Sphagnum centrale+S. angustifolium*, carpets (62% of the area) – *Carex lasiocarpa+Calamagrostis neglecta-Menyanthes trifoliata* (Table 1). *Carex lasiocarpa+Calamagrostis neglecta* associations are characteristic of drained mires. Fragments of *Carex lasiocarpa+Calamagrostis neglecta-Salix myrtilloides* coenoses appeared, occupying 18% of the plot area. The *Carex lasiocarpa+Calamagrostis neglecta* -buckbean association is rather unstable. At this postdrainage stage of the plant cover succession, a mesotrophic string -carpet *Herbeta+Sphagneta centrale* site with rare birch formed in place of the mesotrophic string -flark *Sphagneta centrale+Herbeto-Sphagneta subsecundi* site.

Surveys in the two sample plots 13 years after drainage revealed further changes in the plant cover structure

In sample plot 1, a string -carpet, tree-herb *Betuleto-Herbeta* coenosis was formed in place of the mesotrophic string -carpet *Sphagneta centrale+Herbeta* complex with sparse *Betula pubescens* (Fig. 2). The main keystone plant species was *Betula pubescens*. The plant cover on strings surrounding tree trunks was represented by *Betula pubescens-Chamaedaphne calyculata* coenoses, whereas *Chamaedaphne calyculata-Sphagnum centrale+S. angustifolium* communities formed the cover of lower *Sphagnum* string s. The plant cover of carpets was made up of various tree-herb communities (Table 1). The tree stand is presented by 20-years old birch and pine (single).

In sample plot 2, a forested *Betuleto-Sphagneta angustifolii* community with Betula pubescens as the keystone species formed in place of the, string-flark, slightly treed *Sphagneta angustifolii+Herbeta* complex with rare *Betula pubescens*. The tree stand is presented by birch (80%), pine (20%) and spruce (single).As the upper canopy closed and the forest floor formed, the conditions for emergence of spruce saplings and their further growth and development improved. The following plant coenoses and their fragments were identified through analysis of maps and relevés. The plant cover on strings surrounding tree trunks was represented by the *Betula pubescens-Chamaedaphne*

Figure 2. Tree-*herb Betuleto-Herbeta* coenosis (sample plot 2) 13 years after drainage.

calyculata-Pleurozium schreberi coenosis, whereas carpets held two microassociations: *Carex lasiocarpa-Sphagnum angustifolium* and *Betula nana-Sphagnum angustifolium* (Table 1).

Twenty-five years after drainage, the string -carpet *Betuleto-Herbeta* coenosis in sample plot 1 was superseded by the tree-herb *Betuleto-Herbeta* coenosis (Table 1). The treestand is presented by birch (90%) (30-years old) and pine (10%) at the age of 50. An essential factor for the emergence of spruce undergrowth beneath the canopy of drained birch forests is the ground cover, which development depends on the stand stocking density, time since drainage and site conditions. Thus, formation of various secondary associations dominated by *Calamagrostis neglecta* resulted in soil sodding, which prevent the emergence and development of spruce undergrowth. In evidence of that, undergrowth was still absent from the site even 25 years after drainage (Ананьев & Грабовик 2003).

In sample plot 2, the forested *Betuleto-Sphagneta angustifolii* community with *Betula pubescens* as the keystone species transformed into the birch-herb *Betuleto-Herbeta* community. The following plant coenoses and their fragments were identified through analysis of maps and relevés. The plant cover on hummocks surrounding tree trunks was represented by the *Betula pubescens-Pleurozium schreberi+Hylocomium splendens* coenosis (Table 1). On carpets, the herb-dwarf shrub layer grew sparser because of further upper canopy closure, why the percentage cover of the former was not more than 35%. Individual forest species such as *Dryopteris carthusiana*, *Pyrola rotundifolia*, *Rubus arcticus* formed small-size patches. Mire species like *Andromeda polifolia, Chamaedaphne calyculata* vanished. The *Sphagnum* cover became sparser. A forest floor of fallen birch leaves was formed. The tree stand here is pure birch (age of 45 years) with single pine and spruce trees. Average height of birch trees was 12.3 m, average diameter 12.0 cm, average height of spruce trees 5.2 m, average diameter 6.7 cm, total number of trees was 2011 per ha, including 1978 birch trees per ha. According to the above results, 3,500 per ha of viable spruce undergrowth were present under the canopy of the investigated stand 25 years after drainage. With this amount of undergrowth and its high frequency (68%), given that the drainage network keeps operating steadily, short-living secondary drained birch stands (the life span of the first generation of birch is 70-80 years) would transform into long-living, regular productivity secondary spruce stands (Ананьев & Грабовик 2003). Our data on the dynamics of the plant cover species composition correspond to the studies by Guermanova (in Саковец и др. 2000). According to her results drainage led to formation of the forest floor, increased peat density, a 6- and 2-fold rise in ash elements and nitrogen stores, respectively, in the 30-cm peat layer over 28 years.

Dynamics of the plant cover species composition

In this paper, the dynamics is presented through the example of the Carex lasiocarpa - Menyanthes trifoliata association pertinent to flarks (sample plot 1).

Water level drawdown, loss of significance of mire plants in the plant community generate most favourable conditions for natural forestation of mires in the very first years (7-10 yrs) after drainage. Hygromesophilic and mesophilic species (competitors of young woody plants) are not yet widespread at the time. *Betula pubescens* seeds are massively introduced, falling into the soil favourable for their germination. The number of birch plants 0.5 to 5.5 m tall reaches 3400 per ha (Table 2, 3)

In the more intensively drained part of the mire, no sharp changes took place in the herb-dwarf shrub and moss layers of the hollows in the first 7 years after drainage. Only hygrophilous species *Carex rostrata, C. chordorrhiza* disappeared, and *Sphagnum subsecundum* survived in the moistest sites only (Table 1). *Carex lasiocarpa, Menyanthes trifoliata* remained the community diagnostic species, but their percentage cover fell to 15% and 10%, respectively. The reaction of different mire plant species to drainage in different. Some decline rapidly, others suffer severe suppression and die back gradually. The development of a few species is even promoted, their role in the cover growing notably after drainage, especially that of *Calamagrostis neglecta, Comarum palustre, Thyselium palustre* (Table 2).

In 15-20 years after drainage the processes of peat decomposition on elevations increases, hygrophilous plants grow suppressed, hardly providing any competition. The microrelief grows smoother due to peat compaction, enhancing the growth and development of *Calamagrostis neglecta*, which spreads actively in place of former strings.

In the ground cover of carpets and former flarks, most mire species survived over this period, but their vitality was reduced, no flowering or fruiting taking place. The herb layer grew sparser and new species not present there before drainage appeared, such as *Carex cinerea* and *Stellaria palustris* (Table 2). At the same time, forest species such as *Angelica sylvestris, Pyrola rotundifolia, Deschampsia cespitosa*, etc. appeared, although in minor amounts (Table 2). The total number of trees in the tree-herb coenosis was 1850, including 1700 birches per ha. Mean diameter was 5.6 cm, height 6.9 m. A substantial part of the birch appeared there after drainage.

Twenty five and more years after drainage, the tree stand composition of the tree-herb coenosis demonstrated significant changes. The total number of trees dropped to 1658 per ha, that of birch trees to 1516. At that time, the ground cover of carpets and former flarks still preserved mire plants, but their percentage cover decreased notably, and the introduction of forest species continued (Table 2), although they did not yet play a significant role in the ground cover. The percentage cover of the herb layer was not higher than 45%. There appeared some species of meadow-associated mosses (*Brachythecium oedipodium, Plagiothecium denticulatum*), which settled on micro elevations. One should note that the group of heliophytes growing there, such as *Calamagrostis neglecta, Chamaenerion angustifolium* form reed-herbaceous communities that priventing forest regeneration in open sites (gaps). Species such as *Angelica sylvestris, Dryopteris carthusiana, Equisetum sylvaticum, Trientalis europaea* etc., on the contrary, constitute the group of shade-tolerant species, which are most common under *Betula pubescens* canopy (Table 2).

In the middle of the wide strip between the ditches (Table 3), low-intensity drainage makes the transformation of typical mire communities in hollows slow. The direction of changes in the species composition is the same as in the strip along the ditches, but much slower; the period of domination of hygromesophilic and hygrophilous species grows longer, but as the drainage impact continues, the percentage cover of mesotrophic mire herbs decreases. Forest species reach there only 25-30 years after drainage, but their contribution to the ground cover is minor. In this strip, *Calamagrostis neglecta* still forms various communities hindering forest regeneration. The percentage cover of herbs reaches up to 60% there. When the degree of drainage is low, the index of *Calamagrostis neglecta* presence in the plant cover remains very high, the species spreads out, produces thick sod and a layer of dry grass, so that no tree stand establishment happens because the natural forestation process dies out in the first decade after drainage (Table 3).

Ефремов (1987), Нешатаев (1986) and Laine et al. (1995) point to the dependence of natural forestation rates in treeless drained mires on the character of the soil cover. Open sites that were not forested in the first years after drainage are quickly overgrown with heliophytes (*Calamagrostis neglecta, Chamerion angustifolium, Epilobium palustre, Betula nana).* But such species as *Angelica sylvestris, Dryoptheris cartusiana, Equisetum sylvaticum, Trientalis europaea, Pyrola rotundifolia* and others become stable in the composition of shade-tolerant groups not earlier than the pioneer tree stands reach the age of 20-30 years. Нешатаев (1986) also notes that in 10 years after drainage *Rubus idaeus* was observed to spread in the drained herb-*Sphagnum* mires, it is especially abundant in birch forests with low canopy closure of the tree layer.

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Table 1. Changes in the sample plots' plant cover structure under the effect of drainage

Plant coenoses and their fragments/ Elements of microrelief	Microrelief before drainage	After drainage			
		5 yrs	13yrs	25yrs	30yrs
Area occupied, %					
Sphagneta centrale+Herbeto-Sphagneta subsecundi (mire site 1)					
Betula pubescens –Chamaedaphne calyculata – Sph. centrale strings	-	1	-	-	-
Betula pubescens –Chamaedaphne calyculata strings	-	-	*5*	3	1
Andromeda polifolia – Sph centrale +Sph. angustifolium strings	30	19	8	-	-
Carex lasiocarpa – Menyanthes trifoliata flarks	70	-	-	-	-
Carex lasiocarpa + Calamagrostis neglecta - Menyanthes trifoliata carpet	-	62	-	-	-
Carex lasiocarpa + Calamagrostis neglecta –Salix myrtilloides carpet	-	18	-	-	-
Betula pubescens – Calamagrostis neglecta +Carex lasiocarpa-Salix myrtilloides carpet	-	-	87	-	-
Betula pubescens –Calamagrostis neglecta carpet	-	-	-	97	99
Sphagneta angustifolii+Herbeta with sparse *Betula pubescens* (mire site 2)					
Betula pubescens –Chamaedaphne calyculata – Pleurozium schreberi strings	*8*	-	*10*	-	-
Betula pubescens –Pleurozium schreberi +Hylocomium splendens strings	-	-	-	10	10
Andromeda polifolia – Carex lasiocarpa – Sph. angustifolium strings	*36*	-	-	-	-
Phragmites australis – Carex-lasiocarpa carpet	*56*	-	-	-	-
Carex lasiocarpa – Sphagnum angustifolium carpet	-	-	36	-	-
Betula nana – Sph. Angustifolium carpet	-	-	54	-	-
Betula pubescens – Rubus arcticus - Dryopteris carthusiana+Pyrola rotundifolia carpet	-	-	-	90	90

Table 2. Postdrainage vegetation dynamics in hollows of a mesotrophic herb-Sphagnum mire in the 30 m wide strip along ditches. Roman figures and “r” stand for the species constancy: V 81-100%; IV 61-80%; III 41-60%; II 21-40%; I 11-20%; “r” below 10%;. Arabic figures indicate species abundance: 100-76% 5, 75-51% 4, 50-26% 3, 25-11% 2, 10-1 1, < 1% +. N = number of test plots each year.
*R singular trees; ** number of trees/ha; Descriptions in 1971 were made before drainage

Ecological groups	Study years				
	1971 N=5	1978 N=9	1989 N=9	1999 N=9	2003 N=9
Group Chamaedaphne calyculata					
Chamaedaphne calyculata	III^{1}	II^{+}	-	-	-
Andromeda polifolia	IV^{2}	-	-	-	-
Oxycoccus palustris	II^{1}	III^{+}	-	r	-
Sphagnum angustifolium	-	r	-	-	-
Group Carex lasiocarpa					
Carex lasiocarpa	V^{4}	V^{3}	III^{2}	II^{+}	-
C. rostrata		II^{1}	-	-	-
Group Baeothryon alpinum					
Salix rosmarinifolia	r	r	-	-	-
Equisetum palustre	I^{1}	V^{1}	IV^{1}	r	IV^{1}
Sphagnum warnstorfii	-	-	-	-	I^{1}
Sphagnum centrale	-	-	II^{1}	II^{1}	I^{+}
Campylium stellatum	I^{+}	III^{1}	-	-	-
Group Carex livida					
Sphagnum subsecundum	IV^{4}	II^{1}	-	-	-
Warnstorfii exannulata	II^{1}	II^{+}	-	-	-
Group *Menyanthes trifoliata*					
Menyanthes trifoliata	IV^{3}	V^{2}	IV^{1}	II^{1}	II^{+}
Eriophorum angustifolium	III^{1}	II^{+}	-	-	-
Carex chordorrhiza	V^{2}	-	-	-	-
Equisetum fluviatile	II^{+}	III^{1}	-	-	-
Group Calla palustris					
Salix myrtilloides	III^{2}	III^{2}	-	-	-
Phragmites australis	-	-	-	-	r
Caltha palustris	V^{1}	V^{1}	III^{1}	-	-
Scutellaria galericulata	-	-	-	r	r
Carex cinerea	-	-	III^{1}	I^{+}	II^{1}
Pseudobryum cinclidioides	-	-	-	r^{+}	I^{+}
Climacium dendroides	-	-	-	r^{+}	I^{+}
Group Carex acuta					
Calamagrostis neglecta	III^{2}	V^{4}	V^{2}	V^{3}	V^{3}
Comarum palustre	IV^{2}	V^{3}	V^{2}	V^{2}	IV^{1}
Naumburgia thyrsiflora	IV^{1}	V^{1}	V^{3}	III^{1}	IV^{+}
Stellaria palustris	-	-	r^{+}	II^{+}	r
Galium uliginosum	III^{1}	IV^{+}	V^{1}	V^{1}	II^{+}
Cirsium palustre	-	-	III^{1}	I^{+}	I^{+}
Thyselium palustre	III^{1}	IV^{1}	III^{1}	I^{+}	II^{+}

Ecological groups	Study years				
	1971 N=5	1978 N=9	1989 N=9	1999 N=9	2003 N=9
Group Saxifraga hirculus					
Epilobium palustre	r	II^1	IV^1	-	-
Bryum weigelii	-	-	-	r	r
Group of forest species					
Betula pubescens	*R	2000**	1700	800	800
Picea abies	R	R	R	R	R
Pinus sylvestris	R	R	51	42	42
Equisetum sylvaticum	-	-	-	IV^1	II^1
Dryoptheris cartusiana	-	-	-	III^1	III^2
Angelica sylvestris	-	-	II$^+$	-	I$^+$
Pyrola rotundifolia	-	-	II$^+$	I$^+$	r
Trientalis europaea	-	-	-	III$^+$	III^1
Polytrichum longisetum	-	-	-	r	r
Brachythecium oedipodium	-	-	IV^1	II^1	
Brachythecium rivulare	-	-	-	r	r
Geum rivale	-	-	II$^+$	r	r
Chamaerion angustifolium	-	-	-	I^1	I$^+$
Hepaticae	-	-	-	III^1	-
Plagiothecium denticulatum	-	-	-	-	I$^+$
Plagiomnium ellipticum	-	-	-	r	r
Rubus idaeus	-	-	-	-	r

Table 3. Postdrainage vegetation dynamics in hollows of a mesotrophic herb-Sphagnum mire in the middle of the strip between ditches. For the explanations see Table 2.

Ecological groups	Study years				
	1971^1 N=5	1978 N=9	1989 N=9	1999 N=9	2003 N=9
Group Chamaedaphne calyculata					
Chamaedaphne calyculata	V^1	-	-	-	-
Andromeda polifolia	V^1	-	-	-	-
Oxycoccus palustris	V^1	II$^+$	-	-	-
Group Carex lasiocarpa					
Carex lasiocarpa	III^3	V^4	VI^2	-	-
Group Baeothryon alpinum					
Equisetum palustre	III^1	IV^1	II^1	IV^1	
Sphagnum warnstorfii	-	-	-	-	r^1
Sphagnum centrale	-	-	-	III^1	-
Campylium stellatum	-	III^1	-	-	-
Group Carex livida					
Sphagnum subsecundum	IV^4	III^1	-	-	-
Warnstorfia exannulata	-	II^1	-	-	-
Group *Menyanthes trifoliata*					
Menyanthes trifoliata	V^3	V^2	IV^1	III^1	III$^+$
Eriophorum angustifolium	-	III^1	-	-	-
Carex chordorrhiza	V^4	-	-	-	-
Equisetum fluviatile	-	V^1	-	-	-
Group Calla palustris					
Salix myrtilloides	V^3	V^2	-	-	-
Caltha palustre	V^3	V^1	IV^1	-	-
Scutellaria galericulata	-	-	-	r	r
Carex cinerea	-	-	II^1	r$^+$	r$^+$
Pseudobryum cinclidioides	-	-	-	r$^+$	I$^+$
Climacium dendroides	-	-	-	II$^+$	I$^+$
Group Carex acuta					
Calamagrostis neglecta	-	V^4	V^2	V^3	V^3
Comarum palustre	V^2	IV^3	V^2	V^2	IV^1
Naumburgia thyrsiflora	III^1	IV^1	V^3	V^1	IV$^+$
Stellaria palustris	-	-	II$^+$	II$^+$	r
Galium uliginosum	III^1	r$^+$	V I	IV^1	II$^+$
Cirsium palustre	-	-	III^1	II$^+$	I$^+$
Thyselium palustre	V^1	V^1	IV^1	II$^+$	II$^+$
Group Saxifraga hirculus					
Epilobium palustre	III^1	IV^1	IV^1	-	-
Bryum weigelii	-	-	-	r	r

Ecological groups	Study years				
	1971[1] N=5	1978 N=9	1989 N=9	1999 N=9	2003 N=9
Group of forest species					
Betula pubescens	R	1400	702	716	716
Picea abies	R	R	R	R	R
Pinus sylvestris	R	R	51	42	42
Equisetum sylvaticum	-	-	-	III^{1}	I^{1}
Dryoptheris cartusiana	-	-	-	-	II^{1}
Pyrola rotundifolia	-	-	II^{+}	-	-
Trientalis europaea	-	-	-	II^{+}	IV^{1}
Polytrichum longisetum	-	-	-	r	r
Brachythecium oedipodium	-	-	-	IV^{1}	II^{1}
Brachythecium rivulare	-	-	-	r	r
Deschampsia cespitosa	-	-	-	IV^{2}	IV^{2}
Chamaerion angustifolium	-	-	-	-	I^{+}
Hepaticae	-	-	-	IV^{1}	IV^{1}
Plagiomnium ellipticum	-	-	-	II^{1}	r

The Finnish peat mining paradox: political support to environmental calamity

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Introduction

Peat mining, mainly for fuel and to a lesser degree for horticulture, is a major threat for non-protected peatlands in Finland. As a domestic fuel, peat enjoys strong political support, despite the many environmental problems involved. To promote fuel peat use, the Finnish government lifted the exise duty from peat in 2005. Furthermore, in spring 2006, the government decreed a feed-tariff on electricity generated by peat burning. The status of peat is further boosted by a new storage subsidy, which is considered necessary while variable weather during the short mining season in summer poses an economic risk for the peat mining entrepeneurs.

Advocates of peat industry claim that peat mining affects such a small area that it has no substantial influence on the ecosystems. However, even though in terms of hectares the area exploited is indeed only around 1.0 per cent of the total area of peatlands, peat mining is not an inconsequential mode of land use. The applied prospection criteria (Lappalainen et al. 1984) target the mining reservations primarily on those peatbogs that were considered least suitable for forestry drainage (e.g. Huikari et al. 1963). These are large, predominantly treeless mires with thick peat layer, which indeed were to a considerable extent saved from the major forestry drainage frenzy around the 1970s.

Throughout the history of industrial peat mining, there has been a conflict between mire protection and peat extraction. As a consequence of the energy crisis in the 1970s, the Ministry of Trade and Industry established a Working Group for Cooperation on Energy (EYR), whose brief was to investigate which mires are needed to meet energy-production needs. At about the same time, a programme of mire conservation was initiated, to rescue some of the remaining mire complexes from the rapidly expanding forestry drainage (Lindholm & Heikkilä 2006, Heikkilä & Lindholm 2008).

The Energy working group inspected almost a million hectares of mires, at that time still largely untouched by forestry. At this stage, the remaining mires were crudely divided into those reserved for use in peat mining and those designated for conservation. Notably on state-owned lands, the decisions were straightforward, and assignment of mires for peat extraction was unhindered by any participatory involvement of potential stakeholders, or any environmental impact assessment.

As it is, the current peat policy is based on an unrealistic estimate of peat reserves, which completely ignores several economical, ecological and legal constraints for mire exploitation. It is worth noticing that the official estimate of Finnish peat reserves suitable for peat mining was considerably increased from 622 000 hectares in 1993 (Geological Survey of Finland GSF estimate; Lappalainen & Hänninen 1993) to 1.2 million hectares just ten years later (Virtanen et al 2003). However, this widely cited larger figure (e.g. International Peat Society http://www.peatsociety.org/index.php?id=238) of "geologically and technically exploitable peat reserves" includes even a considerable number of legally protected peatlands, such as national parks and numerous Natura 2000 -protection areas of the EU.

In the following chapters we will analyse the main problems arising of the national peat exploitation policy. The problematic consequences tragically span the entire broad spectrum of to-days environmental issues, starting with simple overexploitation of a limited resource, leading to irretrievable loss of biodiversity values in peatland nature, to environment quality degradation at landscape level and in runoff water quality, and finally ending up with climate deterioration through greenhouse gas emissions. The environmental problems are in many ways linked with a number of weak points in environmental legislation and land use practices, which will also be analysed. The final chapter briefly outlines the mire protection policy of the Finnish Association for Nature Conservation (FANC), which is the largest environmental NGO in Finland.

Environmental consequences and problems of peat mining

Exhaustion of the peat reserves

Approximately 10 per cent of the above mentioned official figure of 1.2 million hectares of "geologically and technically available" energy peat resource is currently being exploited. At present, active mining is carried out on 60 000 hectares, of which some 2000 ha is exhausted every year. As the average extraction time on one site is 20 years, new mining areas need to be opened continuously even with the current rate of extraction. To date, there are already some 30 000 hectares of abandoned peat mining fields.

One third of the peat resources that fill the above mentioned geological mining criteria are located in Lapland. These would theoretically provide peat for 2000 years, but the exploitation of Lapland's peat resources is economically non-viable, owing to impossible conditions for drying the extracted peat and the very long transportation distances. Further south, in the main areas of peat use, the reserves are already in intensive use and, at the present rate of exploitation, will according to GSF estimates last for a period of several decades to maximally a couple of hundred years (e.g. about 100 years in North Ostrobothnia, around Oulu).

Loss of mire biodiversity

Fuel peat mining tends to concentrate in certain areas, where peat utilization is strongly developed. Northern Ostrobothnia, north of the town of Oulu, is a typical focal area. Peat industry here continuously claims new, largely pristine mires, causing an irrevocable loss of the still existing mire nature (Simola et al. 2004). In the area to

Figure 1. Makkarasuo in Utajärvi, North Ostrobothnia (ETRS N 7207715, E 507752) is a 200-hectare pristine aapa-mire in the middle of extensively forestry-drained peatlands. This mire was marked as a peat mining site in a provincial land use plan in 2003. In response to complaints by local nature conservationists, the Supreme administrative court removed this and several other peat mining reservations from the plan on the grounds of insufficient nature inventories in 2006. However, it is not safe from the peat mining (Photo Mauri Huhtala).

the south of the River Oulujoki, a considerably larger proportion of the mire nature was already lost during the 1970s and 1980s due to forestry ditching. However, almost without exception even here, the larger peatland complexes still include extensive unditched central areas of the treeless *neva* site types, which are imminently threatened at landscape level by the mining industry (Fig. 1).

On a local scale, the destruction of mire nature is exacerbated by the fact that, for reasons of economy and logistics, even small and technically marginal mires will be exploited in the vicinity of the major consumers.

Water quality deterioration

An additional serious environmental consequence of heavy concentration of peat mining on certain areas is a significant and persistent deterioration of surface water quality in entire watercourses. The typical water protection installations on peat mining areas work in practice efficiently only during fine weather in summer.

The most commonly used water protection structures, namely sedimentation basins or overland flow areas, do not prevent the outflow of nutrients, suspended solids and dissolved humic substances during spring floods or summer downpours. This loading is inevitably flushed into the waterways downstream, and will have a multifarious effect on many water quality parameters, even in the ultimate recipient, the Baltic Sea.

The way to estimate loading is problematic too, It bases on approximal values of some case studies of mires. Actually variation is vast (see Svahnbäck 2007). Incapability to get hold of the factual impacts frustrates locals and environmentalists, who have much experience and knowledge from the tracks of peat mining sites.

Fuel peat and climate change

Peat is actually the most problematic of all fuels, since its Global Warming Potential (GWB) per unit energy is approximately 12 per cent higher than that of coal (IPCC 2006). The consequence is that energy produced from peat, amounting to approximately 6 – 7 per cent of Finland's total energy production, causes nearly 20 per cent of the national greenhouse gas emissions. During recent years, the annual carbondioxide emissions from the burning of peat have been in the 9 – 10 million tonne range. Subject to the controls of the emissions trade, this leads to a substantial bill for the national economy. However, the Finnish government maintains supportive measures to counteract any potentially negative effects of the emission trade on the energy use of peat, so this Kyoto mechanism probably will not diminish the climate load of peat use.

Policy and practice of peat resource utilization in Finland

Status of peat: fossil or renewable?

While the specific CO_2 emission of fuel peat is even higher than that of coal, its energy use is highly detrimental for the climate. As it is, however, the strong political support for peat industry is maintaining peat exploitation at a high level in the near future at least. A battle over the classification of fuel peat has been fought in Finland. Advocates of peat industry have attempted to remove fuel peat from the category of most harmful to something less detrimental. In the rhetoric of domestic politics, peat is often claimed to be a slowly renewable fuel or, misguidedly, a biofuel, comparable to forestry- and agrobiomasses. However, the Intergovernmental Panel of Climate Change (IPCC) has clearly refuted such claims with the following statement: "Although peat is not strictly speaking a fossil fuel, its greenhouse gas emission characteristics have been shown in life cycle studies to be comparable to that of fossil fuels. Therefore, the CO_2 emissions from combustion of peat are included in the national emissions as for fossil fuels" (IPCC 2006).

Interestingly (and confusingly), two fully opposing arguments have been put forward to justify peat exploitation. The first one (Crill et al. 2000) states that while the total C balance of all Finnish peatlands is positive (mire ecosystems accumulating carbon; a view based on e.g. Laine & Minkkinen 1996), peat could be mined, as long as the extraction remains less than the accumulation. Unfortunately, newer studies have shown that, due to the extensive drainage works, the total mire C balance is actually negative (Lapveteläinen et al. 2007, Turunen 2008). The newer claim indeed is that peat should be mined for energy use, while its *in situ* decomposition would spoil the climate anyway.

The report of Crill et al. (2000) was commissioned by the Ministry of Trade and Industry, to determine the status of peat fuel in climate policy. This report coined the definition of peat as a "slowly renewable biomass fuel", which was readily accepted by the peat industry. For a debate and critique of this reasoning, see Heikkilä et al. (2007).

Figure 2. Saarisuo in Vaala in the province of Kainuu (ETRS N 7174627, E 499423) is a largely natural aapa-mire complex that includes a 5-hectare pond at the upper end of the sloping mire. There are some poorly succesful old forestry ditches on the margins of the mire. The state-owned company Vapo Oy plans to open an 80 hectare peat mining field on the mire, leaving only a 100 m broad protection zone between the excavation area and the pond. The local nature conservationists complained about the plan, while it is in conflict with the Water act, and also against the government-decreed land use principles. The issue is soon debated the second time in the administrative court (Photo Mauri Huhtala).

Ecological and social sustainability thwarted by legislation

According to the Environmental Protection Act (Statutes of Finland 86/2000), peat mining and related ditching are subject to permit when the excavation area is larger than 10 hectares. Permits are handled by the Environmental Permit Authorities.

In reality, the permit pays no consideration to the fate of the actual peatland ecosystem to be excavated - it only deals with the effects outside the mining area, such as effects of discharge waters or dust spreading. According to a ruling of the Supreme Administrative Court this is indeed the case, while the Environmental Protection Act only deals with external environmental consequences of the specific activities listed in the Act as permit-demanding. This is a major fallacy in the Finnish legislation, and there is urgent need for revision. Unfortunately, neither do the Nature Conservation Act (1096/1996) nor Water Act (264/1961) provide direct protection for entire mire ecosystems against extermination by mining (Fig. 2).

For this reason, the provincial (former regional) planning procedure is crucially important as regards peat mining. The Land Use and Building Act (132/1999) governs peat mining only in the initial phase when the plans are being compiled. Unfortunately, at this stage the decisions are often based on technical and economic considerations only, without due regard to ecological and social sustainability issues.

A narrowly legal interpretation means that in the planning and permitting process, the impacts of peat mining on biodiversity and recreation values are often fully disregarded. Designated mire conservation areas are not sufficient for the recreational pursuits: there are numerous hunting and berry-picking areas frequented by many people, which are not protected by any designation. In extensively ditched regions, each remaining pristine mire is important for its landscape value.

Attempts have been made to include the regulation of peat mining in the Extractable Soil Resources Act (555/1981). This Act decrees upon the extraction of stones, gravel, sand, clay and soil in the spirit of sustainable development. The Act thus dictates that soil-resource removal must not result in, for example, spoiling of the scenery, destruction of unique natural features, or extensive transformations detrimental to the natural conditions. So far, however, peat industry has successfully blocked any initiatives to include peat into the Extractable Soil Resources Act.

Land use planning: an ideal of balanced decision-making at landscape level?

In Finland, the various interests in land use are considered and settled in a provincial plan, which is a general plan of land use for the area on the provincial scale. As an example, in North Ostrobothnia, which is a core area for peat mining, the first new lawful provincial plan included comparison of the quantitative options for peat use: declining, current level and increasing. In Central Ostrobothnia, where peat use is also extensive, an inquiry on sustainable use has been undertaken to regulate the scale and location of peat mining. Practices vary, however, in different parts of Finland, although peat is utilised in most the provinces. A provincial mire strategy, with strong emphasis on mire protection, has been worked out by the North Karelia Environment Centre (Ohtonen & Kotanen 2003). Work on a national peatland strategy was started by the Ministry of agriculture and forestry in 2009. Its purpose is to decrease negative environmental impacts as well as contradictions.

At present the position guidance is considered as the most effective way to prevent harmful impacts. In provincial plans, the national land-use objectives is the means to take it into account. The land-use objectives were decreed by the Finnish government in 2000 (updated 2008), based on the Land Use and Building Act, and they apply to major projects of environmental significance. The national land-use objectives state that regional planning must ascertain which peatlands are suitable for peat mining and assess the balance between exploitation and conservation. It is also stated that peat mining is to be concentrated on peatbogs that already earlier have been completely drained. The updating of the provincial plan of North Ostrobothnia will also be the test of the new peatland strategy. Is it possible to guide peat mining to already drained and its naturevalues lost peatlands. But certainly not the problem is solved..

Mire protection: objectives and reality

Mire protection policy and goals in Finland

In the current situation, mire conservation work needs urgently to be continued. A legal basis for mire site protection is established only in cases where a mire complex is found to contain specific mire site types or species that are decreed as nationally or locally threatened. Today it is getting more and more obvious that any well developed and reasonably well-preserved mire complex is worth protection, even if it would lack any specially listed threatened site types or species. This is especially the case in areas with low level of mire conservation, and in areas where most peatlands already have been ditched.

In accordance with the EU biodiversity policy, Finland has aimed at halting the impoverishment of biodiversity by the year 2010, and is committed to establish positive developments in the state of the environment by 2010-2016. Regarding mire ecosystems, to achieve, or at least approach, this goal, an ecologically sufficient and regionally representative conservation network is urgently called for, and an extensive mire restoration programme should be launched in southern and central Finland.

The mire protection policy of FANC

The council of the Finnish Association for Nature Conservation (FANC/SLL) accepted in 2007 a peatland policy paper for the Association, called Peatland Programme 2020 (FANC 2008). This policy paper includes a vision for the state of the Finnish peatland nature and peat utilization in 2020: "In 2020 the Finnish peatland nature is a highly esteemed provider of ecosystem services, the original biological diversity of which is being re-established by active restoration. Mires are places of recreation and sources of natural products. Earlier mistakes done in peatland forestry are being repaired; forestry is practiced on ecologically and economically sustainable way; and the energy use of peat has been terminated."

To achieve this, the policy paper details five major goals for mire conservation work: 1. To make an end for mire destruction, and to get extensive restoration works started; 2. To safeguard and re-establish the hydrological integrity of mire complexes, with an aim to protect mire ecosystems and to comply with the water framework directive's obligations regarding surface water quality; 3. To retain and restore the carbon sequestration capacity of mire ecosystems, which is crucial for the combat against climate change; 4. To effect a thorough reform of the legislation, so that the ecological values of peatlands will be fully considered in all permit processes and environmental impact assessment of peatland utilization plans; 5. To achieve a general change of people's attitude towards peatland nature, so that their true value as an important element in the European and global natural heritage, as well as their value for humans is recognised, and further, that our responsibility for the protection of peatlands is fully reflected in their management - not only in Finland but worldwide.

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Nationally and regionally threatened mire mosses in Finland

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Introduction

Mires are wetlands in which peat accumulation is a characteristic feature. Great variations occur in environmental factors such as the amount, flow and quality of water, and the amount of nutrients contained in the peat. Mires are, therefore, very complex biotopes. Traditionally mires have been divided into spruce mires with a dense tree cover and a thin peat layer, pine bogs and open mires with a thick peat layer and a shortage of available nutrients, and rich fens. In Finland spring mires, swamps in the shores of lakes and rivers, as well as the thawing mires of northernmost Lapland with their very thin peat layers are also regarded as mires (Eurola et al. 1984). Mire sites often form mosaic-like combination types, where ombrotrophic hummocks and calcareous rich fen surfaces can occur side by side. In general, mosses cover most of the mire surface on hummocks, lawns and flarks. Mosses also typically play a main role in peat accumulation and thus considerably influence the growth conditions of mires. Many mire bryophytes have very narrow ecological niches and the classification of mire vegetation is largely based on the mosses of Finland and Scandinavia.

With the exception of rich fens and the most fertile types of spruce mires, all mire types used to be common throughout Finland. Therefore most mire bryophytes are spread all over the country, and used to be very common in the past. A few mosses, however, display a southern or oceanic distribution. Examples include *Sphagnum affine* and *S. molle*, which can only be found growing rather commonly in southwestern Finland. There are also a few arctic species, which are found only in Lapland, such as *Dicranum groenlandicum*. The nomenclature of the bryophytes follows Ulvinen *et al.* (2002).

Result and discussion

Human activities, especially forestry ditching operations, which were widespread from the 1960s to the 1980s, have greatly decreased the area of natural mires, especially to the south of the Arctic Circle. Ditching has mostly affected wooded mires, pine bogs and spruce mires, and has had less of an effect on poor open bogs and fens. The amount of rich fens has collapsed to below 1% of their original area in the southern half of Finland (Eurola *et al.* 1991, Heikkilä 1992), where about 80 % of the original mire area is either under agricultural use or drained for forestry. Agriculture has accounted for the most fertile mires to such an extent that already nearly 100 years ago it was difficult to find examples of southern Finnish rich fens for scientific research (Cajander 1913). In cultivated mires, mire bryophytes are usually totally absent. However, in mires drained for forestry hummock species, in particular, may survive for decades. In general, the poorer the mire the longer these species will survive. When drained mires dry up and become covered with trees the mire bryophytes are gradually replaced by forest species. Mire bryophytes have a great extinction debt (see Hanski 2000), which can lead to the disappearance of many species.

Populations of all mire bryophytes have collapsed in the southern half of Finland (Reinikainen *et al.* 2000), even though many of the species have not yet been classified as threatened. The likelihood of rare species surviving is further limited by the profound fragmentation of habitats suitable for them. In southern Finland there are only three regions where considerable networks of small patches of rich fens still exist. These are the Åland archipelago, the Northern Karelia hill ridge to the north of Joensuu, and the southern part of the Suomenselkä watershed in western Finland. Elsewhere there are only small fragments of rich fens left, and many of these remaining patches are threatened by hydrological changes in the surroundings as well as the cessation of grazing and haymaking. In many places rich fen vegetation can be found in old peat pits. In such locations there is a rapid natural succession leading to poorer conditions and the disappearance of rich fen vegetation. Altogether there are only about 700 hectares of rich fens in some 200 remaining patches in the entire southern half of Finland.

The great majority of threatened mire bryophytes are species associated with rich fens, e.g. *Meesia longiseta, M. hexasticha, Bryum neodamense, Hamatocaulis lapponicus, H. vernicosus* and *Pseudocalliergon angustifolium* (Fig. 1, Appendix 1). In addition, numerous threatened species grow not only in rich fens but also in springs or other small watercourses with a neutral pH, e.g. *Philonotis calcarea, Palustriella decipiens* and *P. falcata*. Some species demand a calcareous substrate and grow in many kinds of habitats. For example, *Amblyodon dealbatus* grows in rich fens, calcareous springs and wet calcareous rocky outcrops (Ulvinen 2001).

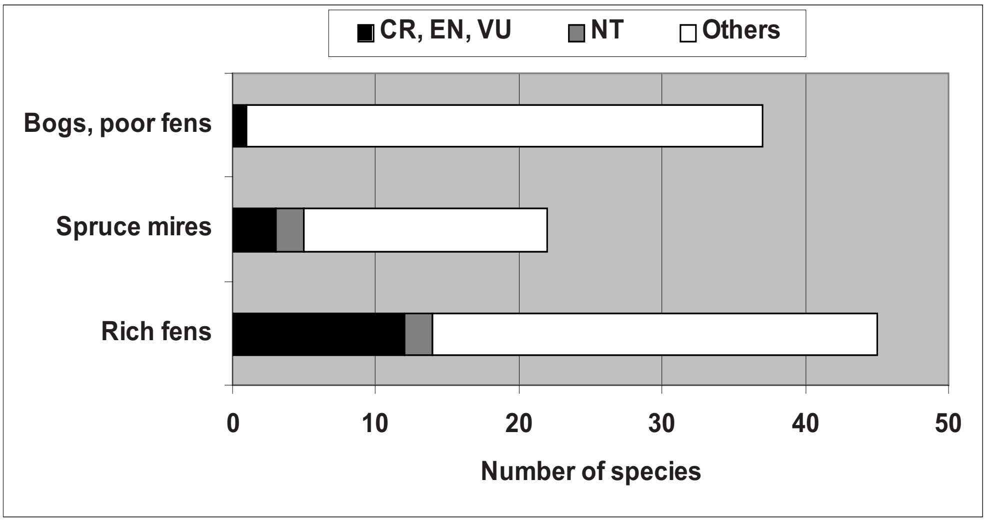

Figure 1. Altogether 104 bryophyte species of Finland grow mainly in mires. Most species are found in rich and intermediate fens (43 %). Thirty-six percent grow in bogs and poor fens, while 21% grow in spruce mires. Numerous forest species are also found in spruce mires. Thirty-one percent of the species in rich fens are threatened or in need of monitoring. The corresponding figure for spruce mires is 21 %, while the figure for bogs and poor fens is just 3 % (Ulvinen et al 2002).

Rich fens have particularly declined in the southern half of Finland and many of their moss species have become regionally threatened or have disappeared altogether (Appendix 2). Even common rich fen species have become regionally threatened. For example, *Calliergon richardsonii, Catoscopium nigritum, Cinclidium stygium, Meesia triquetra, Pseudocalliergon trifarium* and *Sphagnum contortum* are nowadays rare in southern Finland. Furthermore, many species of intermediate fens are disappearing in the south. *Warnstorfia sarmentosa, Loeskypnum badium* and *Sphagnum subfulvum*, for example, have virtually disappeared (Ulvinen *et al.* 2002). According to the inventories of the Finnish Mire Cultivation Society conducted at the beginning of the 1900s, the northern *Sphagnum aongstroemii* growing in poor sedge fens was also fairly common in southern Finland (Warén & Kotilainen 1923, Kotilainen 1924). All the sites recorded in these inventories have since been exploited by agriculture or peat mining. Nowadays the species is known to exist in less than ten localities in the southern half of Finland.

Some oceanic mire bryophytes such as *Sphagnum affine* and *S. molle* extend their distribution into south-western Finland. They do not require fertile sites and *S. molle* has been found even in ombrotrophic bogs (Heikkilä & Lindholm 1988). These naturally rare occurring species have also declined due to forestry, in spite of the fact that they thrive at sites where forestry ditching operations are unprofitable. In addition, *S. subnitens*, which grows in intermediate fens and lakeshores in western Finland, has declined in mires.

Some threatened mire bryophytes grow in both spruce mires and mineral soil forests. Examples include *Herzogiella turfacea* and *Plagiothecium latebricola*. Usually these species grow on decaying wood and demand a continuous supply of dead trees. Such conditions in Finland are more commonly found in spruce mires than in mineral soil forests, which have been subject to more intensive forms of forestry. These kinds of sites are more important for hepatics than mosses.

A part of the Natura 2000 programme, the National Mire Protection Programme was aimed at protecting more or less all the rich fens in southern Finland along with the most important sites in the north. In the south, in particular, there are no longer sufficient rich fens to ensure a sustainable network of reserves. The conservation situation of fertile spruce mires is also very poor in southern Finland (Aapala 2001). The conservation programme for old-growth forests has improved the preservation prospects for the spruce mires of eastern and northern Finland. Elsewhere, however, spruce mire species remain inadequately protected. In the south and west there are no new sites worth protecting outside the present reserves, whilst the small size of these existing reserves creates vulnerability to hydrological changes in surrounding areas. It is clear that as a result of the decline and fragmentation of biotopes, increasing numbers of mire bryophytes will become threatened in the near future and conservation efforts will, at their best, achieve nothing more than a slowing down of the present development. There is no doubt that many species will disappear from the southern part of Finland, while species particularly associated with rich fens and spruce mires will become threatened throughout the whole country.

There are also a number of mire mosses, whose protection translates as an international responsibility for Finland (Appendix 3). Over ten percent of these mire moss populations in Europe are estimated to grow in Finland. While many of these populations are also threatened in Finland, there are some that are still rather common, e.g. *Sphagnum jensenii, S. pulchrum* and *S. wulfianum*.

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Appendix 1. Threatened mire bryophytes in Finland: main habitats and causes of decline and threats (Rassiet et al. 2010)

Species and IUCN class	Habitats	Causes of decline	Threats
CR			
Pseudocalliergon turgescens	Sl, Kk	N, O	Y
Rhizomnium gracile	Sl, Sk	M, O	Y
EN			
Campylium laxifolium	Sl, Vl	O, Vr, R	O, Vr
Drepanocladus sendtneri	V, Sl	O, Vr, R	O, Vr
Bryum longisetum	Sl	O	O
Hamatocaulis lapponicus	Sl, Vs	O, Vr, R	O, Vr
Meesia hexasticha	Rn, Sl	O, R	O
Meesia longiseta	Sl	O, R, Vr, Kh	O
Sphagnum affine	S, Rj, Vl	O, Vr, M	O, Vr, M
Sphagnum molle	S, Rj	O, Vr	O, Vr
Splachnum melanocaulon	M, S	M, O, N	M, O
Philonotis calcarea	Vl, Sl	O, Vr, R, N	Vr, O
VU			
Amblyodon dealbatus	Sl, Vl, Kk	O, Ks, M, R	O, M, Ks
Campyliadelphus elodes	V, Sl, K	O, Vr, K	O, Vr, Ks
Dicranum groenlandicum	Sn	Y	Y
Hamatocaulis vernicosus	Sl	O, Vr, R	O, Vr
Herzogiella turfacea	M, Skr	O, Vr, M, R	R, O, M
Palustriella commutata	Vl, Sl	O, Vr, R	O, Vr
Pseudocalliergon angustifolium	Sl	M, O	O, M
Pseudocalliergon lycopodioides	Sl, Kk, Rjn	R, O, N	O, Vr
NT			
Amblystegium radicale	Sk, M, R	M, O, R, Vr	O, M, Vr
Bryum knowltonii	K, Sl, R	O	O
Palustriella decipiens	Vl, Sl	O, Vr, R	Vr, O
Plagiothecium latebricola	Sk, M	M, R, O	M, O
Palustriella falcata	Vl, Sl	O, Vr, R	O
Sphagnum contortum	Sl	O, Vr	O, Vr, R

M = forests

S = mires

Sl = rich fens

Sk = spruce mires

Sn = poor and intermediate fens

K = rocky outcrops

R = shores

V = waters

M = forestry

O = ditching

Vr = watercourse regulation

R = building, road construction

Y = small population

Ks = mining

N = cessation of grazing and mowing

Vl = springs

Appendix 2. Regionally threatened mire bryophytes in Finland (Ulvinen et al. 2002).
The abbreviations for regions are as follows: S=south, M=middle, E=east, N=north, W=west

Aplodon wormskioldii	S
*Brachythecium turgidum	S
*Bryum pseudotriquetrum	S
*Calliergon richardsonii	S
*Catoscopium nigritum	S
*Cinclidium stygium	S
Cinclidium subrotundum	S
Cratoneuron filicinum	M
*Dicranum angustum	S
Dicranum leioneuron	S
Hylocomiastrum pyrenaicum	S
Hylocomiastrum umbratum	M
Loeskypnum badium	S
*Meesia triquetra	S
*Meesia uliginosa	S
Mnium hornum	N
Oncophorus virens	S
Oncophorus wahlenbergii	S
Philonotis seriata	S
Plagiomnium elatum	N
Plagiomnium undulatum	M
Plagiothecium ruthei	N
Pohlia wahlenbergii	M
*Pseudocalliergon trifarium	S
*Rhizomnium pseudopunctatum	S
Sphagnum aongstroemii	S
Sphagnum cuspidatum	N
Sphagnum auriculatum	N
Sphagnum inundatum	N
Sphagnum palustre	N
Sphagnum pulchrum	S
Sphagnum subfulvum	S
Splachnum ampullaceum	S
Splachnum luteum	S
Splachnum rubrum	S
Splachnum vasculosum	S
*Tayloria lingulata	M
Thuidium tamariscinum	M
Warnstorfia sarmentosa	S
*Warnstorfia tundrae	S

* Rich fen species

Appendix 3. Mire moss species for which Finland has an international responsibility (Ulvinen et al. 2002).

Bryum wrightii
Campylium laxifolium
Cinclidium subrotundum
Dicranum angustum
D. leioneuron
Hamatocaulis lapponicus
H. vernicosus
Herzogiella turfacea
Meesia hexasticha
M. longiseta
Philonotis seriata
Polytrichum jensenii
Pseudocalliergon angustifolium
Rhizomnium gracile
Sphagnum annulatum
S. aongstroemii
S. jensenii
S. pulchrum
S. subfulvum
S. wulfianum
Splachnum melanocaulon
S. rubrum
Tayloria tenuis
Warnstorfia tundrae

Assessment of threatened mire habitats in Finland

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Introduction

The first assessment of threatened habitat types in Finland was carried out during 2005-2008 (Raunio & al. 2008a, 2008b). The assessment of threatened species has already a long tradition in Finland. Since the 1980s there have been three assessments of threatened species, the latest made by Rassi & al. (2001), and the fourth one is going to be published in 2010. When it concerns recognizing the value of all biodiversity, species approach is not enough, and the habitat approach is also needed. The need for more detailed information on habitats has increased in the last few years. Several legal acts and international conventions oblige Finland to protect and monitor habitats. Information on habitats is also needed for planning of land use and sustainable use of natural resources, and for the restoration, management and protection of habitats. Assessments of threatened habitats have previously been carried out in some other European countries; e.g. in Germany (Riecken & al. 1994), Estonia (Paal 1998), Norway (Fremstad & Moen 2001) and Austria (Essl & al. 2002a, 2002b).

The project was co-ordinated by the Finnish Environment Institute and the assessment was conducted by over 80 specialists from various research institutes, universities, and administrative bodies. The assessment work was divided between seven expert groups: the Baltic Sea and its coast, inland waters and shores, mires, forests, rocky habitats, traditional rural biotopes and fell habitats.

Members of the mire expert group have been: *Eero Kaakinen* (chairman, North Ostrobothnia Regional Environment Centre), *Pekka Salminen* (deputy chairman, Ministry of the Environment), *Aira Kokko* (secretary, Finnish Environment Institute), *Kaisu Aapala* (secretary, Finnish Enviroment Institute), *Satu Kalpio* (secretary, Natural Heritage Services of Metsähallitus), *Seppo Eurola* (Professor emeritus), *Tuomas Haapalehto* (Natural Heritage Services of Metsähallitus), *Raimo Heikkilä* (Finnish Environment Institute), *Juha-Pekka Hotanen* (Finnish Forest Research Institute), *Hanna Kondelin* (Finnish Environment Institute), *Tapio Lindholm* (Finnish Environment Institute, until 12/2007), *Hannu Nousiainen* (Finnish Forest Research Institute), *Rauno Ruuhijärvi* (Professor emeritus), *Seppo Tuominen* (Finnish Environment Institute), *Harri Vasander* (University of Helsinki) and *Kimmo Virtanen* (Geological Survey of Finland).

The habitat expert groups also prepared the first list of Finnish habitats of international responsibility (Raunio & al. 2008a). They also made proposals on measures to be taken in the future in order to improve the state of the habitats.

The concept of threatened mire habitats is not totally new in Finland. Ruuhijärvi (1978) made a list of "rare mire site types" which especially in southern Finland would need more inventories, establishment of small nature reserves, and which should not be drained for forestry purposes. These mire site types were listed as threatened or rare in mire conservation programs (Haapanen & al. 1977, Haapanen & al. 1980). The list was updated by Heikkilä (1993, see also Aapala & al. 1996). Some examples of previously listed threatened mire site types are rich fens, rich pine fens, rich spruce-birch fens, thin-peated rich spruce mires, herb-rich spruce mires, and springs and spring fens.

Method for the assessment

In the preliminary stage of the project in 2003-2004, a method was developed for the assessment, based on the methods used in Germany and Austria (Blab & al. 1995, Essl & al. 2002a). The method for the assessment is based on two main criteria (Figure 1; Raunio & al. 2008a). Criterion A relates to the change in the total area or the number of occurrences of the given habitat type. Criterion B relates to the qualitative development of the habitas, including three main factors: the structural features typical of the habitat, functional features that maintain the habitat, and species typical for the habitat. The stepwise process of defining the Red List Category for each habitat is started from the sub-criteria A1 or B1 by assessing the quantitative or qualitative development during the past 50 years (Figure 1). The assessment based on the sub-criteria A1 or B1 has been adjusted with development forecast (sub-criteria A2 and B2), which concerns the predicted qualitative or quantitative development of each habitat type in the near future (approx. next 20 years). Sub-criteria A3 and B3 provide an option to tighten the Red List Category if a significant decline or deterioration was evident prior to the 1950s. For the more detailed description of the use of each sub-criterion see Raunio & al. (2008a).

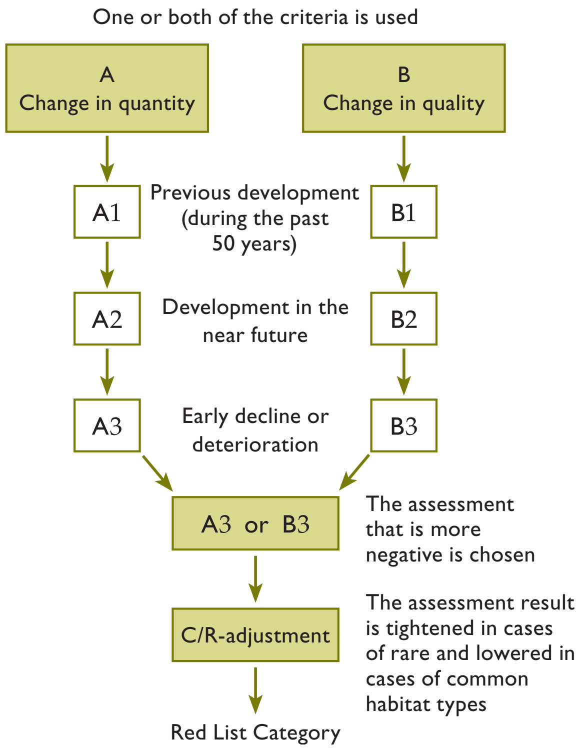


Figure 1. The criteria and the stepwise assessment method of the habitats.

If the A1-A3 and the B1-B3 criteria provided different results, the more negative one was applied. The resulting preliminary Red List Category of the habitat might still, if needed, be tightened on the basis of the habitats extreme rarity or lowered on the basis of its commonness. Final assessment result is one of the following Red List Categories: regionally extinct (RE), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT) or least concern (LC). Habitat types that are critically endangered, endangered or vulnerable are considered to be threatened. The category data deficient (DD) is applied to habitat types of which Red List Category cannot be defined due to insufficient information.

The threat assessment of mire habitats was made on two hierarchy levels, habitat level and habitat complex level. The habitat level assessment included mire site types and the habitat complex level assessment mire complex types, succession series of the land uplift coast and seasonal wetland complexes. The assessment included 54 mire site types / type groups and 18 mire complex types / type groups. In addition to this two spring complex type groups were assessed in inland waters and shores expert group in co-operation with mire expert group (Leka & al. 2008).

Both criteria A and B were used in the assessment of the mire site types but only criterion B, when assessing the habitat complex types. When using both criteria, criterion A provided the more critical result in most of the cases. The red listing of habitats was carried out both on the national level, and on the regional level for southern and northern Finland (Figure 2). In the mire vegetation zonation (e.g. Ruuhijärvi 1983) southern Finland includes bog zone and southern parts of the aapa mire zone, northern Finland includes the rest of the aapa mire zone, as well as palsa mire and oroartic mire zone.

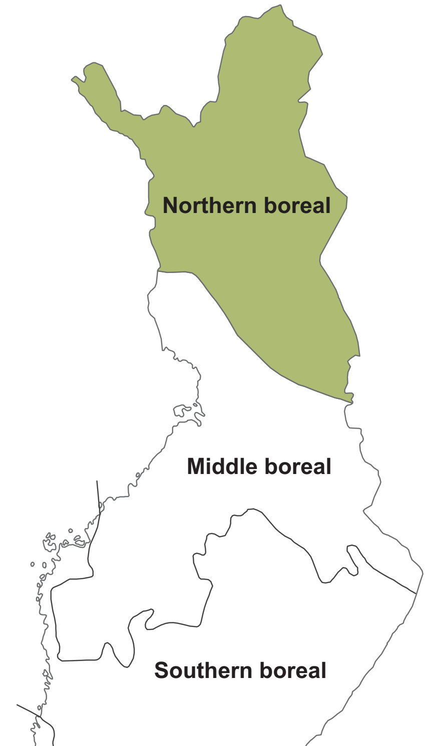


Figure 2. The division of Finland into sub-regions in the assessment of threatened habitats. Southern Finland includes hemi-, southern and middle boreal vegetation zones, Northern Finland northern boreal vegetation zone.

Figure 3. All spruce mire habitats are threatened in Finland. Dwarf shrub spruce mire, Mäntsälä, southern boreal zone (Photo Seppo Tuominen).

The mire expert group assessed all open and forested peat forming habitats. On habitat level we assessed different types of spruce mires, spruce-birch fens and rich spruce-birch fens, pine mires and bogs, pine fens and rich pine fens, fens, rich fens and swamps (Kaakinen & al. 2008a, 2008b). The classification of mire site types was based on existing national mire site type classifications (e.g. Cajander 1913, Lukkala & Kotilainen 1951, Ruuhijärvi 1960, Eurola 1962, Eurola & al. 1984, Eurola & al. 1995, Laine & Vasander 2005, Eurola & Huttunen 2006, Ruuhijärvi & Lindholm 2006).

On habitat complex level different sub-types of raised bogs, aapa mires and oroarctic mires (e.g. Cajander 1913, Ruuhijärvi 1960, Eurola 1962, Ruuhijärvi 1983, Eurola & al. 1994, Lindholm & Heikkilä 2005) were assessed. These are climatic mire complex types – their macro- and microtopography, hydrology, peat stratigraphy and typical vegetation communities are primarily dependent on macroclimate, for sub-types also on topography and soil.

Local mire complexes were also described, but because of lack of information, the Red List Categories were not assessed for them. They are a heterogeneous group of usually small-size complexes, whose development is mostly regulated by the local conditions, such as topography, bedrock, soil, hydrology or location in relation to water bodies. Mires that have developed in small depressions, in kettleholes in the eskers, on shores of lakes and ponds or spring mires are examples of local mire complexes.

Land uplift phenomenon in Fennoscandia has formed a unique succession series of mires on the coastland of the Bothnian Bay (e.g. Aario 1932, Brandt 1948, Huikari 1956, Rehell 2006). On the uplift coast the land that has been revealed from the sea may paludify and through time the development may lead to either a raised bog or an aapa mire. Mire succession series of the land uplift coast are formed by a series of mires with a continuous succession of ages: young mires on the coast and then older mires towards inland. In the southern part of the coastal area the succession usually

Figure 4. Flark-surfaced aapa mire complex. Joutsenaapa, Salla, northern boreal vegetation zone (Photo Rauno Ruuhijärvi).

leads to a raised bog, whereas in the northern part it usually leads towards an aapa mire. The soil (sand or till) also affects the mire succession, mainly due to the different water holding capacities.

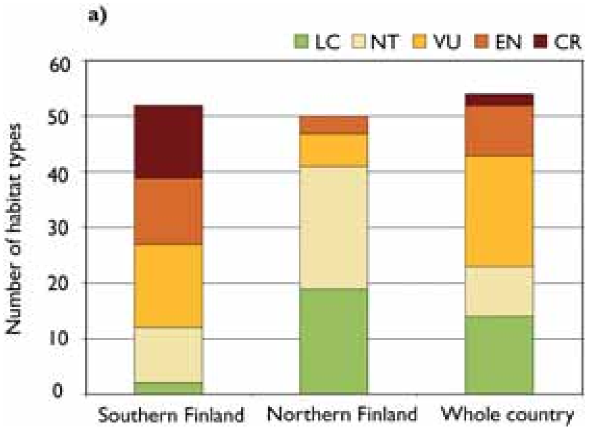
Seasonal wetlands (Laitinen & al. 2005, 2007) were also covered by the mire expert group, but the available data was too scant to make the actual threat assessment. Seasonal wetlands occur on well-drained mineral soils and they are characterized by open fen vegetation, but usually do not accumulate peat. They can occur in different types of environments, for example in depressions in forests, as part of larger mire complexes or on fells. Bedrock and soil conditions cause regional differences. Ecologically they are not mires, but they are often hydrologically connected to a mire ecosystem. The best known seasonal wetlands occur on sand in North Pohjanmaa and Kainuu (Laitinen & al. 2005, 2007).

There were no new field inventories for this assessment project. Instead, the results of ongoing projects of partners in co-operation (e.g. National Forest Inventory by Finnish Forest Research Institute, inventory of protected areas by Metsähallitus) were used. The latest results of mire research and the knowledge of experts were utilized. Different kind of GIS-data were combined and used especially in the assessment of mire complex types.

Results of the assessment

About half of the mire site types and mire habitat complex types assessed are threatened in the entire country (Red List Categories CR, EN or VU) (Figure 5, Table 1 and 2) (Kaakinen & al. 2008a, 2008b). More mire habitats were listed as threatened than previously (Ruuhijärvi 1978, Heikkilä 1993, Aapala & al. 1996). Mire habitats, both mire site types and complex types, are much more threatened regionally in southern Finland (hemi-, southern and middle boreal vegetation zones) than in northern Finland (northern boreal vegetation zone). That is because of more intensive utilization of mires in southern and central parts of Finland.

The assessment shows differences between main mire site type groups (Figure 6). The proportion of threatened mire site types is highest among rich fens, spruce mires, and spruce-birch fens and rich spruce-birch fens. Also some of the swamp site types on the land uplift coast belong to the most threatened mire site types. In the whole country, category LC (least concern) typically includes still quite common, poorest and wettest mire site types that occur throughout the country or are concentrated on northern Finland.



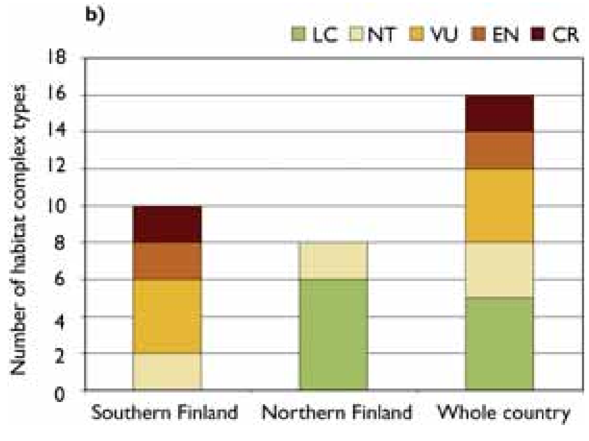


Figure 5. Number of mire habitats (a) and habitat complexes (b) in different Red List Categories regionally (southern and northern Finland) and nationally. In addition, two habitat complex groups have been assessed to DD-category.

Only two ombrotrophic mire site types were assessed to be in the category LC in southern Finland – *Sphagnum fuscum* bogs and ridge-hollow pine bogs, and most of the mire site types are threatened or near threatened (Figures 5a and 6, Table 1). Critically endangered (CR) in southern Finland are all rich fen site types, as well as herb rich sedge fens, rich spruce-birch fens, rich pine fens, herb rich pine fens, some of the thin-peated rich spruce mire site types and *Alnus glutinosa* swamps. The proportion of threatened mire site types is clearly lower in northern Finland. Rich fens, spruce mires, and spruce-birch fens and rich spruce-birch fens have deteriorated most – most of them are near threatened (NT) in northern boreal vegetation zone.

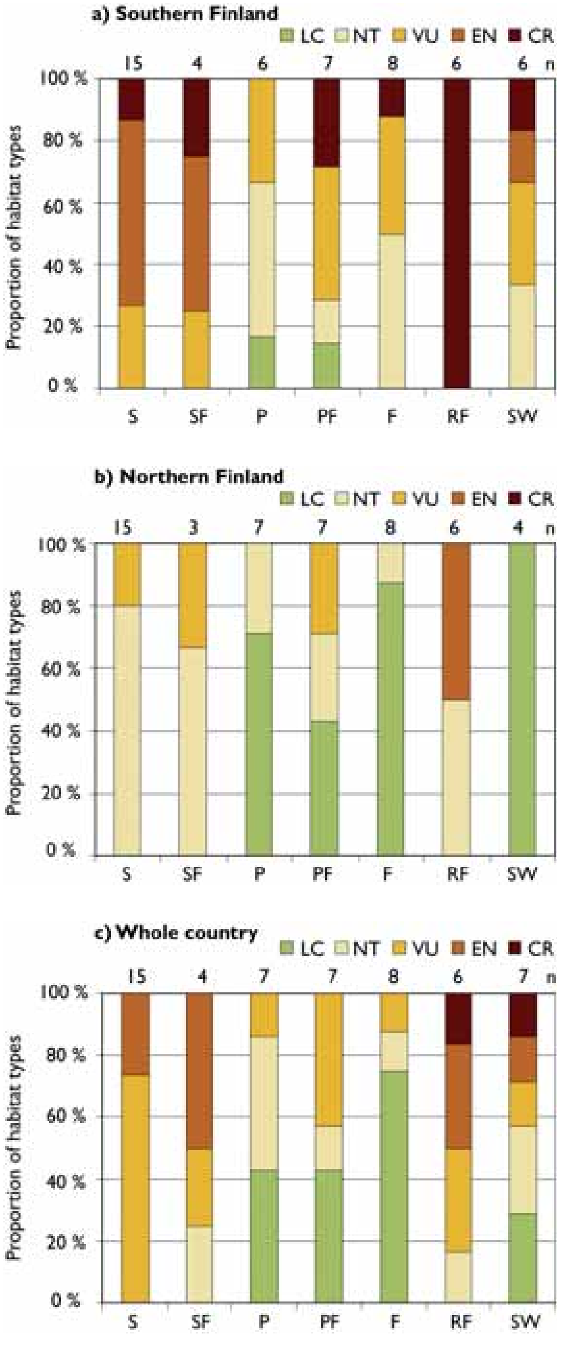


Figure 6. The proportion of the Red List Categories in the main mire site type groups in southern Finland (a), northern Finland (b) and whole country (c). S = spruce mires, SF = spruce-birch fens and rich spruce-birch fens, P = pine mires and bogs, PF = pine fens and rich pine fens, F = fens, RF = rich fens, SW = swamps, n = the number of site types assessed.

Table 1. The results of the assessment of threatened mire habitats in Finland. CR = critically endangered, EN = endangered, VU = vulnerable, NT = near threatened, LC = least concern, DD = data deficient. Explanations of the abbreviations for the reasons for being threatened and future threats are in the end of the table.

Habitat type	**Red List Category**			**Reasons for being threatened**	**Future threats**
	Southern Finland	**Northern Finland**	**Whole Finland**		
Spruce mires					
Thin-peated spruce mires	VU	LC	VU	Dr, F, AgCl, Cst	F, Dr, Cst
Thin-peated herb spruce mires	EN	NT	EN	Dr, F, AgCl, Cst	F, Dr, Cst
Thin-peated *Vaccinium myrtillus* spruce mires	VU	NT	VU	Dr, F, AgCl, Cst	F, Dr, Cst
Thin-peated *Vaccinium vitis-idaea* spruce mires	EN	NT	VU	Dr, F, AgCl, Cst	F, Dr, Cst
Thin-peated rich spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst	Dr, F, Cst
Thin-peated rich fern spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst	Dr, F, Cst
Thin-peated rich herb-grass spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst	Dr, F, Cst
Thin-peated rich fen spruce mires	CR	VU	EN	Dr, AgCl, F, WE, Cst	Dr, F, Cst
Thin-peated rich spring spruce mires	CR	VU	EN	Dr, AgCl, F, GwE, WE, Cst	Dr, F, GwE, Cst
Herb-rich spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst, PH	Dr, F, Cst, PH
Fern spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst	Dr, F, Cst
Herb and grass spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst, PH	Dr, F, Cst, PH
Spring spruce mires	EN	NT	VU	Dr, AgCl, F, GwE, WE, Cst	Dr, F, GwE, Cst
Herb-rich *Vaccinium myrtillus* spruce mires	EN	NT	VU	Dr, AgCl, F, WE, Cst	Dr, F, Cst
Dwarf shrub spruce mires	VU	NT	VU	Dr, F, AgCl, WE, Cst, PH	F, Dr, Cst, PH
Vaccinium myrtillus spruce mires	VU	NT	VU	Dr, F, AgCl, WE, Cst	F, Dr, Cst
Equisetum sylvaticum spruce mires	EN	VU	EN	Dr, F, AgCl, WE, Cst, PH	F, Dr, Cst, PH
Vaccinium vitis-idaea spruce mires	VU	NT	VU	Dr, F, AgCl, WE, Cst	F, Dr, Cst
Rubus chamaemorus spruce mires	VU	NT	VU	Dr, F, AgCl, WE, Cst, PH	F, Dr, Cst, PH
Spruce-birch fens and rich spruce-birch fens					
Rich spruce-birch fens	CR	VU	VU	Dr, AgCl, F, WE, Cst, GwE, PH, OGr	Dr, F, Cst, OGr, GwE, WE, Mi
Tall-sedge spruce-birch fens	VU	NT	NT	Dr, F, WE, AgCl, PH, Cst	F, Dr, PH, Cst
Carex nigra birch fens	EN	■	EN	Dr, F, AgCl, Cst, WE	F, Dr, Cst
Eriophorum vaginatum birch fens	EN	NT	EN	Dr, F, AgCl, PH, Cst, WE	F, Dr, Cst
Pine mires and bogs					
Thin-peated pine mires	NT	LC	NT	Dr, F, Cst	F, Dr, Cst
Spruce-pine mires	VU	NT	VU	Dr, F, Cst, AgCl	F, Dr, Cst
Carex globularis pine mires	VU	LC	NT	Dr, F, Cst	F, Dr, Cst
Dwarf shrub pine bogs	NT	LC	LC	Dr, F, Cst, PH	F, Dr, PH, Cst
Eriophorum vaginatum pine bogs	NT	LC	LC	Dr, F, PH, Cst, AgCl	Dr, PH, F, Cst
Sphagnum fuscum bogs	LC	LC	LC		PH, Dr, Cst
Frost bogs and mires	■	NT	NT	ClC, OGz	ClC, OGz
Pine fens and rich pine fens					
Rich pine fens	CR	VU	VU	Dr, AgCl, F, PH, WE, Cst, GwE, OGr	Dr, F, WE, Cst, OGr, GwE, Mi
Herb rich pine fens	CR	VU	VU	Dr, AgCl, F, PH, Cst, GwE, OGr	Dr, F, Cst, WE, GwE, OGr, Mi
Tall-sedge pine fens	VU	LC	LC	Dr, F, AgCl, PH, Cst	Dr, F, PH, Cst
Sphagnum papillosum pine fens	VU	NT	VU	Dr, F, PH, AgCl, Cst	Dr, F, PH, Cst
Flark pine fens	NT	LC	LC	Dr, PH, F, AgCl, Cst, WE	Dr, PH, Cst, WE
Low-sedge pine fens	VU	NT	NT	Dr, F, AgCl, PH, Cst	Dr, PH, Cst
Ridge-hollow pine bogs	LC	LC	LC		PH, Dr, Cst, ADE

	Red List Category				
Habitat type	**Southern Finland**	**Northern Finland**	**Whole Finland**	**Reasons for being threatened**	**Future threats**
Fens					
Herb rich sedge fens	CR	NT	VU	Dr, AgCl, PH, Cst, WE	Dr, PH, WE, Cst, GwE, OGr
Swamp fens	NT	LC	LC	WE, WLR, Dr, Cst, AgCl, OGr	WE, WLR, Dr, Cst, OGr
Tall-sedge fens	VU	LC	LC	Dr, AgCl, PH, Cst, WE	Dr, PH, Cst
Sphagnum papillosum fens	VU	LC	NT	Dr, AgCl, PH, Cst	Dr, PH, Cst
Flark fens	NT	LC	LC	Dr, AgCl, WE, PH, Cst	Dr, PH, WE, Cst
Minerotrophic low-sedge fens	VU	LC	LC	Dr, AgCl, PH, Cst	Dr, PH, Cst
Hollow bogs	NT	LC	LC	Dr, PH, AgCl, Cst	PH, Dr, Cst, ADE
Ombrotrophic low-sedge bogs	NT	LC	LC	Dr, PH, AgCl, Cst	Dr, PH, Cst, ADE
Rich fens					
Rich swamp fens	CR	EN	EN	WE, WLR, Dr, AgCl, Cst, OGr	WE, WLR, Dr, Cst, OGr
Rich spring fens	CR	NT	VU	Dr, GwE, F, AgCl, Cst	GwE, Dr, F, Cst
Rich birch fens	CR	NT	VU	AgCl, Dr, WE, PH, GwE, Cst, F	Dr, PH, WE, GwE, Cst, F
Rich birch flark fens	CR	NT	VU	AgCl, Dr, WE, PH, GwE, Cst	Dr, PH, WE, GwE, Cst
Rich birch lawn fens	CR	EN	CR	AgCl, Dr, WE, PH, GwE, Cst, F	Dr, PH, WE, GwE, Cst, F
Rich lawn fens	CR	EN	EN	AgCl, Dr, PH, F, WE, OGr, Cst, GwE	Dr, F, OGr, PH, GwE, WE, Cst
Rich flark fens	CR	NT	NT	Dr, PH, WE, AgCl, Cst	Dr, PH, WE, Cst
Swamps					
Wooded swamps	VU	LC	VU	WLR, WE, Cst, Dr, F, AgCl	WE, WLR, Cst, Dr, F, AgCl
Birch swamps	VU	LC	NT	WLR, WE, Cst, Dr, F, AgCl	WE, WLR, Cst, Dr, F
Alnus glutinosa swamps	VU	■	VU	WLR, WE, Cst, Dr, F, AgCl	WE, WLR, Cst, Dr, F
Alnus incana swamps	CR	■	CR	Dr, AgCl, F, WE, Cst	Dr, F, WE, Cst, AgCl
Scrub swamps	NT	LC	LC	WE, WLR, Dr, Cst, AgCl	WE, WLR, Cst, Dr, AgCl
Willow swamps	NT	LC	NT	WE, WLR, Dr, Cst, AgCl	WE, WLR, Cst, Dr
Northern willow swamps	■	LC	LC		WE, WLR
Myrica gale swamps	EN	■	EN	Dr, WE, Cst, AgCl	Dr, WE, Cst, AgCl
Open swamps	NT	LC	LC	WE, WLR, Dr, Cst, AgCl, OGr, WEP	WE, WLR, Dr, Cst, OGr, WEP

Er = Erosion or physical degradation of vegetation, soil and bedrock, caused by human activities (e.g. trampling, rock climbing, off-road traffic)
OGz = Overgrazing (e.g. reindeer)
Cst = Construction (towns, rural areas, roads, etc.)
Mi = Mining, sand and gravel quarrying (also underwater)
AgCl = Clearing of agricultural land
OGr = Overgrowth of open areas (e.g. meadows become overgrown due to neglect or lack of management, such as mowing or grazing)
F = Forestry (incl. all forest management activities)
Dr = Drainage for forestry (ditching)
PH = Peat harvesting
WE = Water engineering (hydropower stations, mill dams, harbour and waterway construction, artificial lakes, dredging)
GwE = Groundwater extraction
WLR = Water level regulation (incl. shore erosion from regulating water levels)
WEP = Eutrophication and non-toxic pollution of water (e.g. increase of suspended solids, oxygen-demanding substances or nutrients, resulting from discharges from land, caused by human activities)
ADE = Airborne deposition of eutrophying substances
CIC = Climatic changes

Mire succession series of the land uplift coast are critically endangered (CR). Only a few nearly complete succession series are left. Also climatic mire complex types have become threatened, especially in southern Finland, where none of them were classified to category LC (Figure 5b, Table 2). Wooded raised bogs and middle boreal lawn-surfaced aapa mires are the most threatened mire complex types (endangered, EN). However, southern eccentric raised bogs, *Sphagnum fuscum* raised bogs, middle boreal flark-surfaced aapa mires and middle boreal sloping fens have also become threatened (vulnerable, VU).

In northern boreal vegetation zone there are no regionally threatened mire complex types. However, palsa mire complexes, the ecology of which is dependent on frost activities, were classified near threatened (NT) because of the likely threat from climate warming in the future.

Spring complexes (including spring pools, spring brooks, seeps, and the surrounding spring-influenced vegetation) were assessed separately by the inland waters and

Table 2. The results of the assessment of threatened mire habitat complexes types in. Explanations of the abbreviations, see table 1.

	Red List Category				
Habitat complex type	**Southern Finland**	**Northern Finland**	**Whole Finland**	**Reasons for being threatened**	**Future threats**
Raised bogs					
Plateau raised bogs	NT	■	NT	Dr, AgCl, PH, F	Dr, F, ADE
Concentric raised bogs	NT	■	NT	Dr, PH, AgCl, F, Cst	PH, Dr, Cst, F, ADE
Eccentric raised bogs	VU	LC	VU	Dr, PH, AgCl, F, Cst, WE	PH, Dr, Cst, F, ADE
Southern eccentric raised bogs	VU	■	VU	Dr, PH, AgCl, F, WE, Cst	PH, Dr, Cst, F, ADE
Northern eccentric raised bogs	■	LC	LC		Dr, Er
Sphagnum fuscum raised bogs	VU	LC	VU	Dr, PH, Cst	PH, Dr, Cst, ADE
Wooded raised bogs	EN	■	EN	Dr, F, PH, Cst	F, Dr, Cst, ADE
Aapa mires					
Middle boreal aapa mires	EN	NT	EN	Dr, AgCl, PH, F, Cst, WE, GwE, OGr	Dr, PH, F, Cst, GwE, WE
Middle boreal lawn-surfaced aapa mires	EN	■	EN	Dr, AgCl, PH, F, Cst, WE, GwE, OGr	Dr, PH, F, Cst, GwE
Middle boreal flark-surfaced aapa mires	VU	NT	VU	Dr, AgCl, PH, F, Cst, WE, GwE	Dr, PH, F, Cst, GwE, WE
Northern boreal aapa mires	■	LC	LC		Dr, F, PH, Cst, Mi, WE, Er, ClC
Southern subtype of northern boreal aapa mires	■	LC	LC		Dr, F, PH, Cst, Mi, WE
Northern subtype of northern boreal aapa mires	■	LC	LC		F, Er, ClC
Palsa mires	■	NT	NT	ClC, Er, OGz, Cst	ClC, Er, OGz
Sloping fens	VU	LC	NT	Dr, F, Cst	Dr, F, Cst, Er
Middle boreal sloping fens	VU	■	VU	Dr, F, Cst	Dr, F, Cst
Northern boreal sloping fens	■	LC	LC		Dr, F, Cst, Er
Oroarctic mires		LC	LC		
Local mire complexes	DD	DD	DD		F, GwE, Dr, Cst, WE
Mire succession series of the land uplift coast	CR		CR	Dr, AgCl, F, Cst, WE	Dr, F, Cst, WE, AgCl
Raised bog succession series of the land uplift coast	CR	■	CR	Dr, AgCl, F, Cst, WE	Dr, F, Cst, WE, AgCl
Aapa mire succession series of the land uplift coast	CR	■	CR	Dr, AgCl, F, Cst, WE	Dr, F, Cst, WE, AgCl
Seasonal wetlands	DD	DD	DD		F, Dr, GwE, Cst

shores expert group in co-operation with mire expert group (Leka & al. 2008). They were divided in two habitat complex groups: spring complexes and *Cratoneuron* spring complexes. Both of these were assessed to be vulnerable (VU) in the whole country, endangered (EN) in southern Finland and least concern (LC) in northern Finland.

Reasons for the mire habitats being threatened and future threats

All the various ways to use mires have affected mire diversity for a long time (see also Lindholm & Heikkilä 2006). Approximately one third of the total land area, about 10,4 million hectares, was originally covered by mires in Finland (Ilvessalo 1956). Now the area of undrained peatland is about 4 million hectares and most of it is located in northern Finland (Metsäntutkimuslaitos 2007). In addition to direct habitat loss, extensive use of mires has caused deterioration of the quality of undrained mires especially in southern Finland. Land use in catchment areas of mires have caused changes in natural hydrology of mires and tree management of forested mires, even undrained ones, have changed the structure of tree stands. Land use has also caused habitat fragmentation and increasing isolation of the remaining populations of mire species (Kallio & Aapala 2001, Hanski 2005).

Drainage for forestry is the most significant reason for the mire habitats becoming threatened (Figure 7). Approximately 5,6 million hectares of mires have been drained for forestry (Hökkä & al. 2002, Metsäntutkimuslaitos 2007). Drainage has been most intensive in southern Finland, but quite intensive also in the southern parts of the northern boreal vegetation zone. The end of the 1960s and the whole of the 1970s were the most intensive drainage period, but drainage for forestry continued up to the 1990s.

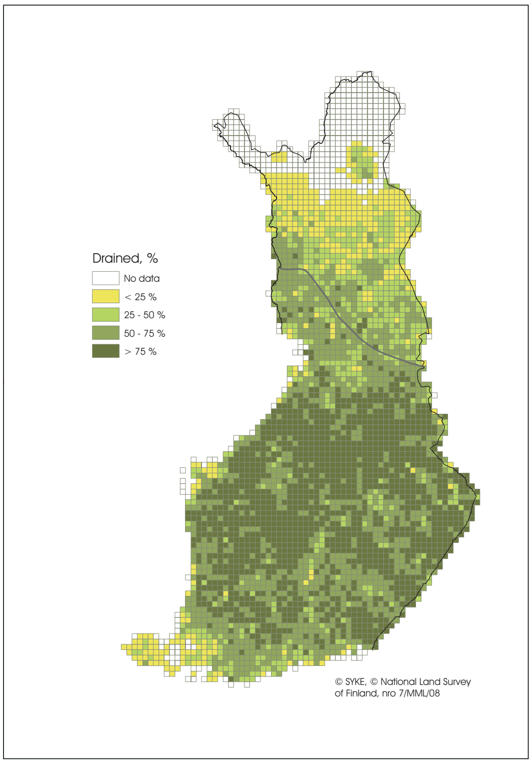


Figure 7. The proportion of drained peatland of the total peatland area in 10 x 10 km grid.

Agricultural use has also reduced the mire area especially in southern Finland, but also locally in northern Finland in areas with rich fens and fertile spruce mires. Rich fens, but also other fertile mire habitat types were the most sought-after. However, *Sphagnum fuscum* bogs were also exploited by using special cultivation methods. Many southern ombrotrophic raised bogs had already lost their minerotrophic lagg zones by the 1950s. Industrial peat harvesting has expanded from the 1970s onwards and regionally it has had a major impact on mire biodiversity. Other reasons for deterioration of mires are e.g. water engineering and regulation, construction (incl. road networks), logging and soil treatment in undrained forested mires and groundwater extraction.

Although mire conservation has progressed and the drainage of pristine mires for forestry is not any more supported by the state, there are still many threats to the mires. The maintenance of old ditches can destroy mire margin habitats as well as change the natural hydrology of undrained mire habitats. Moreover, undrained forested mire habitats are still used for forestry. Peat extraction can still decrease the diversity of mires, if undrained mires are taken into use. There are plans to inundate large mire areas for hydro-electricity, threatening even protected mires. Building and infrastructure projects may harm, destroy or fragment mires. Groundwater extraction threatens spring mires and other groundwater fed mires. Long-distance effects of drainage and other land use activities may have a negative impact on undrained mires. Some of the rich fens were formerly used as pastures, which kept them open and more diverse. Overgrowing after abandoment now threatens this diversity in many of the smaller rich fens especially in southern Finland.

Climatic warming first affects northern mires with permafrost formations, palsas and pounikkos, and frost bog and mire vegetation (Zuidhoff & Kolstrup 2000, Luoto & Seppälä 2003, Luoto & al. 2004, Fronzek & al. 2006). Palsa mire complexes and frost bogs and mires may become threatened.

Figure 8. Frost bog vegetation covers the palsa hummocks in a palsa mire complex Enontekiö (Photo Seppo Tuominen).

Conservation areas save a network of some of the most valuable mires (Kaakinen & Salminen 2006). According to the results of the 9. National Forest Inventory made by Finnish Forest Research Insitute (Finnish Forest Research Institute 2006) the protected mire area is about 1,1 million ha, 12 % of the present total area of peatlands (9,1 million ha according to 9. NFI). Especially in southern Finland the boundaries of mire reserves do not always include the entire hydrological entities, mire complexes or systems, and thus cannot prevent the drying effects of drainage and other land use in the surroundings.

Finland has special responsibility for certain mire habitats

There are certain elements in our mires that are typically Fennoscandian. The mire expert group listed some Finnish mire site types and mire habitat complex types of special international responsibility (Raunio & al. 2008a).

One of the most "endemic" mire habitat complex types in Finland is the mire succession series of the land uplift coast. Land uplift is a globally rare phenomenon, which together with cool and humid climate and flat, low-lying topography of coastal areas have enabled the development of these unique succession series.

Our slightly oceanic climate and flat topography have also favored the development of large, continuous and diverse aapa mire systems. Flark-surfaced aapa mires are especially typical for Finland, but lawn-surfaced aapa mires, as well as palsa mires can also be regarded as our responsibility. From raised bog types Finland has great responsibility of concentric raised bogs with well developed ridge-pool pattern.

Flark fens, rich flark fens and rich birch fens are typical mire site types for flark-surfaced aapa mires and therefore Finland has special responsibility also for them, as well as for frost bogs, which are typical mire vegetation for palsa mires and other northernmost flark-level aapamires. Dwarf shrub spruce mires are also typical for Finland, further east or west spruce mires are more nutrient and species rich.

Acknowledgements

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Monitoring restored peatlands in Finnish nature reserves

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Introduction

The ecological structure and function of mire ecosystems are dependent on waters they receive by precipitation and by surface, subsurface or groundwater runoff from the surrounding areas. When mire is drained for forestry, minerogenic waters from the catchment area can not reach the mire anymore. Natural surface and subsurface flow paths of waters across the mire are also changed and the water table level is lowered. Hence, the most important aims of peatland restoration are to restore the natural flow paths of waters, both from the catchment area and through the peatland, and to raise the water table level. Meeting these goals is a prerequisite for the recovery of the functional (e.g. peat accumulation) and structural (e.g. species diversity, habitat complexity) elements of drained peatlands.

Drainage for forestry has affected more than every other hectare of peatland in Finland. Within the Finnish nature reserves there are approximately 50 000 ha of peatlands drained for forestry purposes. Drainage areas immediately outside the nature reserve boundaries may also have serious negative impacts on protected mires because ditches upslope may prevent minerogenic waters from reaching the protected mires and ditches down slope may increase the outflow of waters.

Peatland restoration work has been ongoing in protected areas since 1987. After a modest start the yearly restoration volumes increased substantially when European Union LIFE-Nature funding became available in the mid 1990s. Later, the Forest Biodiversity Programme for Southern Finland has made resources available for restoration (Etelä-Suomen metsien suojelutoimikunta 2002). So far 19 000 ha of peatlands have been restored.

At first the focus was on developing and testing restoration methods (Fig. 1, Fig. 2) (Seppä et al. 1993, Heikkilä & Lindholm 1995a, Heikkilä et al. 2002). At the same time, the importance of monitoring the effects of restoration was also recognized and long-term monitoring began in several sites (Seppä et al. 1993, Heikkilä, H. & Lindholm, T. 1995b, 1997, 1998). A systematic and uniform monitoring in a network of restoration sites is essential to a large-scale, general evaluation of restoration success (e.g. Neckles et al. 2002). In Finland national monitoring guidelines for restored mires and forests in protected areas include restoration objectives, monitoring methods and principles for setting up a monitoring network (Hyvärinen & Aapala 2009). Metsähallitus (Finn-

Figure 1. After several unsuccessful attempts to restore drained peatlands by damming the ditches with hand-made dams, it was realized, that the only way to do it efficiently in large scale would be to use machinery. Excavators can be used to fill-in the ditches tightly in both semi-open and forested sites. Photo Maarit Similä, 2.8.2006, Koitajoki Natura area, East-Finland.

ish Forest and Park Service, Natural Heritage Services), as a responsible party, has set up a monitoring network at restored peatlands.

The framework for monitoring restored peatlands is hierarchical. It has a landscape level, which includes qualitative monitoring of certain hydrological and vegetation variables at all restored peatlands. Quantitative monitoring of vegetation and butterflies represent species and community level. Because hydrological recovery is the key element for successful peatland restoration, qualitative or quantitative hydrological monitoring is integrated into both general and vegetation monitoring. In addition, more intensive, quantitative, hydrological monitoring is carried out at certain sites.

This paper presents the methods and variables of general and vegetation monitoring of restored peatlands. The principles of hydrological monitoring are also described. For butterfly monitoring, see Uusitalo et al. (2012).

General monitoring

The main objectives for general monitoring of restored peatlands are: 1) to ensure consistency and accuracy in the technical restoration work; 2) to ensure the activation of the restoration succession process (re-wetting); and 3) to identify possible problems in the restoration process as early as possible.

General monitoring is carried out on all restored peatlands two times during the first ten years after restoration. It is based on visual, qualitative evaluation of the hydrological and vegetation attributes of the restored site. The baseline situation is described in the restoration plan.

Figure 2. The restoration of originally open mire usually involves felling most of the trees in a given area. Tree removal from mires is easier during the winter, when it is possible to create a frozen winter road over the mire for the trees to be trucked out. Photo Jere Ekosaari, 9.2.2004, Haapasuo nature reserve, Central Finland.

The first monitoring is an overall survey, where the focus is on the most critical areas of the restored sites, as pointed out in the restoration planning and implementation stages. The second monitoring, 10 years after restoration, is a more detailed survey of the entire restoration site. Each site is evaluated with respect to the amount, spread and quality (as can be visually assessed) of water and the amount and condition of trees and saplings. The assumption is that in 10 years the most extensive effects of restoration disturbance will be over, creating the possibility for a reliable evaluation of the restoration success. If the site shows a positive progress in the restoration process, then it could be concluded that restoration has succeeded and that continued monitoring is no longer necessary. On the other hand, if it is observed that restoration has not completely succeeded, a proposal of future actions is required. It may be e.g. a suggestion of complementary restoration work or continuation of general monitoring.

Identifying possible problems and the need for corrective actions as early as possible, is an important part of general monitoring. To find out the reasons for and to solve the problems requires close co-operation with nature reserve managers. Whenever necessary and possible, corrective restoration actions should be carried out. For example, if dams are found to be eroded and too low, they have to be elevated at strategic points. Sometimes birch or pine colonize the restored site and grow too densely, necessitating cutting. The basic idea is to ensure constant information flow and feedback between managers and those who plan and monitor, so that restoration methods can be adapted when necessary.

Vegetation monitoring

Because plants, especially *Sphagnum* mosses, have a very important role in the function and structure of mires, changes in vegetation will also indicate more generally ecosystem recovery.

The network of vegetation monitoring sites has been established in the southern, middle and northern boreal vegetation zones. The network includes restored and pristine reference sites in seven different habitats with ten to seven replicates of each, altogether 134 sites (Fig. 3). These habitats represent the most common habitats that have been drained and they cover the majority of the natural variation of Finnish mire habitats: spruce mires, pine mires and open fens (two types of each habitat). In addition, the most threatened mire site type, rich fens have been included in the monitoring network. Assessment of the response of mire vegetation to restoration will be based on comparison of the vegetation composition and species abundance before and after restoration. The pristine reference sites enable evaluation as to whether the vegetation is developing along the desired trajectories and towards targeted pristine vegetation composition.

For the field and ground layer vegetation there are ten permanent, 1m^2 sample plots on each monitoring site (Fig. 4). The abundance of species is evaluated by visual cover estimation. Calibration between field workers is done before each field season. Tree regeneration is monitored in three circular (radius 2 m) sapling plots (Fig. 4). For each sapling, species, height, condition and origin (seedling, sprout), is recorded. For monitoring changes in the tree stand structure, there is one circular (radius 10 m) plot on each site (Fig. 4). Both living and dead trees are measured. Climatic and geographic background data is collected from every site.

The first vegetation monitoring has been done before restoration and it will be repeated 2, 5, 10, 15 years after restoration. Pristine reference sites are also monitored each time.

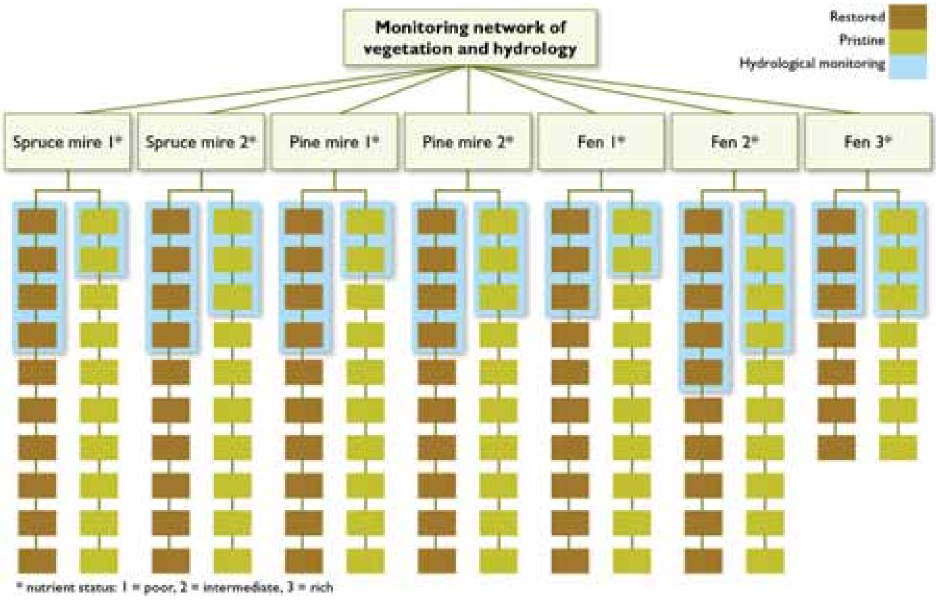

Figure 3. Network of restored and pristine vegetation monitoring sites in seven different habitats.

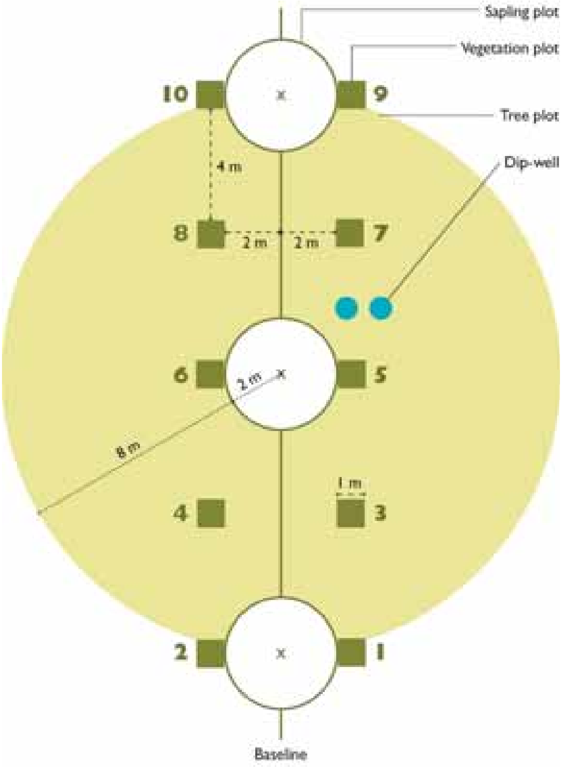

Figure 4. Sampling set for monitoring vegetation, seedlings and trees.

Hydrological monitoring

The main operations, as well as the theoretical basis and the expected success of peatland restoration focus on restoration of the natural hydrology. The state of peat accumulation, nutrient dynamics and mineral element balance are chiefly regulated by hydrology and their balance is partly indicated by certain hydrological variables. Thus, the direct monitoring of hydrological conditions is a straightforward approach to the evaluation of peatland restoration.

One component of hydrological monitoring lies in its purpose to provide estimates of the influence of peatland restoration on runoff water quality and the impacts of the restoration on down-stream aquatic environments. In addition, hydrological monitoring gives explanatory data for interpreting changes in vegetation and other species groups such as insects and birds. Perhaps most remarkably, hydrological monitoring is expected to give information about the functional development of mire ecosystems after restoration.

Hydrological monitoring involves a wide range of observational and instrumental data collection at different stages of the monitoring (Fig. 5). Firstly, the general monitoring, conducted at all restoration sites, includes subjective observation of hydrological attributes, as explained above. A more detailed method of hydrological inventory complements the general monitoring in cases where hydrological problems are indicated and where threatened species or mire types require specific attention on hydrology. The inventory method provides a tool for planning the complementary restoration operations. The method includes instrumental data acquisition comprising general water quality and water table leveling measurements.

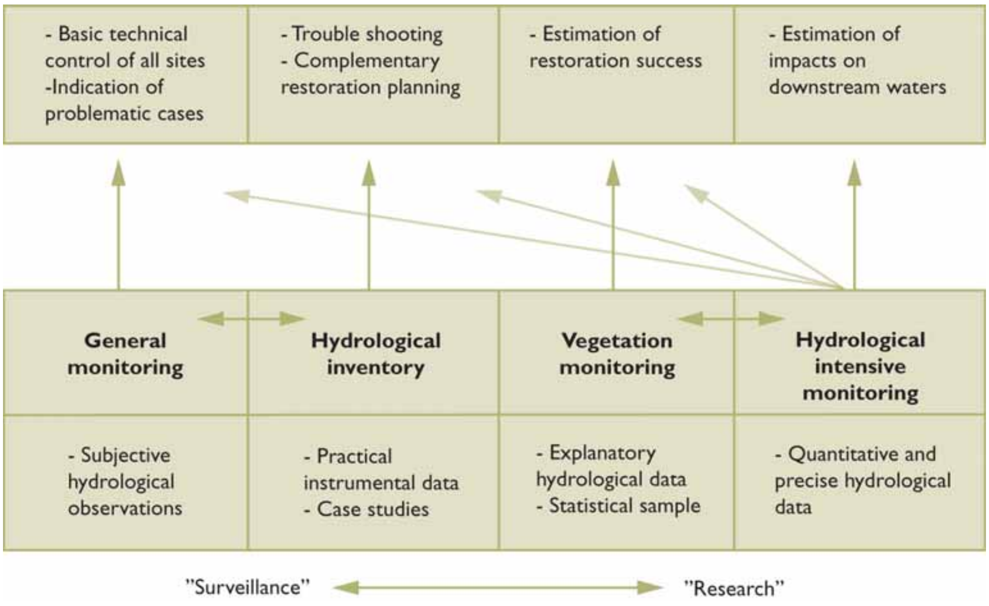

Figure 5. Observational and instrumental hydrological data collection in different monitoring set-ups.

Secondly, from the vegetation monitoring network, a subset of 46 sites has been selected for explanatory hydrological monitoring (Fig 3). This includes continuous water table level monitoring with automatic pressure gauges and water quality monitoring with four laboratory samples collected per year at each site. Monitoring was started before restoration and it will be carried out annually at least for ten years both at pristine and restored sites.

Thirdly, more elaborate and intensive hydrological monitoring is conducted at eleven sites. Intensive hydrological monitoring produces validated mass balance estimates of water-carried fluxes, which can be used to estimate the impacts of restoration on water quality downstream. It also provides ecohydrological data of the development of natural functioning of restored peatlands that helps to predict the general success and succession of restoration.

The methods of intensive monitoring include estimating the catchment-scale hydrological balance by continuous monitoring of water storage and fluxes. Water levels at restoration areas and separate or connected pristine reference areas are monitored using automatic pressure gauges. Water chemistry is monitored by seven standard laboratory samples from run off. Additional research of water chemical patterns will be conducted both on spatial and temporal scales, using water temperature, pH, conductivity and colour, as well as other inexpensive measurements.
Data from the intensive hydrological monitoring sites will be used for validation and calibration of the more general data from vegetation monitoring sites, which in turn will serve to widen the total coverage of the data. Because of the high labour and technical costs of intensive monitoring, these sites have been concentrated in certain areas.

As there are no exact values for the hydrological variables to indicate naturalness, the interpretation will therefore always be somewhat subjective in each specific case. The search is focused, however, on general patterns, such as the range of fluctuations or succeeding trends towards conditions indicating a more or less natural development.

Also, the estimates of the impacts of restoration on downstream water quality need to be generalized as reliable predictions of restoration management.

Monitoring of fauna

Restoration has potentially large effects on the species composition and population sizes of animal species. To monitor the effect, a butterfly monitoring network has been established in Eastern and Central Finland. The network includes 21 pine bog sites with three different treatments (drained, restored and pristine) at each site (see also Uusitalo et al 2012). In addition, short term monitoring of birds and odonates (dragonflies and damselflies) is done during 2010-2014 on twelve sites in a five year restoration project Boreal Peatland LIFE.

Conclusions

Long-term, uniform monitoring is the only means to evaluate the ecological effects of restoration, as well as the success and cost efficiency of restoration operations on a large-scale. The baseline data from the degraded ecosystems is also essential to assess the impact of restoration.

The built-in troubleshooting element in general monitoring will help to identify possible problems, while the more detailed hydrological inventory and monitoring will help to solve the problems. Restoration methods can then be adapted accordingly.

While it is not possible to monitor all relevant species groups in this basic set-up, the network for vegetation monitoring forms a good framework, as there will be data from the sites before restoration, sufficient replicates of each habitat type, and references in pristine mires. The response of other species groups can then be studied in e.g. five, ten, etc. years after restoration, in these same sites. This having been said, research on e.g. the effects of restoration on carbon cycling, peat accumulation and peat properties, is still needed.

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Species richness and abundance of butterflies in natural and drained mires in Finland

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Introduction

Approximately half of Finnish peatlands have been drained for forestry. However, there is considerable variation regionally, and in particular in southern southern half of Finland ca 80-90 % of the original mire area has been ditched. Drainage was most intensive in 1960s and 1970s, but ditching has gradually decreased since that. Drainage has extensive effects on flora and fauna of mire habitats (Laine & al. 1995b, Aapala & Lappalainen 1998a, Aapala & Lappalainen 1998b, Vasander 1998, Heikkilä & al. 2002). Restoration of drained mires has began relatively recently and the research based knowledge of the ecological effects of the restoration are still forthcoming. Nevertheless, in order for the restoration to be effective, the ecological effects of restoration must be known. Therefore, the monitoring of the effects of restoration should be planned and carried out carefully in experimental setups with appropriate controls.

There is a distinctive butterfly fauna associated with mire habitats and the highest butterfly species richness is found in pine mires with stunted and patchily distributed pines (Mikkola & Spitzer 1983, Marttila & al. 1990, Väisänen 1992). In Finland, drainage has been heavily concentrated on these mire types (Eurola et al. 1991), and it is suggestive that it is the mire butterflies associated in these habitats that have clearly declined (Pöyry 2001, Marttila 2005). Interestingly, the extensive drainages have been carried out 30-40 years ago, but the declining of mire butterfly populations have been observed only during the last 10-20 years. The reason may be that there are no empirical studies carried out before. However, this phenomenon may also reflect the fact that species seem to persist in an area some time after the area has already become unsuitable; this phenomenon is known as extinction debt (Tilman & al. 1994, Hanski & Ovaskainen 2002).

Many mire butterfly larvae feed on rather common mire plants, e.g. *Rubus chamaemorus*, *Vaccinium uliginosum* or *V. oxycoccos*, many of which grow on hummocks. Dwarf shrubs and hummock plants usually decline less or even increase after the drainage. They start to decline only when the forest becomes too dense and shady, which may take decades (Laine & al. 1995a).

Other factors, such as physical characteristics of the habitat and the microclimate, may be more important for mire butterflies than the mere plant species composition (Väisänen 1992, Marttila 2005). Indeed it seems that most effects on butterfly adult and larvae populations are caused by changes in mire microclimate (Laine & al. 1995b, Pöyry 2001). Mire species that have been suggested to be most vulnerable to habitat changes are e.g. *Pyrgus centaureae, Clossiana freija, Clossiana frigga* and *Erebia embla* (Pöyry 2001).

The aim of the research presented here was two fold: i) to determine the effects of drainage on total abundance of the mire and generalist butterflies, on species richness of mire and generalist butterflies and on the abundance of each individual species and ii) to establish a replicated experimental setup to allow effective monitoring of the effect of restoration on the butterflies and to collect before restoration treatment data on the variables listed above. A section of each of the study areas was due for restoration after the study (Figure 1) and the restoration was completed during the winters 2003-2004 and 2004-2005.

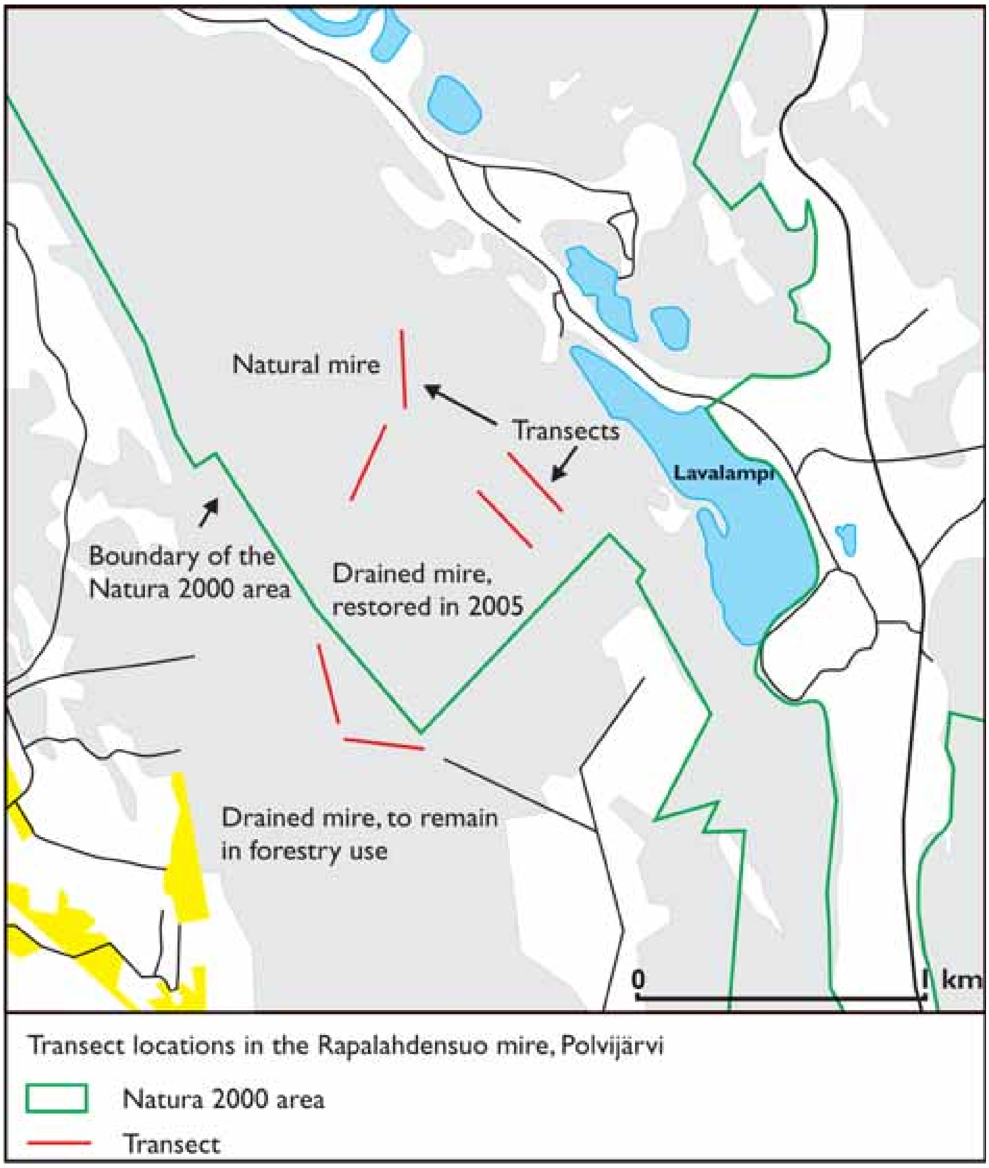

Figure 1. Transect locations in the mire Rapalahdensuo, Polvijärvi.

Materials and methods

Study areas

The study was conducted at nine mires in southern Finland (Table 1, Figure 2). Four study areas were located in Central Finland province and five areas in North Carelia province in eastern Finland. Study areas were located in the mire complexes which included both drained and natural mire habitats. We chose the study areas in the mires where mire habitat type would have been as uniform as possible if the mires had not been drained in the past. It may be expected that level of ground water has been affected also in the "natural" parts of the study mires. In this study we call the unditched mires as natural.

Natural habitats i.e. the undrained parts of the mires are included in the Natura 2000 network. Some areas are included also in the Finnish mire conservation programme. Two mires in Kulhanvuori are part of the Kulhanvuori Natura area. Parts of the mires in Kulhanvuori were drained in the end of 1960s or in the beginning of 1970s. Some of the ditches were cleaned in 1980s (Kuosmanen, pers. comm. 5.11.2004). Väljänneva and Kiemanneva are included in the Seläntauksen suot Natura area. Also parts of these mires were drained in the end of 1960s or in the beginning of 1970s (Kuosmanen, pers. comm. 5.11.2004).

Juurikkasuo, Heinäsuo and Ristisuo are included in the Koitajoki Natura area. Parts of Heinäsuo mire were drained in 1977 and Juurikkasuo mire in 1967. Juurikkasuo mire was fertilised in 1968 and the ditches were cleaned in 1987. The drainage plan of Ristisuo was made in 1977 and the mire was drained probably shortly after the plan was finished (Similä, pers. comm. 5.11.2004). Both Rapalahdensuo mire and Tiaissuo mire are included in Viklinrimpi Natura area. Both mires were drained between 1965-1975, probably in the end of 1960s (Kondelin, pers. comm. 5.11.2004).

The most common natural mire habitat type in the study areas was pine mire. The most common pine mire types were ordinary dwarf-shrub pine bog, *Eriophorum vaginatum* pine bog, *Empetrum-Fuscum* bog and *Calluna-Fuscum* bog. The study areas contained also fens and combination site types. All the combination site types were combinations of fen and pine mire. The field and bottom layer vegetation and the tree stand structure in drained parts of the study mires resembled forest structure.

Table 1. The location of the study areas, main natural mires types and the date of drainage.

Study area	Municipality	Coordinates	Main natural mire type	Date of drainage
Kulhanvuori, Iso-Musta	Multia, Saarijärvi	62°34’ N, 24°57’ E	Pine mire	The end of 1960s or the beginning of 1970s
Kulhanvuori, Iso Sarasuo	Saarijärvi	62°35’ N, 24°58’ E	Combination type	The end of 1960s or the beginning of 1970s
Väljänneva	Pihtipudas, Kinnula	63°19’ N, 25°18’ E	Combination type	The end of 1960s or the beginning of 1970s
Kiemanneva	Pihtipudas	63°23’ N, 25°16’ E	Pine mire	The end of 1960s or the beginning of 1970s
Ristisuo	Ilomantsi	62°56’ N, 31°21’ E	Pine mire	The end of 1970s
Juurikkasuo	Ilomantsi	62°57’ N, 31°26’ E	Pine mire	1967; fertilised 1968; ditches cleaned 1987
Heinäsuo	Ilomantsi	62°54’ N, 31°28’ E	Pine mire	1977
Rapalahdensuo	Polvijärvi	62°54’ N, 29°30’ E	Combination type	Between 1965-1975
Tiaissuo	Polvijärvi	62°56’ N, 29°24’ E	Pine mire	Between 1965-1975

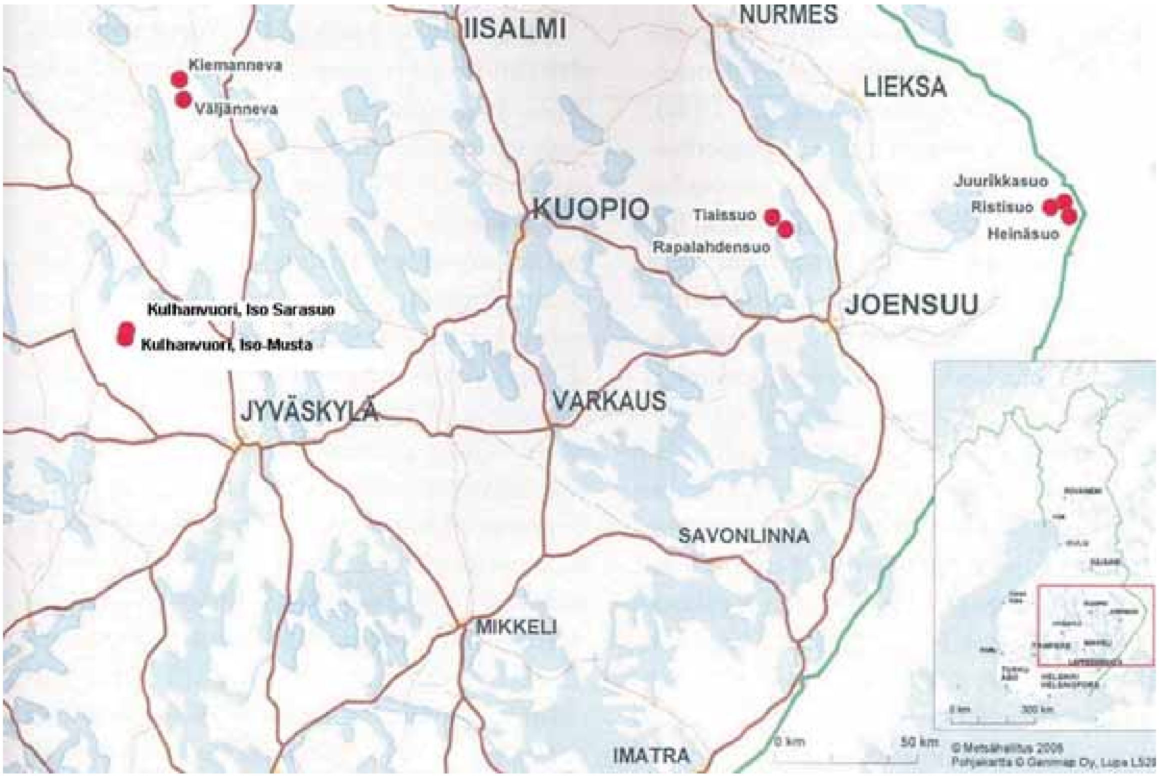

Figure 2. Study area locations

Our experimental design was such that we chose three different study sites (treatments) in each of the nine study areas: i) natural mire habitat, ii) drained mire habitat to be restored after the study and iii) drained mire habitat remaining in forestry use in the future. In each of the treatments we established two 250 m long transects for butterfly monitoring resulting in six transects per study area (Figure 1). The study included 54 transects in all. To determine the effects of drainage on butterflies, we combined the treatments ii) and iii) in the analyses. This is possible because the restoration of drained mires were not made until after our study.

Transect method

In the study we used a transect method developed by Pollard (1977; see also Somerma & Väisänen 1990). The method has proved to be effective in studies on habitat preferences of butterflies and on the species diversity of various habitats. Butterfly counting was conducted in transects which were marked permanently by wood sticks or tape in the field.

Field studies were carried out during the summer 2003. Counts started in the second week of May and they were carried out weekly through the summer. The last counts were made on the third week of August. Total number of counts was 15 in Central Finland and 12 in North Carelia.

During the butterfly monitoring, the recorder walked slowly and at the steady pace along the transect and recorded all butterflies seen within 5 x 5 m square in front of the recorder (5 m forward and 2.5 m left and right from the recorder). If the recorder was not able to identify the species in flight, the individual was caught with a butterfly net. The count was stopped until identification of this individual was made and restarted from the point where the recording was interrupted. The butterfly individual was released after identification. Each butterfly individual was counted only once. The result of every count was marked on the field observation sheet. On the sheet was also marked the study area, the treatment, the date, the name of a recorder, starting time, sun condition (sunny, half shadow, shadow), temperature and strength of the wind using the Beaufort scale (Somerma & Väisänen 1990).

The weather conditions were taken into account on the transect counts. Counts were not made when the temperature was below 13°C. If temperature was between 13-17°C counts were carried out only in sunny conditions (minimum 60 % sunshine). Above 17°C weather conditions might be cloudy but not rainy. Temperature was measured 1.5 m above ground. Counts were made mainly between 11 a.m. and 4 p.m. The time limits were not strictly followed when the conditions were otherwise good (Somerma & Väisänen 1990). In the study we observed superfamilies Hesperioidea and Papilionoidea. Butterflies were identified to species level. The nomenclature follows Marttila & al. (2001).

We categorized butterflies into mire butterflies and generalist butterflies. Mire butterflies that were recorded in the study were *Boloria aquilonaris, Clossiana freija, Clossiana frigga, Colias palaeno, Coenonympha tullia, Erebia embla, Proclossiana eunomia* and *Pyrgus centaureae*. These species feed as larvae and reproduce mainly on mire habitats. Some of these species may fly also in other habitats, e.g. on shores (*B. aquilonaris, C. tullia*). *C. freija, C. frigga, E. embla, P. eunomia* and *P. centaureae* feed and reproduce only in mire habitats. Generalist butterflies refer to species that fly and reproduce also in other habitats than in mires (Marttila & al. 1990, Pöyry 2001). In this article, we use the names mire butterflies and generalist butterflies to refer to these butterfly categories.

Statistical analyses

Differences of butterfly total abundance and species richness between study areas and the treatments were analysed with analysis of variance (ANOVA). As the study was completed in two geographically distant provinces (Figure 2), the province was initially included in the analyses. As expected not one of the results were dependent on the province and thus it was excluded from the final analyses. In the analyses we included the treatment, the study area and the interaction between the two. However, not one of the interactions were significant, and they were excluded from the final analysis. Abundance data was (ln+1)-transformed before the analyses. Statistical analyses were performed with SPSS version 14.

Results

The total sample comprised of 1909 individual observations from 21 butterfly species. Eight species were classified as mire species and 13 as generalist species.

Total abundance and the species richness of mire butterflies were significantly higher in natural mire habitats than in drained habitats (Table 2, 3, Figure 3, 4). However, when we analysed the generalist species the pattern was different: there were no difference in the total abundance or in the species richness between natural and drained habitats (Table 4, 5, Figure 5, 6).

When we analysed the effect of drainage on the abundance of each species we found that five of the mire butterflies and two of the generalist butterflies were significantly

Table 2. Total abundance of mire butterflies

Source	SS	df	MS	F	P
Area	17.99	8	2.25	4.18	0.001
Drainage	16.87	1	16.87	31.34	< 0.001
Error	23.68	44	0.54		

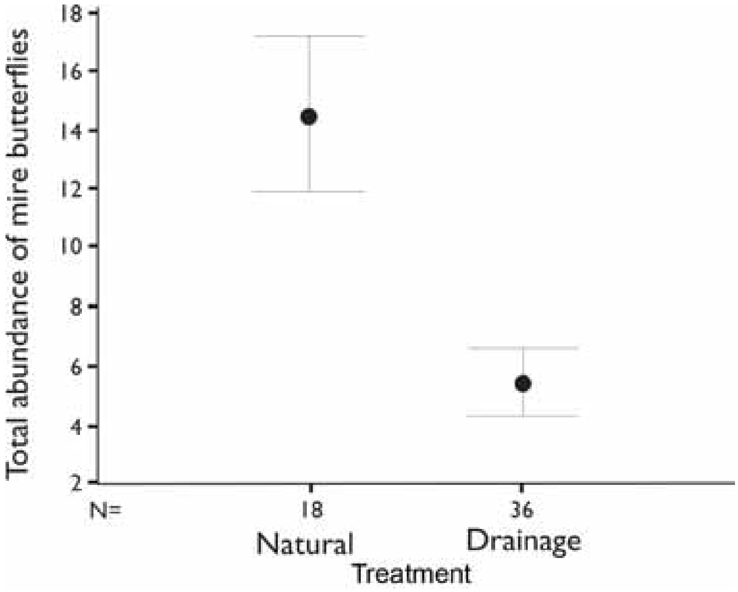

Figure 3. Total abundance of mire butterflies

Table 3. Species richness of mire butterflies

Source	SS	df	MS	F	P
Area	27.26	8	3.41	2.42	0.029
Drainage	45.37	1	45.37	32.22	< 0.001
Error	61.96	44	1.41		

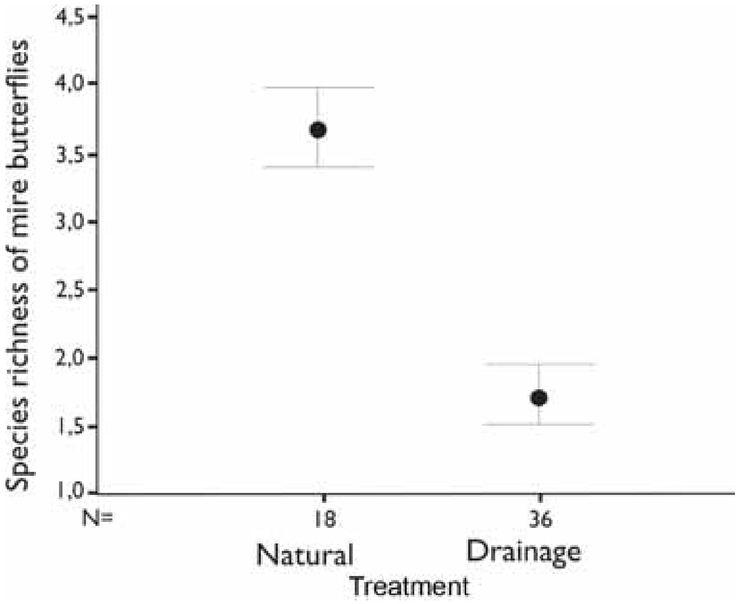

Figure 4. Species richness of mire butterflies

Table 4. Total abundance of generalist butterflies

Source	SS	df	MS	F	P
Area	23.65	8	2.96	4.54	< 0.001
Drainage	0.40	1	0.40	0.61	0.438
Error	28.66	44	0.65		

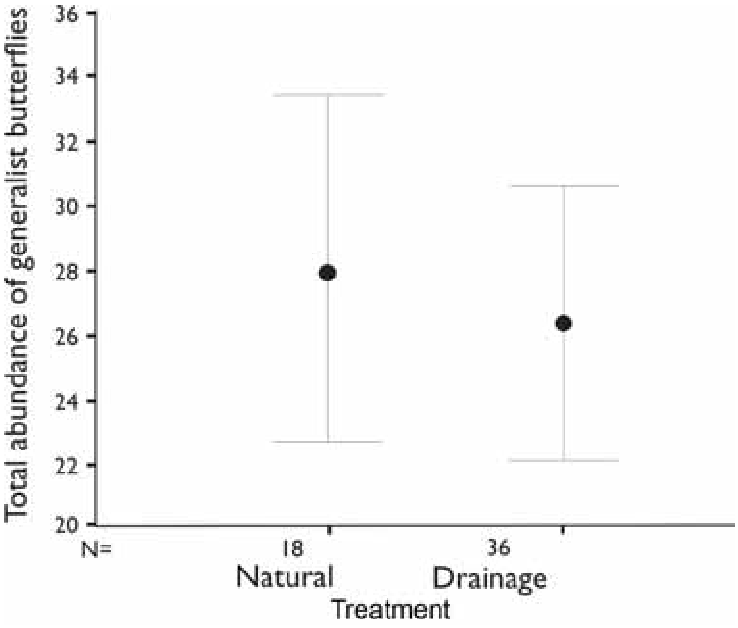

Figure 5. Total abundance of generalist butterflies

Table 5. Species richness of generalist butterflies

Source	SS	df	MS	F	P
Area	42.00	8	5.25	3.55	0.003
Drainage	0.33	1	0.33	0.23	0.638
Error	65.17	44	1.49		

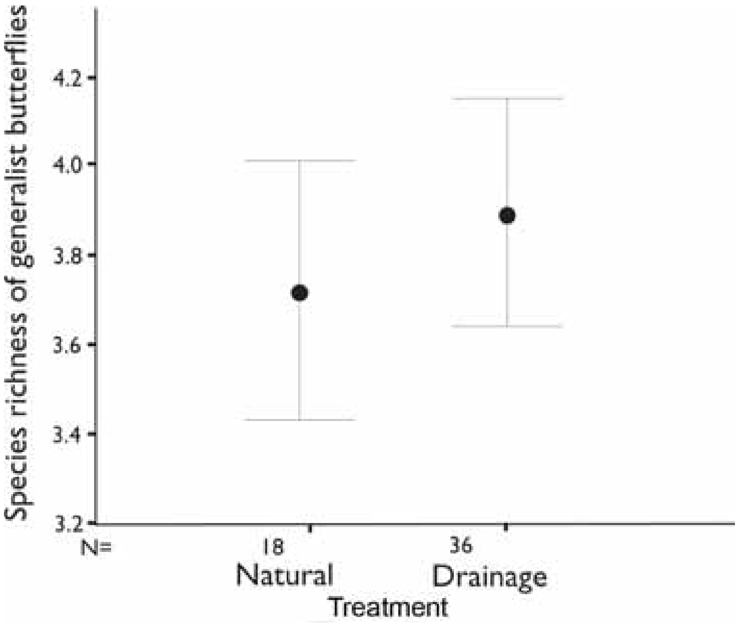

Figure 6. Species richness of generalist butterflies

Table 6. The effect of drainage on the abundance of each species. Species marked with * are classified as mire butterfly. + = drainage has positive effect on species abundance; - = drainage has negative effect on species abundance. When +/- is in brackets the difference is not significant. Species that were observed less than seven times are not included in the analyses.

Species	Abundance	Area		Drainage		
		F	P	F	P	+/-
Boloria aquilonaris*	32	1.07	0.403	10.15	0.003	-
Brenthis ino	64	2.81	0.013	0.67	0.419	(+)
Callophrys rubi	123	0.76	0.643	1.18	0.284	(+)
Clossiana euphrosyne	171	5.86	< 0.001	3.95	0.053	(+)
Clossiana freija*	14	3.44	0.004	7.80	0.008	-
Clossiana frigga*	17	1.61	0.150	13.21	0.001	-
Coenonympha tullia*	58	1.41	0.219	39.56	< 0.001	-
Colias palaeno*	198	6.51	< 0.001	5.00	0.030	-
Erebia embla*	7	2.19	0.046	0.85	0.362	(-)
Erebia ligea	22	2.07	0.060	10.21	0.003	+
Gonepteryx rhamni	7	6.05	< 0.001	4.40	0.042	+
Plebejus argus	911	5.26	< 0.001	5.04	0.030	-
Proclossiana eunomia*	123	2.98	0.009	2.97	0.092	(-)
Pyrgus centaureae*	10	0.86	0.560	2.28	0.138	(-)
Vacciniina optilete	138	3.96	0.001	6.74	0.013	-

more abundant in natural mire habitats than in drained mire habitats (Table 6). The remaining three mire butterflies were also more abundant in natural mire habitats than in drained mire habitats but the difference was not significant (Table 6). Only two species, both generalist butterflies, were significantly more abundant on the drained mires than in the natural mire habitats (Table 6).

Discussion

Mire drainage and species diversity

In the drained mire habitats both abundance and species richness of the mire butterflies were lower than in natural mires. Similar results have been found also in other studies (Rintala & al. 2000, Hiltula & al. 2005). Some mire butterfly species have been observed to disappear shortly after drainage, and Pöyry (2001) suggested that species most vulnerable to habitat changes are *Pyrgus centaureae, Clossiana freija, Clossiana frigga* and *Erebia embla*. Our results are partly in line with this suggestion as the effect of drainage was most pronounced on *C. freija* and *C. frigga*. However, the effect of drainage on the abundance of *P. centaureae* and *E. embla* seemed to be less pronounced although it still tended to be negative. The lack of significant effect on the last two species may be due to the fact that we had only 10 and 7 observations of these two species respectively and thus the power of the analysis is weak. In a study conducted in SW Finland, *Proclossiana eunomia* was observed to be very tolerant to the effects of mire drainage (Pöyry 2001). This appears to be consistent with the marginally significant effect of drainage in this study.

Dwarf shrubs and hummock plant species have been observed to benefit from drainage at first, but later they decline due to forest canopy closure and increased shading

(Laine & al. 1995a). Mire butterflies that declined after drainage feed mostly on hummock plants as larvae. For example, *Rubus chamaemorus* is the food plant of monophagous *Clossiana frigga* and *Pyrgus centaureae*. *Clossiana freija* feeds on two species, *R. chamaemorus* and *Vaccinium uliginosum*. *V. uliginosum* is also the food plant of very mobile *Colias palaeno*. *Vaccinium oxycoccos* and *Andromeda polifolia* are food plants of *Boloria aquilonaris* (Marttila & al. 1990, 2001). As the food plants of the species seem to tolerate the effects of drainage rather well or may even benefit from it, we must search other reasons for the decline of mire butterflies. These changes may be related to the changes in microclimate (Väisänen 1992, Marttila 2005). On the other hand, *Coenonympha tullia* is the only mire species found in this study that feeds on sedges as larvae. Sedge species growing on wet habitats are among the first species that disappear after mire drainage (Eurola & al. 1995, Laine & al. 1995a). This is reflected also in our data as the drainage had the strongest negative effect on *C. tullia* (Table 6).

Methodological considerations

Transect method has been proved to be efficient in studying species diversity of day-active butterflies (Väisänen 1992, Pöyry & al. 2004). Butterflies are also mostly rather easy to spot and recognise in the field. However, in transect method a few practical issues must be considered. Since butterflies are sensitive to weather conditions and some species have rather short flying period, even few week long bad weather conditions may skew the results. Also flexible working circumstances may be required to be able to make butterfly counting during the best weather conditions.

Some butterfly species have two years life cycle and they are in flight in every other year only, e.g. a pine mire species *Oeneis jutta* is in flight only in even years and rare *Erebia embla* mostly in odd years in southern Finland. The flying pattern might vary in different parts of the country however (Marttila & al. 2001). These life cycle patterns should be taken into account when planning a monitoring program.

Conclusion

Our study found a clear effect of drainage on both the abundance and species richness of mire butterflies. However, such effects were not evident on the generalist species which may even benefit from disturbances such as drainage. Unlike the mire specialists, generalists species have not strict habitat requirements related to microclimate prevailing in natural mires (Marttila & al. 1990, Pöyry 2001).

This study provided data that will be used as a reference to which to compare the results of the future monitoring. In the present study we had nine study areas in two provinces. We acknowledge that this is not a large sample size and suggest that it should be taken into consideration to include more areas into the monitoring network especially in southern Finland. That would greatly improve the reliability of the monitoring program.

Butterflies are a useful species group to use in restoration monitoring for several reasons: i) there are several specialist species that are restricted to mire habitats, ii) some of these mire butterfly species are very sensitive to changes in their environment and can be used as indicators and iii) there are efficient and reliable monitoring methods available. In the future, butterfly monitoring sites will form an important part of the network for monitoring biodiversity effects of mire restoration in Finland (see Aapala et al. this volume).

Acknowledgements

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Impacts of peatland restoration on nutrient leaching in western and southern Finland

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Introduction

The most important conservation programme for mires in Finland has been the Mire Conservation Programme from 1979 to 1981. Also, the Programme for the Development of National Parks and Nature Reserves, which was first established in 1978, has been important (Kaakinen & Salminen 2006).

Compared with peatland utilization, these programmes were realized rather late. For example, the peak year of forestry drainage was 1969, with about 300 000 ha impacted. Due to the forestry practices, altogether over 40 000 ha of mires in the Finnish nature conservation network had been drained by landowners before final inclusion into nature reserves. On a national scale, this was less than 4 % of the total protected mire area, although in southern Finland where drained mires were much more common, nearly half of the protected spruce mires, for instance, had been drained before protection.

On principle, drained areas are restored in nature conservation areas. The most important goal is to regain a functional peatland ecosystem, with peatlands expected to recover their original biodiversity in the long run. In partially drained peatland complexes, the restoration may be essential to restore the hydrology of undrained parts of the mire. Because in some cases the mosaic of open mires and forests on firm land has disappeared due to drainage, promoting landscape diversity is also an aim of restoration.

Some drained mires have become important hotspots for dead and decaying wood. These may be left unrestored, as the restoration process could lessen their importance. However, as pristine forested mires are rare in southern Finland, and many threatened peatland and forest species require them as their habitats, restoring forested peatlands is also considered important.
By the end of 2008, approximately 16 000 ha of mires had been already restored in Finland. Monitoring of success and possible problems is important to be able to develop good practices and to avoid unwanted impacts (Aapala & al. 2008). A pioneering large-scale restoration project was “Restoration of active raised bogs, aapa mires and bog woodland in Natura 2000 sites”, coordinated by the former Finnish Forest and Park Service, Natural Heritage Services Division, western Finland. The project received funding from the Life Nature Programme and was conducted in the years 1996–1999.

Since this was a pioneer project, there was not much information about the overall impacts of restoration at this stage. Concerning water quality impacts, it was hypothesized that in the long run restoration would be beneficial to water quality in recipient watercourses but that short term deterioration was to be expected.

Seitseminen National Park was the largest of the 17 target areas in the project. The monitoring of water quality impacts was concentrated in this area, and the data presented in this paper was collected during the course of the project. Today, almost the entire 1 000 ha of drained mires in Seitseminen have been restored.

The initial results proved that restoration may have short term harmful impacts on runoff water quality, with the possibility of changes in water quality being substantial (Sallantaus 2004). The mires of Seitseminen are mainly unfertile bogs or very poor fens, and the original tree stand consisted mainly of stunted pines (Leivo & al. 1989). To obtain a wider perspective of the impacts in different kinds of restored peatlands, monitoring was also initiated in very contrasting fertile spruce mires in southern Finland. Results concerning leaching of the main nutrients, phosphorus and nitrogen, in these two very different kinds of restoration targets are presented in this paper.

Study areas

Western Finland: Seitseminen National Park

Seitseminen National Park (61° 58′ N, 23° 22′ E) is situated in western Finland, in the Pirkanmaa municipalities of Ylöjärvi and Ikaalinen. The park, founded in 1982 and covering an area of 4 200 ha, is situated 160 – 200 m a.s.l., locating the area in the southernmost part of the middle boreal zone in Finland (Kalela 1961). The annual precipitation is 666 mm on average (1961–1990, the Finnish Meteorological Institute 1991), with a mean annual temperature of 2.9 °C.

The bedrock at Seitseminen is mainly coarse granite or granodiorite, and the soils are fairly acidic and nutrient-poor. The area is situated somewhat higher than most of southern Finland, which is reflected in the slightly higher precipitation and cooler climate found there compared with areas at lower elevations of the same latitude. Since the terrain is also fairly flat, mires are abundant, covering about half of the total area of the park, and dominated by oligotrophic and ombrotrophic mire site types (Leivo *et al*. 1989). Before drainage, the tree stand proportion in these mires was much lower compared with mires typical of southern Finland (Fig. 1). About 60 % of the mires had been drained in the 1960s before the foundation of the park (Heikkilä & Lindholm 1994), the majority of which have already been restored to date.

Hydrological monitoring, begun in the spring of 1997, took place in three catchments: Saukkolamminsuo, Tuulimäensuo and Käsikivenlamminsuo. These are small lakeless basins, containing a high proportion of mires needing restoration. Each catchment, approximately 50 ha in area, comprised between 36% and 44% of drained mires. The restoration measures, which started in Saukkolamminsuo at the end of 1997, were finalized for all the three catchment areas by the end of 1999 (Table 1).

While most of the mires had clearly responded to drainage, they were still transitioning towards real forest vegetation, or in some cases, mire vegetation had already started to redevelop due to the deterioration of ditches (Fig. 2). It is also worthwhile

Figure 1. Ombrotrophic or weakly minerotrophic pine mires with scattered stunted pines characterized Seitseminen National Park before drainage (Photos Tapani Sallantaus).

Table 1. Properties of monitoring sites in Seitseminen and Nuuksio, and of the lakes monitored. The sizes of the lakes are in parentheses.

	size	monitoring month.year	time of restoration month.year	%
Seitseminen				
Saukkolamminsuo	50	4.97-1.07	12.97	36
Tuulimäensuo	54	10.96-1.07	11.98	44
Käsikivenlamminsuo	68	4.97-1.07	11.98-12.99	40
Nuuksio				
Mustakorpi E	24	4.01-12.07	10.01	32
Mustakorpi N	13	4.01-12.07	10.01	20
Mustakorpi total	48	4.01-12.07	10.01	29
Lakes				
Särkijärvi	190(8)	4.01-10.08	11.97	28
Pitkäjärvi	220(9)	4.01-10.08	11.97-11.99	30
Vähä Ruuhijärvi	50(6)	12.00-11.08	1.01	20

to note that all the areas had been fertilized in the past. During restoration, the trees were mostly removed before the ditches were filled, mainly in late autumn. The sites have been in a restored state for about a decade now, and the successes as well as problems of the restoration have been closely monitored (Figs. 3 and 4).

Figure 2. A peatland forest in Seitseminen National Park drained 40 years ago. The mean stand of the growing stock in Seitseminen before restoration was only ~ 50 m³/ha.

Figure 3. A successful restoration site in Seitseminen National Park, 10 years after the filling of ditches and the harvesting of most of the post-drainage tree stand.

Figure 4. A. problematic restoration site in Seitseminen National Park, 10 years after the filling of ditches and the harvesting of most of the post-drainage tree stand. Birch thickets may form in the more fertile or heavily fertilized sites if the peatland area does not receive water from a large catchment or if wetting is inadequate for some other reason.

Southern Finland: Nuuksio National Park

An important recreational area for nearby Helsinki, Nuuksio National Park was founded in 1994 and is situated in southern Finland, within the municipalities of Espoo, Kirkkonummi and Vihti. Forming the southern part of the southern boreal zone, the park area is subject to a steep gradient in precipitation. While the exact long term annual precipitation for the study site is not known, the mean long term precipitation in Vihti and Maasoja is 619 mm (Finnish Meteorological Institute 1991); due to warmer conditions in Nuuksio (3.9 ^{o}C being the annual mean temperature in Maasoja) and a greater tree stand area, difference in runoff compared with Seitseminen is much more significant than precipitation. Hydrological differences in the southern boreal zone compared with those of the middle boreal zone show up especially in the much lower summertime low flow values as well as the much earlier and much increased irregular snow melting runoff peaks (Sallantaus 2006).

Mustakorpi, the mire area studied in Nuuksio National Park, is ~ 80 m a.s.l. and representative of much more fertile mires than those located within Seitseminen. Before drainage, the mires were already found to be mainly densely treed, the main tree species being spruce, with birch and occasional black alder in the mire lower parts with greatest through flow (Fig. 5). The first ditches were dug at the end of the 1930s, and completed in the years 1967–1968. The main mire site types recorded before drainage were bilberry (*Vaccinium myrtillus*) spruce mire, *Equisetum sylvaticum* spruce mire, fern spruce mire and herb-rich spruce mire (see e.g. Laine & al. 2004, Ruuhijärvi & Lindholm 2006).

Figure 5. A natural spruce mire displaying the characteristics that would have occurred in a pre-drained Mustakorpi (Nuuksio National Park).

Given the milder conditions of southern Finland, fertile site types respond quickly to forest drainage and mires have, therefore, greatly changed. Before restoration, the areas supported a spruce stand exceeding 300 m^3/ha, and the vegetation was fairly similar to hemiboreal and southern boreal mesic or semi herb rich forests (see Lindholm & Heikkilä 2006).

Despite restoration, all trees were left unaltered in the site. Growing patches of dead wood have formed after damming of ditches in the fall of 2001. In addition, during damming, the excavator imitated wind throws, creating some extra dead wood in this site which was actively logged until very recently. Vegetation has responded quickly and well to increased light and moisture; patches of *Sphagna* are taking over the ground layer, and tall ferns are now a striking feature in the landscape (Fig. 6).

The size of the catchment in the outflow of Mustakorpi is 48 ha, 29 % of which consist of restored mires. Three subcatchments can be distinguished from the whole catchment. The eastern subcatchment has an area of 23.5 ha, and a peatland that occupies 20% of the area (Fig 7). The northern subcatchment has an area of 13 ha and a peatland proportion of 32%. However, a large part of the peatland area consists of a small bog, which had responded very poorly to drainage. Nevertheless, this is not thought to be the cause for water quality changes following restoration. The effective peatland percentage responding to restoration is probably only 20%.

Figure 6. View over the Mustakorpi (Nuuksio National Park) main basin six years after the damming of ditches.

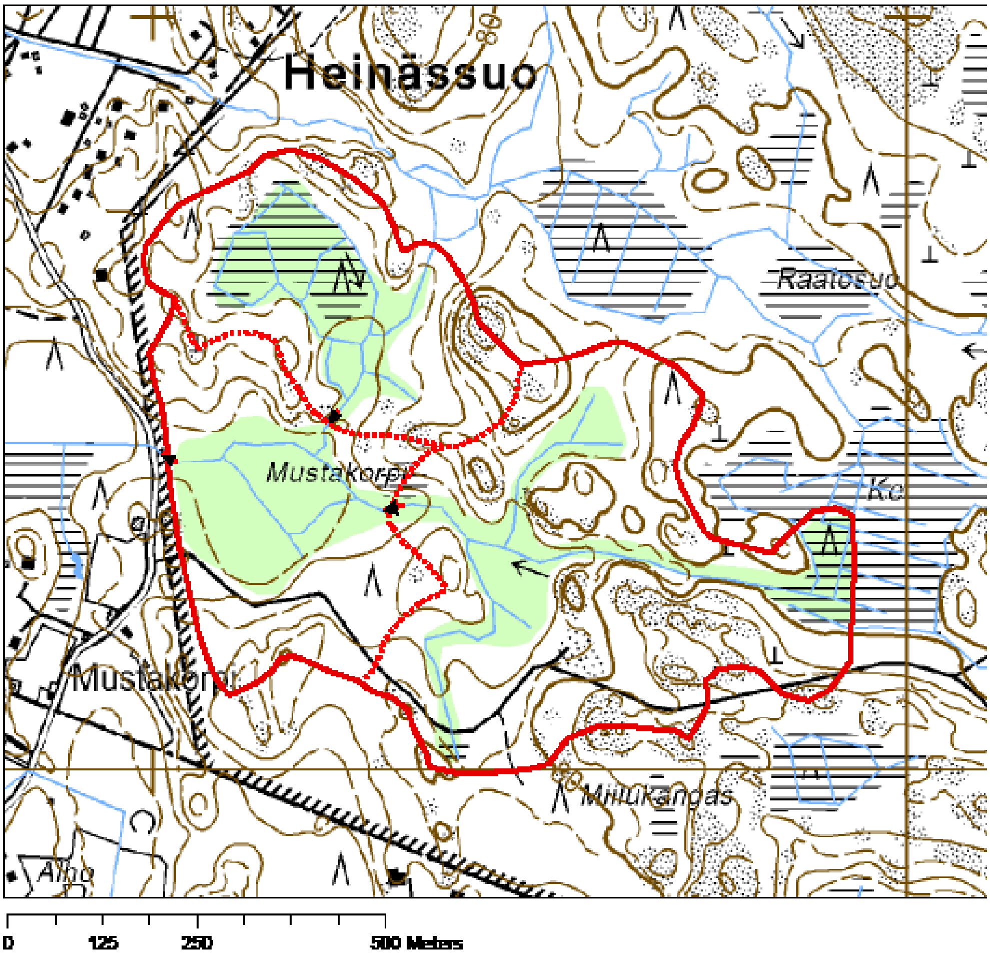

Figure 7. Study subcatchments in Nuuksio National Park.

The western subcatchment, which makes up the rest of the whole catchment, is 11.5 ha in size with a mire proportion of 44%. In this subcatchment adjacent to the outflow of Mustakorpi and above the sampling point, there is a "natural" restoration area, gradually formed due to the settling of silt in the ditches originating from ditch erosion in the upper stretches. The size of this naturally restored part is 1 ha, 20 % of the peatland area in the lowest part and 7 % of the total peatland area in the catchment. The reduction of leaching rates in this buffering area is discussed in detail in another paper. Here, we only present the results of the whole catchment and its two subcatchments.

Monitoring of lakes affected by mire restoration

There were two additional lake monitoring sites in Seitseminen, with about 30 % of the watershed restored during monitoring. The main results have been briefly described in Sallantaus (2004). There is also one monitored lake in southern Finland receiving waters from similar restored spruce mires as in Nuuksio: Lake Vähä Ruuhijärvi in Evo, Lammi, 154 m a.s.l., 180 km NNW from Nuuksio. The lake area is 6 ha and the maximum depth, 7.4 m. A large part of peatlands discharging into the lake, 10 hectares or 20 % of the catchment, were restored in the winter of 2000–2001. These peatlands are slightly less fertile than those in Nuuksio, originally largely *Vaccinium myrtillus* spruce mires. The results from this site are also briefly described and compared with the results of the Seitseminen lakes.

Monitoring of nutrient leaching

In 1997, measuring weirs were constructed in two brooklets in the Seitseminen area for water sampling. The sampling ranged from nine months to nearly two years before restoration in each catchment was initiated. Hence, 10 years' data from the Seitseminen study area are available for use in the present study.

With respect to the Nuuksio study area, seven years' data are available for use in the present study. In the Nuuksio area, water samples were collected from three catchment outlets: two of these were subcatchments of the main catchment, with measuring weirs constructed at two of the sampling points. Sampling started in April 2001, six months before restoration took place

During the study, water samples were collected about 11 times on average each year at both the Seitseminen and Nuuksio study areas. Runoff was recorded from the weirs at the time of sampling.

The lakes in Seitseminen and Evo were sampled three to four times a year during the study.

Approximately 20, thoroughly identified/defined water quality variables were analyzed in the Pirkanmaa Regional Environment Centre laboratory. Only the results of the main nutrients in the samples, P and N,, are presented in detail here, as well as some results of lake responses to restoration (oxygen status, chlorophyll-a). The following standards were used:

Total nitrogen	SFS-EN ISO 11905-1:1998
Nitrate nitrogen	SFS 3030:1990
Total phosphorus	SFS 3026:1986
Phosphate phosphorus	SFS 3025:1986
Chlorophyll	SFS 5772:1993
Oxygen	SFS-EN 25813:1993

Calculation of leaching rates and loads due to restoration

The concentrations observed were interpolated to get an annual course of concentrations. Since we did not have continuous runoff measurements from the sites, we used simulated runoff data for both the Seitseminen and Nuuksio areas, obtained from the Finnish Environment Institute, Hydrological Services Division. The simulation system is based on a watershed model, which simulates the hydrological cycle using standard meteorological data. The results were calibrated against real discharge and water level monitoring data (e.g. Vehviläinen & al. 2005). We also compared the simulated values with the runoff data observed in the weirs during sampling, and found good agreement (results not shown). By multiplying daily concentration (e.g. g/l) and daily runoff (e.g. l/ha) values for the whole year, it was possible to obtain the annual leaching rates (g/ha).

The calibration period ranged from nearly a year to two years in Seitseminen, and by contrast, only six months in Nuuksio. To calculate the theoretical unrestored leaching rate for the years after restoration, we used the flow weighted mean concentrations of the calibration period for the winter and spring periods and for the summer and autumn periods, and multiplied these two values with the actual runoff obtained by the model for these periods. Subtracting this calculated unrestored leaching rate from the observed leaching rate gave the rate of excess leaching caused by restoration.

Since the excess can be assumed to originate from the restored part only, dividing this excess by the proportion of restored area in the catchment, e.g. 0.36–0.44 in the case of the Seitseminen lakeless catchments, gave an annual excess caused by restoration of one hectare. The annual values were summed up to get the total excess. If monitoring continues long enough for the effects to become stabilized, it would enable the calculation of the total load caused by the restoration of one hectare of peatland. Termed as “specific load”, this load can be compared with other forms of land use, e.g. forestry practices (Kenttämies 2006).

Results

Seitseminen

The annual runoff during the study period varied from 189 mm to 625 mm (mean 348 mm) in Seitseminen. The year 2002 was the driest while the years 1998, 2000 and 2004 were wet (Fig. 8).

The background or pre-restoration annual leaching rates for total N were 1.8 kg/ha on average, with small differences between the areas (1.5 – 1.9 kg/ha) (Table 2). The proportion of inorganic nitrogen was very low, on average 0.08 kg/ha, about 4 % of the total. The annual mean background leaching of phosphorus was 0.07 kg/ha (range 0,06–0,09 kg/ha), about one third of which was phosphate P.

The total excess leaching of nitrogen due to restoration as a mean of the three restored areas was 17 kg per restored hectare (range 12 – 24 kg/restored ha), and only a very small proportion of this was inorganic (range -0.07 – 1.5 kg/restored ha, mean 1.1 kg/restored ha). These values are total sums for the 7 – 9 years; maximum annual increases varied from 2.6 to 5.2 kg/restored ha for total N, and 0.05 – 0.9 kg/restored ha for inorganic N.

The total increase in phosphorus leaching varied between 1.5 and 3.5 kg/restored ha, the mean being 2.4 kg/restored ha. The share of reactive phosphate-P was 59 – 70 %. The excess leaching of phosphorus from the restored mires had almost ended by 2006, even in an area like Käsikivenlamminsuo, with one of the largest loads and having very recently undergone restoration (Fig. 9).

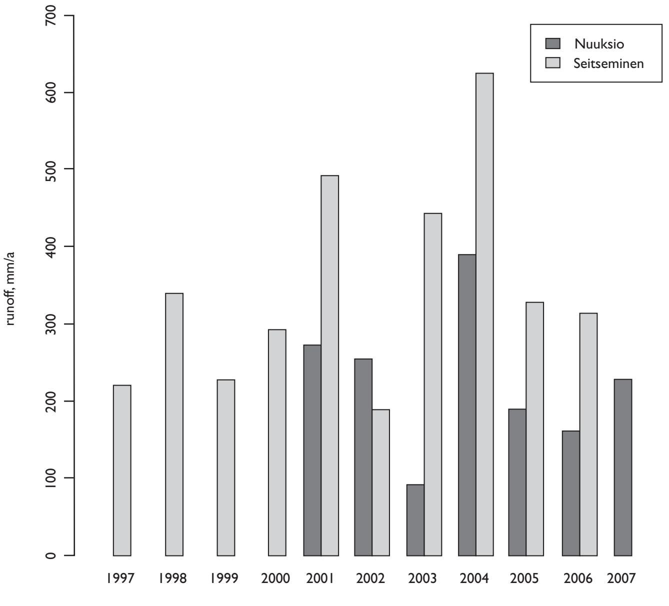

Figure 8. Annual runoff in the study periods

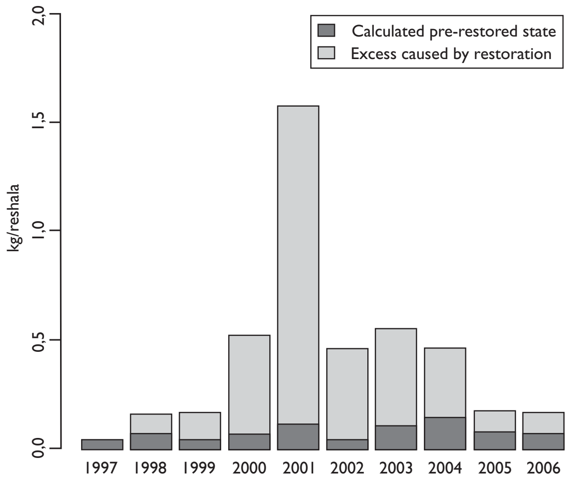

Figure 9. Leaching of phosphorus from the Käsikivenlamminsuo catchment in Seitseminen National Park. The area was restored gradually, in small sections during 1997–1999, and in the main section in the fall of 2000. The increase in the leaching was calculated per final restored area.

Table 2. Background leaching rates, mean of 10 years in Seitseminen, 7 years in Nuuksio) of total N, inorganic N, total P and phosphate P in the studied catchments.

	Total N	NH4-N	NO3-N	Total P	PO4-P
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Seitseminen					
Saukkolamminsuo	1,5	0,03	0,03	0,06	0,02
Tuulimäensuo	1,9	0,05	0,01	0,09	0,03
Käsikivenlamminsuo	1,9	0,04	0,04	0,08	0,03
Nuuksio					
Mustakorpi E	0,9	0,03	0,10	0,05	
Mustakorpi N	1,7	0,01	0,14	0,04	
Mustakorpi total	1,3	0,03	0,10	0,05	

Nuuksio

Nuuksio, situated in southernmost Finland, has a much less predictable hydrology than Setseminen in the middle boreal region. In the south, there are often warm periods during winter and resulting snow melt. Summers are warm and runoff often ceases completely, although the incidences of summer and autumn rains can be great. This can best be observed in the long term runoff statistics (Sallantaus 2006), but differences are already evident in the monitoring periods. Annual runoff in Nuuksio during the study period varied from 92 –392 mm. The driest year was 2003 and the wettest, 2004. There was no runoff for long periods during the dry years, and this is shown in the number of water samples (Fig. 10).

The background, or pre-restoration, leaching of total N varied between 0.9 and 1.7 kg/ha, with 1,3 kg/ha being the mean value (Table 2). The background leaching of inorganic N, that is, ammonium and nitrate nitrogen, was between 0.13 and 0.31 kg/ha. The largest leaching loss of inorganic N came from the northern subcatchment. The annual background leaching of phosphorus was between 0.03 and 0.05 kg/ha, with 0.04 kg/ha being the mean. About one third of this was phosphate P.

The increase in total N was 26 kg/restored ha for the whole area, but more than 50 kg/restored ha in the eastern and northern subcatchments for the six-odd post-restoration years. The increase of ammonium-N alone was 22 kg/restored ha for the northern

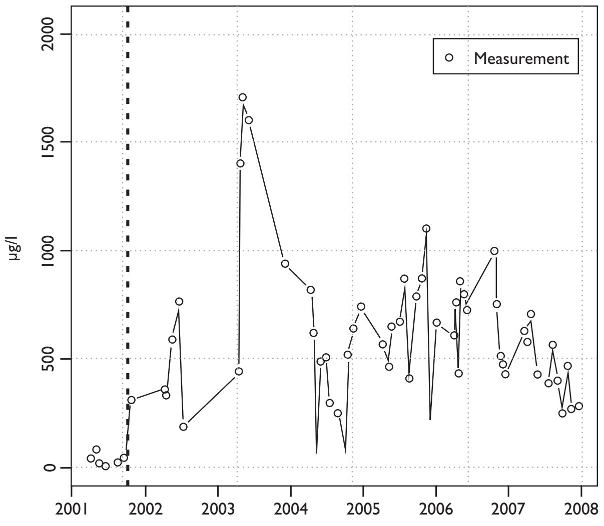

Figure 10. Total nitrogen concentrations in the Mustakorpi northern subcatchment during the study period.

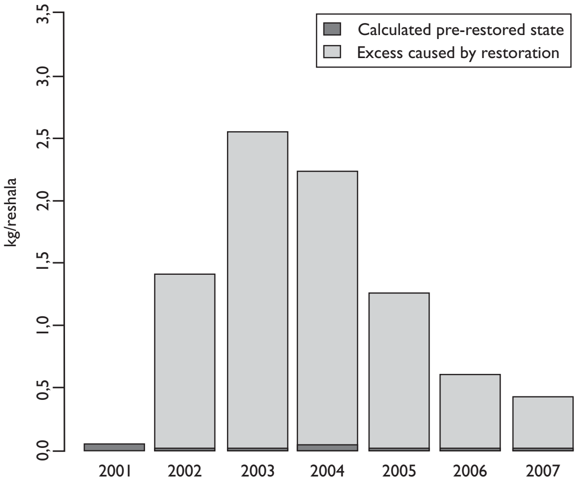

Figure 11. Background leaching of ammonium nitrogen in Mustakorpi, eastern subcatchment (lower dark part of column) and increase in leaching, calculated per restored hectare (light part of column).

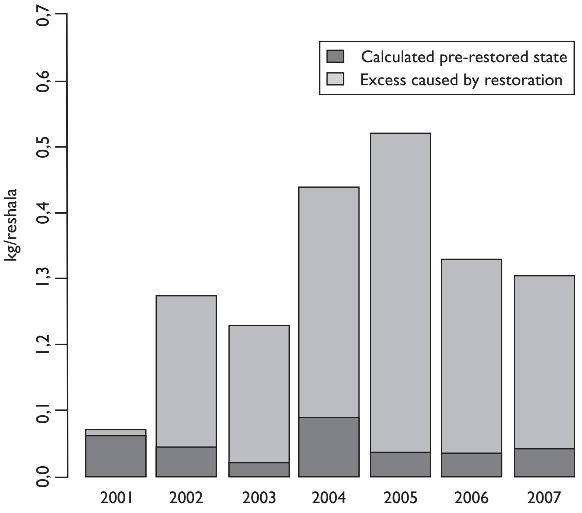

Figure 12. Leaching of phosphorus in the outflow of Mustakorpi. The increase in the leaching was calculated per restored area. A naturally restored part just above the sampling point delayed the leaching, which had the effect of lowering the total load.

subcatchment, in which nitrate-N leaching was reduced due to restoration (-2 kg/restored ha). If the values for the northern catchment are calculated per effective restoration area, the excess of total N would be 84 kg/restored ha and the excess of inorganic N, 32 kg/restored ha. For the eastern subcatchment, the increase in inorganic N was 19 kg/restored ha (Fig 11) and for the whole catchment, 6 kg/restored ha.

The total increase of phosphorus leaching after restoration was 1.8 – 2.7 kg/restored ha, 54 – 75 % of which was phosphate P. The excess leaching of phosphorus continues at a high level six years after restoration, still about six times the background level in 2007 (Fig. 12).

Lakes

As a consequence of restoration, the phosphorus concentration in the two lakes studied in Seitseminen rose initially ~ 100 µg/l, i.e. more than fivefold. The lakes are brown watered, fairly acidic and poor in inorganic nitrogen, and restoration increased the leaching of inorganic nitrogen only slightly. Therefore, no clear signs of eutrophication could be detected in spite of the high increase in phosphorus concentration. The lakes' oxygen status remained fair, with chlorophyll-a having a maximum concentration of 14 µg/l in the ~ 30 samples collected.

The lake Vähä Ruuhijärvi in Nuuksio, located below the restored spruce mires, also displayed a rise in phosphorus concentration by 100 µg/l However, nitrogen leaching increased substantially as well, contrary to that in Seitseminen. Hypereutrophic chlorophyll-a values, above 80 µg/l, were observed in seven samples of the 21 collected in 2002 – 2007. Phosphorus leaching was clearly affected by a wet year in 2004 and especially by one extreme rain event in late July that year, resulting in a second phosphorus peak in the lake, up to 200 µg/l. The lake's oxygen status was also poor following this event, already nearly anoxic at a 1 m depth, and totally anoxic in the deeper layers of this 7 m deep lake. A similar situation, one that was commonly observed for this lake during the study period, also occurred in the late winter of 2003 when anoxia was found to establish under ice cover in the deeper layers of the lake. As this lake was affected by beaver activity before monitoring started, water quality was already slightly disturbed before the restoration.

Discussion and conclusions

The study sites indicate that forest drained peatlands can be successfully restored. Even peatlands, which had developed into drained peatland forests, responded quickly to rewetting. The initial vegetation responses were characterized by a rapid decline of vegetation depending on the aerated root zone created by drainage, followed by bursts of a few benefitting species. The reasons behind these bursts are connected to the release of nutrients, as described in this study.

Before the restoration of the study sites, nutrient leaching rates were found to be very similar to values originating in unmanaged areas in Finland (Mattsson & al. 2003), in spite of having a forestry history. Long term responses to restoration could be speculated as being more or less the opposite of drainage effects (Laine & al. 1995). In the short term, large hydrological changes take place after the filling of ditches, which can have a great effect on the ecosystem adapted to drained conditions. As a consequence, e.g. nutrient mobilization can have large effects not only in the peatland itself, but also in recipient ecosystems, as shown by the results of this study.

Other than restoration, there are widespread forestry practices that result in similar or even more specific nutrient loads. The few reliable values for forestry drainage, applied to nearly 6 million ha in Finland, suggest a specific load of nitrogen above 20 kg/ha (total for 10 years), and even higher loads for clear-cutting followed by ploughing (Kenttämies 2006). The latter may also mobilize phosphorus more than that observed in this study (5.75 kg/ha), but the largest specific load of phosphorus in forestry comes from peatland fertilization practised in Finland during 1978–1988, using soluble phosphorus (above 10 kg/ha). The effects of mobile phosphorous have also been noted in watercourses (Saura & al. 2000).

The mean specific load of N in Seitseminen at 17 kg/ha, or in the Nuuksio outflow at 26 kg/ha are very comparable to the forestry values available, while the mean specific load of phosphorus in Seitseminen at 2.4 kg/ha, and in Nuuksio at1.8 kg/ha, seem comparatively low. These forestry practices were performed annually in an area that was many orders of magnitude greater than restoration, and the recipient watercourses of the study sites have experienced drainage in all cases and fertilization in at least Seitseminen.

Today, there are less harmful practices in forestry, and it must be kept in mind that the recipient watercourses in the protected areas are often of special value. Locally, the proportion of restored areas can be high. In addition, the effects may be long lasting and there may be variations depending on hydrological conditions and properties of the landscape. The excess leaching in Nuuksio has not yet ended, and the results in the outflow are less significant than in the subcatchments, due to buffering caused by a natural restoration area just above the sampling point. There are also variations in the responses of individual areas. The Evo Vähä Ruuhijärvi lake monitoring case shows that problems can arise, and that in smaller hydrological systems, the effects can be even more severe (Ilmonen & al. 2006).

It is not entirely clear, which components in the nutrient stores of drained peatlands are the actual sources of the leaching. The values are just a fraction of the total stores in drained peatlands (Westman & Laiho 2003) but are nevertheless high compared with typical annual background leaching values in Finland: mean of 1.4 kg/ha for N, and mean of 0.05 kg/ha for P (Mattsson & al.2003).

Analysis of the exact causes of nutrient mobilization continues and new monitoring approaches are applied (Aapala & al. 2008). However, there is already enough knowledge to be cautious: restoration is a positive action and requires every effort so that harmful impacts can be avoided. This means that peatland restoration planning also requires hydrological and limnological skills.

The study sites described in this paper represent small basins within peatlands completely drained and existing in this state for a long time prior to restoration. Therefore, the water quality impacts for these sites are probably higher than on average. The most urgent need for restoration is in these areas, where ditches in the upper parts of the basins prevent waters from discharging in their natural direction, instead the waters are diverted into a ditch network, which overall affects the hydrology of the undrained peatlands below. This is a severe problem in many aapa mires and some other minerotrophic mires, and no water quality effects due to restoration measures are expected in these kinds of cases due to buffering effects in the undrained mire below.

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Role of protected areas in maintaining the diversity of peat mosses in the Karelian Isthmus and Gulf of Finland islands (Leningrad Region, northwest Russia)

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Introduction

The study area, situated on Russian territory in the Karelian Isthmus, lies between the Gulf of Finland and Lake Ladoga and is bounded by the Neva River to the south and the Finnish-Russian border and Russian Karelia to the north. The Karelian Isthmus belongs to the Baltic coastal province of the concentric (raised) bog zone (Боч, Мазинг 1979). The degree of paludification in the Karelian Isthmus is quite low – mires occupy ca. 5% of the territory, in contrast to 12% for the whole Leningrad Region (Боч, Смагин 1993).

The degree of paludification, types of prevalent mire vegetation and dominant mire landscapes vary notably over the territory of the isthmus (Абрамова 1957; Абрамова 1963; Боч, Смагин 1993). The main geomorphological features that influence the prevalence of mires of a certain type are outcrops of the Baltic shield in the north of the isthmus, the kame-moraine upland in the isthmus' centre, and extensive lowlands covered by glaciolacustrine deposits in the rest of the territory. The factors influencing the characteristics of mires are the hydrological parameters of the terrain related to mire water supply and the depth at which the waterproof rock is bedded.

There are 17 protected areas in the Karelian Isthmus, including regional and municipal nature reserves and monuments: ten special nature reserves and seven nature monuments. Projects have been planned and proposals for designation have been submitted for the establishment of another 14 special nature reserves and six nature monuments (Носков 2004).

To conserve the Karelian Isthmus mires, special reserves, such as the bogs Lammin-Suo and Ozyornoye Rakovyye Lakes and the Yuntolovsky area, were established in the region. There are plans to establish four additional reserves, namely the bog Nizovskoye, and the areasMorye, Kokorevsky and Sestroretsky .

The Lammin-Suo and Ozyornoye reserves were established to conserve the typical raised bog feature with a ridge-hollow and ridge-pool pattern (Noskov & Botch) commonly distributed in the reserve areas. . Most of the Nizovskoye Reserve also exists as a raised massif, the biggest raised bog found to the north of the Karelian Isthmus. The Rakovyye Lakes Reserve serves as a bird sanctuary, where waterfowl and shorebird stopover and staging grounds as well as complexes of eutrophic mires are conserved. The Morye and Kokorevsky reserves were designed to conserve southern-type aapa mires at the margin of their distribution range, as well as to protect rare plant species (Botch 1990). Mires also occur within other protected areas of the Karelian Isthmus designated for other reasons and where the main conservation elements are different. Fens and transitional mires are found within the Melkovodnoye Lake Reserve, and the Ostrovskoye raised bog lies in the planned Termolovsky Reserve, serving as the source for numerous rivers in the Karelian Isthmus. Mires are a component of the Beryozovye Islands Reserve, a Ramsar site, and the planned Ingermanlandsky Strict Nature Reserve located on the eastern Gulf of Finland islands (Malyy Tyuters, Bolshoy Tyuters, Seskar, etc.).

One of the key elements of mire ecosystems is peat mosses. They act as edificators in most mire communities – plants that largely predetermine the structure and functioning of phytocoenosis, and consequently the survival of other plants. Peat mosses can absorb great amounts of water, control the acidity of surrounding water, possess antiseptic properties and are main mire characteristics.

To date, 37 species of *Sphagnum* are known for Leningrad region (Курбатова et al. 1999). Among them are *S. subfulvum* and *S. quinquefarium* whose existence is well documented in old collections (e.g. Isoviita 1970), and *S. annulatum*, distributed in the southern and eastern parts of the region (Волкова et al. 1996, Вьюнова & Кузьмина 1991).

The species typical of raised bogs widespread in the region are *Sphagnum fuscum, S. angustifolium* and *S. magellanicum* growing on ridges and hummocks, and *S. balticum, S. majus* and *S. cuspidatum* growing in hollows. *S. obtusum*, *S. teres* and *S. subsecundum* grow in open fens, while *S. fallax* is widespread in transitional sedge mires. A typical feature of southern aapa mires is *Sphagnum papillosum* lawns and low hummocks. The most common species of paludified pine forests, wet spruce forests and paludified birch forests are *Sphagnum russowii* and *S. capillifolium*, *S. girgensohnii* and *S. squarrosum*, and *S. fallax*, respectively. *S. riparium* thrives in very wet conditions and flowing water (Боч & Кузьмина 1985).

Red-listed species for Leningrad oblast include *Sphagnum aongstroemii, S. auriculatum, S. palustre, S. pulchrum*, and *S. subnitens* (Tzvelev 2000). According to Боч & Смагин (1993) there are a total of ten species of *Sphagnum* mosses that are rare or unique for Northwest Russia (Pskov, Novgorod, and Leningrad regions) (Table 1). In the present paper, rare species referred to are the red-listed peat mosses found in Leningrad region (Курбатова 2002). Species considered to be rare were those with distribution in less than 15 localities in the region: *Sphagnum aongstroemii, S. auriculatum, S. contortum, S. flexuosum, S. inundatum, S. jensenii, S. lindbergii, S. palustre, S. platyphyllum, S. pulchrum, S. subnitens, S. tenellum, S. teres* and *S. wulfianum*. However, based on field observations, *S. contortum, S. teres* and *S. flexuosum* must be removed from the list, because they are frequently encountered in the fens of the region. On the other hand, *S. warnstorfii* and *S. compactum* must be added in the list, since both of them are rarely found in the Karelian Isthmus.

The peat mosses rare for Leningrad *oblast* are species found at the very margins of their distribution ranges or confined to regionally rare habitats. The former group comprises hypoarctic species mainly distributed in the southern tundra and northern taiga woodlands, such as *Sphagnum aongstroemii, S. lindbergii* and *S. jensenii*; oceanic species such as *S. pulchrum, S. subnitens, S. inundatum, S. auriculatum* and *S. tenellum*; and a South European species, *S. palustre.* The latter group includes *S. wulfianum*,

Table 1. Peat mosses of the Karelian Isthmus and Gulf of Finland protected areas

Sphagnum spp.	NW Russia (Boch, Smagin, 1993)	Lammin-Suo (existing)	Nizovskoe (planned)	Ozyornoe (existing)	Morye (planned)	Kokorevo (planned)	Rakovye Lakes (existing)	Ingerman-landskyy + Suursaari (planned)
angustifolium	V	V	V	V	IV	IV	IV	II
aongstroemii*	I	-	-	-	I	-	-	-
auriculatum*	-	-	-	-	II	II	-	I
balticum	V	IV	V	IV	III	III	-	II
capillifolium	III	-	-	III	II	I	I	V
centrale	III	II	I	-	II	III	III	II
contortum	III	I	-	-	I	II	II	II
compactum	III	-	-	-	-	-	-	I
cuspidatum	IV	III	II	IV	II	-	-	III
fallax	V	IV	IV	III	V	IV	III	V
fimbriatum	III	II	I	II	III	I	III	III
flexsuosum	II	III	-	II	I	III	II	II
fuscum	V	V	V	V	IV	II	II	IV
girgensohnii	III	II	-	-	II	II	II	II
inundatum	II	-	-	-	I	II	-	I
jensenii	III	-	-	-	II	III	-	-
lindbergii	III	II	-	-	-	-	-	-
magellanicum	V	V	V	V	V	V	III	V
majus	IV	III	IV	II	II	IV	-	I
obtusum	III	I	-	I	II	IV	IV	I
palustre*	II	-	-	-	-	-	I	I
papillosum	III	II	I	III	V	V	-	V
platyphyllum	II	-	-	-	-	III	-	I
pulchrum*	II	-	I	-	II	-	-	I
riparium	III	II	II	-	II	III	IV	I
rubellum	III	IV	V	V	II	-	I	II
russowii	III	IV	-	II	II	II	II	IV
squarrosum	III	-	-	-	II	III	V	III
subnitens*	II	-	-	-	I	II	-	I
subsecundum	III	-	-	-	IV	V	-	III
tenellum	II	II	II	III	II	-	-	-
teres	II	-	-	-	II	III	IV	I
warnstorfii	IV	-	-	-	I	-	-	II
wulfianum	II	-	-	-	-	-	-	I

V = ubiquitous, IV= often, III = sporadic, II = rare, I = unique
* red-listed species (Red Data Book of Nature of the Leningrad Region)

an indicator species for old-growth forests, as well as mosses living in temporarily flooded fens such as *S. platyphyllum* (Боч & Кузьмина 1985).

In 2005, the St. Petersburg State University's Biological Research Institute implemented a project for assessing the performance of the Karelian Isthmus protected areas network. The principal aim of the project was to detect gaps in the network, i.e. to decide how comprehensively the protected areas represent model, rare and unique elements (species, natural complexes and sites with high species diversity) for conservation. The mire complexes of the Karelian Isthmus were selected as a conservation target to be investigated, which special focus on peat mosses given their significant role in ecosystems. Research tasks were to: 1) find out whether all characteristic and rare species were represented in the protected areas; and 2) determine which of the planned protected areas are most crucial for maximal species diversity conservation of *Sphagna*.

Materials and methods

Within the project, peat moss floras of the Karelian Isthmus protected areas Ozyornoye, Lammin-Suo, Rakovye Lakes, Nizovskoye, Kokorevsky, and Morye were surveyed based on data collected by the author during 2001–2005. In addition, data from the 1993–1994 surveys of the planned Ingermanlandsky Strict Nature Reserve and the Suursaari Reserve located on Gogland Island were used.

Literature data (Tzvelev 2000, Кузьмина et al. 2000, Курбатова & Носкова 2002. Курбатова 2007), RAS Botanical Institute herbarium collections and personal communications of V. Smagin and E. Kuzmina complemented the data on the locations of rare Sphagnum species.

The peat moss nomenclature used in this paper follows Ignatov et al. (2006).

Results

Species inventories conducted during 2001–2005 not only confirmed the presence of the peat moss species mentioned earlier but revealed some new species as well (Боч & Василевич 1992). Table 1 shows the composition of peat moss flora in the Karelian Isthmus protected areas of Ozyornoye, Lammin-Suo, Rakovye Lakes, Nizovskoye, Kokorevsky, Morye, Ingermanlandsky and Suursaari. Figure 1 shows the distribution of rare Sphagnum species over the Karelian Isthmus and Gulf of Finland islands.

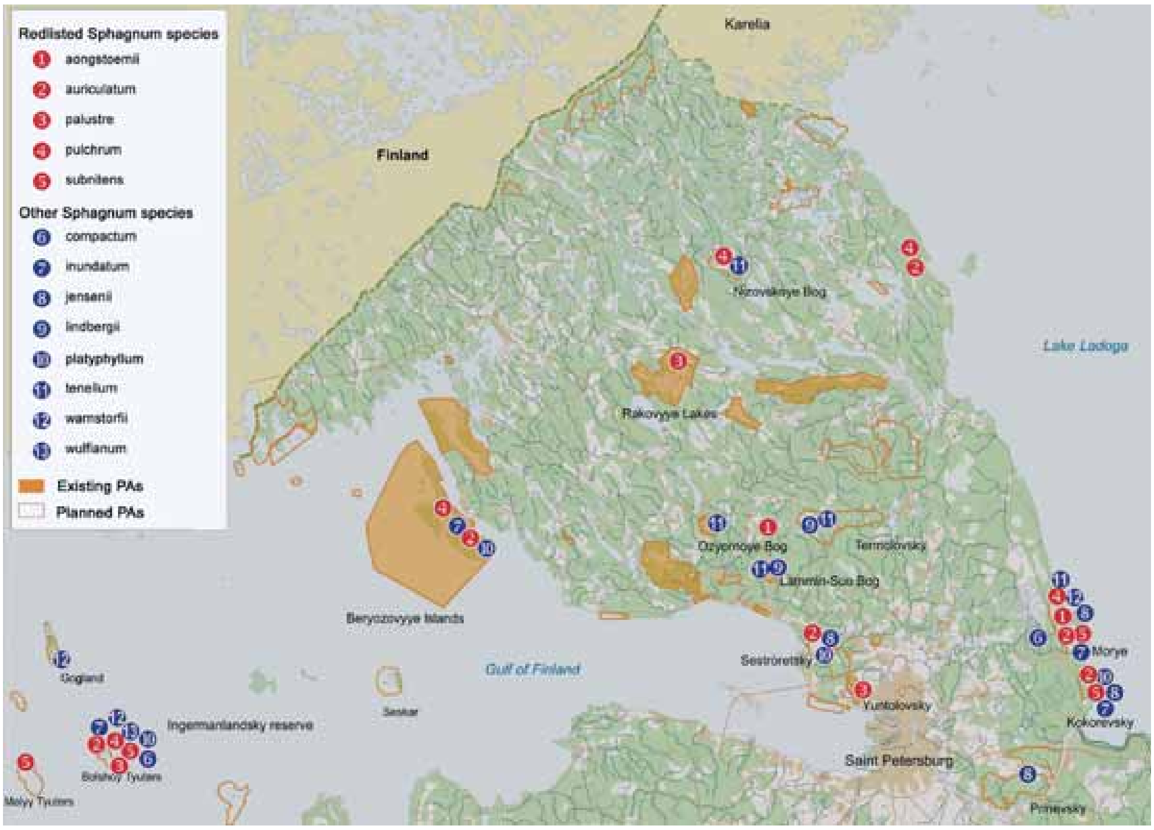

Figure 1. The distribution of rare *Sphagnum* species over the Karelian Isthmus and on the Islands of Gulf of Finland

Regionally rare Sphagnum species were found in the following habitats:

1) *Sphagnum aongstroemii* C. Hartm: waterlogged margins of fens

2) *Sphagnum auriculatum* Schimp.*: Carex rostrata – Eriophorum polystachyum* fen*,* flarks among *Sphagnum papillosum carpets* of *Carex lasiocarpa dominated* fens*, Carex acuta – Carex lasiocarpa – Equisetum fluviatile* coastal fens, paludified former lagoon*s*

3) *Sphagnum palustre L.*: alder swamps

4) *Sphagnum pulchrum* (Lindb.) Warnst.: flarks among *Eriophorum vaginatum – Calluna vulgaris – Sphagnum papillosum* hummocks, flarks of *Carex lasiocarpa* dominated fens among *Sphagnum papillosum* carpets

5) *Sphagnum subnitens* Russ. et Warnst. ex Warnst.: single specimens growing on wooded mesotrophic mires or forming hummocks (pure or together with *Sphagnum papillosum*) on sedge fens with birch shrubs (*Betula pendula – Carex lasiocarpa – Sphagnum subsecundum*);

6) *Sphagnum compactum* DC in Lam. et DC: on peat together with *Rhynchospora alba*

7) *Sphagnum inundatum Russ.:* flarks among *Eriophorum vaginatum – Calluna vulgaris – Sphagnum papillosum* hummocks*, Carex lasiocarpa – Menyanthes trifoliata* fens*, Salix rosmarinifolia – Comarum palustre – Equisetum fluviatile – Carex lasiocarpa* coastal fens

8) *Sphagnum jensenii* H. Lindb: *Rhynchospora alba – Equisetum fluviatile – Menyanthes trifoliata* flarks among *Carex lasiocarpa (or C. dioica) – Sphagnum papillosum* carpets, *Rhynchospora alba – Utricularia intermedia* flarks among *Carex lasiocarpa – Sphagnum papillosum* carpets, *Carex lasiocarpa* – *Menyanthes trifoliata – Sphagnum subsecundum* fens,

9) *Sphagnum lindbergii* Schimp ex Lindb.: bog hollows with *Sheuchzeria palustris in pure stands* or mixed with *Sphagnum majus*

10) *Sphagnum platyphyllum* Sull. ex Warnst: *Rhynchospora alba – Utricularia intermedia – Menyanthes trifoliata* flarks among *Carex dioica – Sphagnum papillosum* carpets*, Salix rosmarinifolia – Comarum palustre – Calamagrostis neglecta – Equisetum fluviatile – Carex lasiocarpa* coastal mires, *Carex acuta – Carex lasiocarpa – Equisetum fluviatile* coastal mires

11) *Sphagnum tenellum* (Brid.) Perss. Ex Brid.: bog hollows mixed with *Sphagnum balticum, S. rubellum, S. angustifolium, S. magellanicum or Eriophorum vaginatum – Menyanthes trifoliata – Sphagnum papillosum* carpets

12) *Sphagnum warnstorfii* Russ.: hummocks of *Carex lasiocarpa – Sphagnum papillosum* mires, *Pinus sylvestris - Molinia caerulea – Trichophorum cespitosum – Sphagnum* mires

13) *Sphagnum wulfianum* Girg.: *Vaccinium myrtillus – Hylocomium splendens* spruce forests

Discussion

Best represented in the existing protected areas network of the Karelian Isthmus are peat mosses associated with oligotrophic mires. Their species diversity is not high – the operating Ozyornoye and Lammin-Suo protected areas and the planned Nizovskoye reserve harbour only 15, 18 and 14 species, respectively. Although the number of species is relatively low, species typical of the zone of concentric raised bogs such as *Sphagnum angustifolium, S. fuscum, S. magellanicum and S. balticum* are abundant throughout and act as edificators of the communities. Thus, species typical of raised bogs are not just present in the protected areas but play a defining role in the plant coenoses.

An interesting find from Lammin-Suo and some other protected areas is the regionally rare arctic species *S. lindbergii*, which forms carpets within the hollows of raised bogs in contrast to its presence on arctic mires, where it also occurs in mesotrophic communities. The oceanic species *S. tenellum*, growing in hollows with other species to avoid drying out (Rydin 1985), can be found in Ozernoye, Lammin-Suo and Nizovskoye. In addition to the presence of *S. tenellum*, frequent occurrence and high abundance of sub-oceanic species such as *S. rubellum* and *S. cuspidatum*, reflect the Baltic coastal province influence on the Karelian Isthmus mires (Боч & Мазинг 1979). These species also occur further to the east of the region, but their abundance there is much lower. Thus, in terms of the *Sphagna* flora and their role in the coenoses, the Ozernoye, Lammin-Suo and Nizovskoye protected areas can be regarded model raised bog reserves besides the characteristics they share in typifying Karelian Isthmus mires.

Fens in the Rakovye Lakes Reserve also demonstrate relatively low *Sphagnum* moss species diversity (17 species). Most mires in the reserve are quite young, having originally formed on lake shores, after the fall in water level caused by human activities in 1857. The *Sphagna* flora is typical of fens – the most frequent species are *S. squarrosum, S. teres, S. riparium, S. obtusum* and *S. fallax*.

The species diversity of Sphagna is highest in the planned Morje and Kokorevsky protected areas, amounting to 29 and 24 species, respectively. The protected areas are situated in the southern Ladoga area and designed to ensure protection of southern aapa mires. One of the dominants in mires of this type is *S. papillosum*, which forms wide cushion-like hummocks characteristic of southern aapa mire complexes (Botch 1990). Another species growing throughout the Kokorevskoye mire is *S. subsecundum*, a eutrophic species rarely recorded for other Karelian Isthmus protected areas. The Morje and Kokorevsky mires harbour a number of rare species such as *Sphagnum aongstroemi, S. auriculatum, S. inundatum, S. platyphyllum, S. jensenii, S. warnstofii, S. pulchrum* and *S. subnitens*. The latter species, red-listed in Leningrad region, occurs in several localities within the mires and forms large single-species hummocks.

Some Karelian Isthmus protected areas where mires are not the main protection target have also been found to feature a high diversity of peat mosses. *Sphagnum* flora is the richest in the planned Ingermanlandsky Strict Nature Reserve and the Suursaari Special Reserve. Thirty Sphagnum species have been reported for the Gogland, Bolshoi Tyuters and Malyi Tyuters islands. These islands feature *S. wulfianum* and *S. compactum*, both unknown to exist in any of the already operating or planned Karelian Isthmus protected areas.

It is noteworthy that the highest species diversity is typical of areas lying in the immediate vicinity of the Gulf of Finland or Lake Ladoga. Apparently, availability of vast water bodies connected to the Atlantic Ocean and interconnected by the Neva River facilitates the spread of peat moss diaspores. Further, as the mires and wetlands lie along the Baltic-White Sea migratory route Sphagna dispersal may be facilitated by migrating waterfowl and shorebirds.

The presence of several species of peat mosses with a tendency for oceanic distribution (*Sphagnum pulchrum, S. auriculatum, S. inundatum, S. subnitens*) in mires along the Gulf of Finland and Lake Ladoga is probably due to a number of climatic factors. Gignac (1993) cites precipitation and extreme temperatures as major factors limiting the spread of oceanic *Sphagna*. Despite the vicinity of large water bodies, it is not in the coastal zone but in the central upland of the Karelian Isthmus that precipitation is most plentiful. The most probable factors that have promoted the growth of oceanic species in the area seem to be elevated air humidity and milder extreme temperatures, particularly winter minima. One should also note that the longest frost-free period in the Karelian Isthmus and Leningrad *region* as a whole is in coastal areas, lasting130–150 days (Дуров 1967).
The Karelian Isthmus has 33 of the 37 *Sphagnum* species known for Leningrad *region*. All regionally red-listed species – *S. aongstroemii, S. auriculatum, S. palustre, S. pulchrum and S. subnitens* – occur in the existing or planned protected areas.

Among the red-listed *Sphagna*, surveys of existing protected areas show presence of *Sphagnum palustre* in the Rakovye Lakes and Yuntolovsky reserves, and that of *S. auriculatum* and *S. pulchrum* in the Beryozovye Islands Reserve. *Sphagnum aongstroemii* and *S. subnitens* are not found in the existing protected areas.

Other species rarely found in Leningrad *region* but found growing in the existing protected areas are *S. platyphyllum, S. inundatum, S. tenellum* and *S. lindbergii.* Species such as *S. warnstorfii* and *S. jensenii* are only present in the planned Karelian Isthmus protected areas.

Sphagnum wulfianum has been reported for the Bolshoi Tyuters Island only. Occurrence of *S. compactum*, a species having never been encountered in any of the existing or planned Karelian Isthmus protected areas so far, has been also noted on the island. *S. wulfianum*, which is not a mire species, is ecologically related to coniferous, mostly old-growth forests. It is strongly recommended that surveys of this species be carried out in the north of the Karelian Isthmus, in the border area, where fragments of old-growth forests still survive.

In sum, the majority of rare species are found within the zones of planned protected areas. Hence, to ensure full representativeness of the Karelian Isthmus and Gulf of Finland mire landscapes and mire plant communities in the protected areas network and to conserve rare species and habitats with high biological diversity, there is an urgent need for the planned Ingermanladsky Strict Nature Reserve and the Morye, Kokorevsky and Suursaari special nature reserves to be designated. .

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Sphagnum cover surface shape variations during vegetation period

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Introduction

The aim of this paper was to study the growth of the *Sphagnum* moss, and the moisture conditions and irregularities of the *acrotelm* in coordinated, mechanical moss layer movements in the moss cover. A moss sod is a part of a moss cover / layer with the moss stems tilted in the same direction. The boundary between individual sods is located on the place where the moss stems tilt direction changes relatively abruptly. The more uniform the conditions are, the greater the sod size is. Each moss layer is "searching" optimal conditions for survival. The movement of the moss layers occurs in the interval between excessive and insufficient humidity of the substrate. The transition of the moss stems from vertical to horizontal position results in horizontal movement of the moss layer (Fig. 1) as demonstrated in the works of Конойко (1989) and Антипин & Лопатин (1989). The interaction of the moss layers results in «repacking» or «compaction» of a part of the moss cover, affecting the size, thickness and the resistance of the *acrotelm* (Воробьев 1965, Смоляницкий 1977, Кузьмин 1980, Лиштван et al. 1989).

The moss layers spread out on the surface of the *acrotelm* according to the *acrotelm's* spatial and temporal irregularities (Панов 1991). The relief and fluctuations in the *acrotelm,* connected to the patterns of moss layer movements, are a proof of the independent development of peat bogs.

Figure 1. Inclination of moss stems causes horizontal movement in the moss cover (Photo Vladimir Panov).

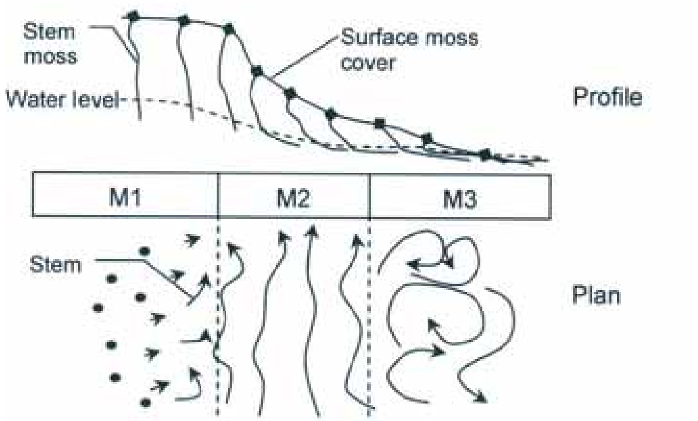

Figure 2. Morphodynamic zones of a complex mire surface: M1 – zone of predominantly vertical growth of the mosses, M2 – zone of continuous horizontal movement, M3 – zone of inconstant movements

The boundaries of *Sphagnum* moss layers are defined by the characteristics of their growth and the direction of the moss layer movements. According to previous studies (Панов 2006) complex mire surface can be represented by morphodynamic zones (Fig. 2).

The major objective of this work is to study the shape of the surface formed by Sphagnum heads and its behaviour during the vegetation period. It has been substantial to evaluate the moss cover surface dependence on: a) amount of water in *acrotelm*, b) moss stem deviations from the vertical direction, c) spatial structure of moss sod motion.

Object and method of study

The study area is Terelesovskiy-Gryadskiy mire complex, located in the Vyshnevolotsk area in the Tver Region. It is a typical southern boreal mire of 14 000 hectares. The average depth of the peat layer is 2 meters (max. 6,5 m). The uppermost layer (1-2 m) is poorly-decomposed *Sphagnum* peat, whereas the middle peat layer is composed of cotton grass and *Sphagnum*, including remains of pine. The lowermost layer consists mainly of the remains of sedges.

At the mire margin, the vegetation cover consists of eutrophic plant communities dominated by sedge and birch. Towards the centre, the plant communities become first mesotrophic and sedge and Sphagnum dominated, and then oligotrophic and pine and *Sphagnum* or Rannoch-rush (*Scheuchzeria palustris*) dominated. The centre of the mire is occupied by an oligotrophic complex of ridges and pools. In the elevations, the moss communities are dominated by *Sphagnum fuscum* and *Sphagnum magellanicum*, whereas in the depressions *Sphagnum cuspidatum, Sphagnum majus* and *Sphagnum balticum* are dominating. There is cotton grass (*Eriophorum* spp.), Rannoch-rush (*Scheuchzeria palustris*), snoutbean (*Rhyncospora alba*) and mud sedge (*Carex limosa*) in the grass layer. In addition, pine has covered the elevations.

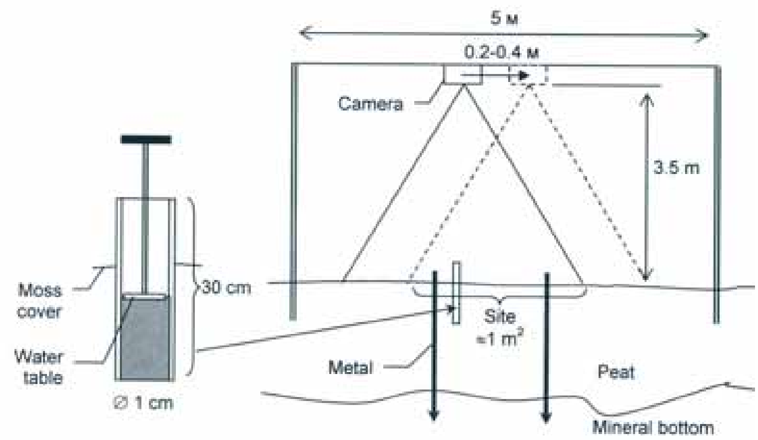

Figure 3. Site arrangements and water level measurements (water surface position)

This paper discusses the areas that lie on the same smoothed profile in the direction from the edge to the center of a convex mire and have a marked microrelief. The surface microrelief is formed by elevations or hummocks or lowerings or hollows. So, the study was mainly aimed at the slopes, from hummock tops to hollow bottoms. The other areas have a hardly noticeable microrelief. Area No. 8 was chosen arbitrarily to present the data obtained. The studies were carried out from April to October 1990, with 10-20 day-long intervals. Metallic benchmarks, joint together, are pegged down to the mineral soil to mark each study plot (Fig. 3). It allowed evaluation of absolute variations in the moss and water surface.

With the help of systematically attained stereo pictures and stereophotogrammetrical equipment, a geometrical model of the plant cover with the accuracy of up to 1 mm was made (Fig. 3). The systematic method of attaining the stereo pictures is described in Панов (1991), and more in detail in Панов (1992). The relief profiles of 12.5 mm and 25 mm were chosen as most suitable for this study.

Changes in the water level were followed with the help of a special float in each study plot (Fig. 3). On some float pipes, regular cuts were made in every 1 centimeter, which allowed considering the pipes as "water-permeable". No differences in water levels were found. The water level meters were placed for the whole study period and suffered no impacts from outside. The only exclusions were the cases when the moss covered the pipes.

In interpreting the directions of the moss layers movement, the ability of the moving moss layers to bend the aboveground parts of the grasses was observed. The direction of the grass stalk inclination is easily detectable with the help of stereo pictures (better in spring and autumn).

In order to define the criteria for moss layer movements, measurements of the grass stalk inclination and height, number of inclination directions and stalks per unit area were carried out. As a result, cartograms of significant correlation between the criteria above were obtained (Панов 2006).

Results

The study plot number 8 is taken here as an example showing the boundary between the elevation in the lower part of the picture and the depression in the upper part of the picture (Fig. 4). In the centre of the picture, open water surface is shown in greyish blue colour. The stalks of *Eriophorum vaginatum* are shown in light stripes and the moss cover of *Sphagnum fuscum* and *Sphagnum cuspidatum* is illustrated in taupe and taupish green colours. The white marks show metal bars, 1 cm in diameter, forgotten in the mineral soil. In addition, there is a water level measures in the centre of the picture. The amplitude between the depressions and elevations is an average of 10-20 cm (max. 30 cm). The visual boundary between the depressions and elevations is shown in the picture as a front where the elevations and depressions in the moss cover meet (Fig. 4). It is not always possible to define the geometrical boundary between elevations and depressions. In addition, the boundary changes its position in time due to fluctuations in water level and the resulting fluctuations in the mire surface.

Based on the surface moss cover or open water surfaces, geometrical models (Fig. 5) are made as an example of the analysis of surface and water level dynamics in the study plot number 8. Arrows show sod motion tracks. However, surface models based on small relief profiles have proved too complicated, mostly reflecting biological characteristics of individual mosses. The chosen profile of 12,5-25 mm represent average sizes of *Sphagnum* moss tops and smoothen differences between characteristics of individual mosses, whereas bigger profiles smoothen the boundaries between different moss layers.

The analysis of stereoshots of the surface of all the areas shows that the moss cover is decompacted after thawing and gaps can be seen among the moss heads. There exists only a general relationship between the relief and moss motion tracks. In May the hollow surface is smoothed because of sod sagging. By late May the hollow contours becomes clear. The moss growth results in a new microdifferentiation of the surface. The relationship between the sod tracks and relief becomes evident. This process occurs the whole June, and when the water lowers by the late June, the moss cover is dried and compact. *Acrotelm* water accumulation by the late July causes the moss sods surface elevation and decompaction in the hollows. The surface relief becomes

Figure 4. Photograph of the mire surface at the height of 3,5 m (plot number 8) on October 15th 1990. 1:20 (dash line showing the conditional boarder of the elevation and the depression) (Photo Vladimir Panov).

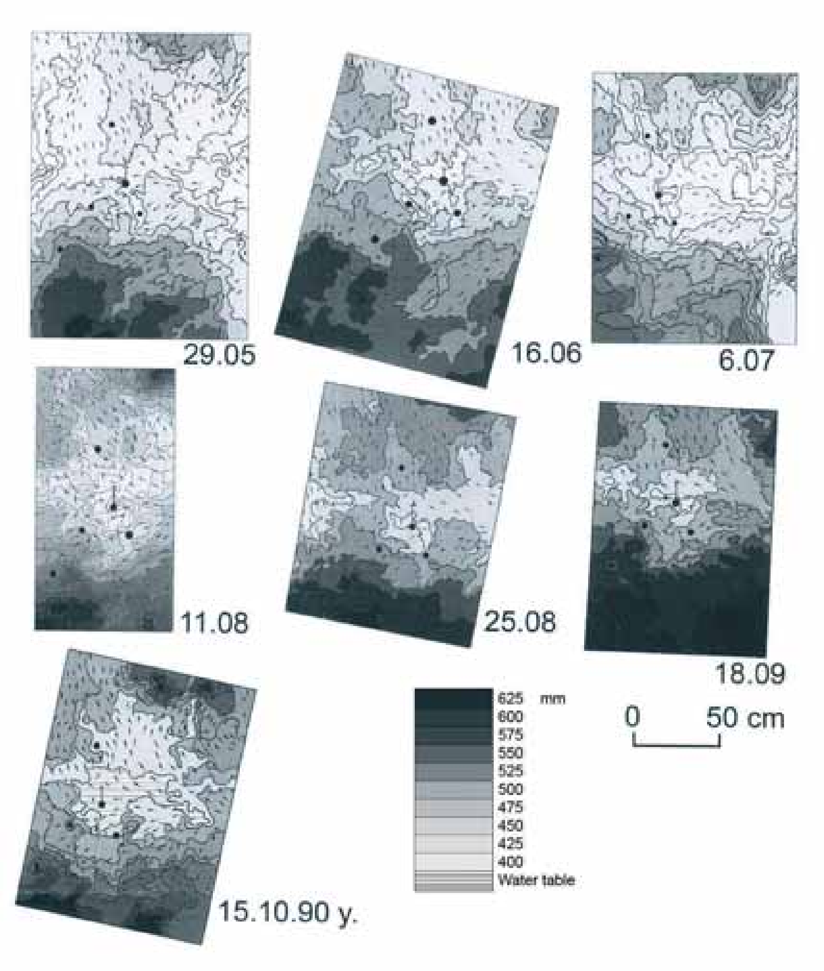

Figure 5. Model of the surface model of plot number 8

the most evident and complicated. The pressure on the grass grows. In august the sod is closed and smoothed – the second moss growth stage begins. By the late August, water can be seen in the hollow, among the moss heads. The open water surface difference is up to one centimeter. The horizontal surfaces become smoother. In September, microlakes appear on most areas. The surface elevation id still going on, and all the grass tilts. In autumn, the moss track effect on the surface relief becomes the most evident. The horizontal lines of the surface are mostly perpendicular to the moss tracks. During time periods between the observations, an abrupt water elevation elevates the moss layer that covers the marks on metal rods after water lowering. The wettest places look like "draining" because of their own mass (Fig. 2, M3). The middle parts of the relief M2 show a noticeable motion away from the wettest places. The moss motion in zone M1 is independent from the hollow growth.

Figure 6 shows variations in the levels of the surface of the moss, water and the top mark on the float pipes. The surface was measured at the float bottoms. The pipes show the vertical motion of the *acrotelm*, and the surface also shows the moss layer motion. All the areas differ in their amplitude and time-match of the short-time variations, but show a certain similarity (in their variations caused by sedimentation and evaporation variations) for the whole period (Fig. 7). These variations depend on heterogeneity of individual places of the mire.

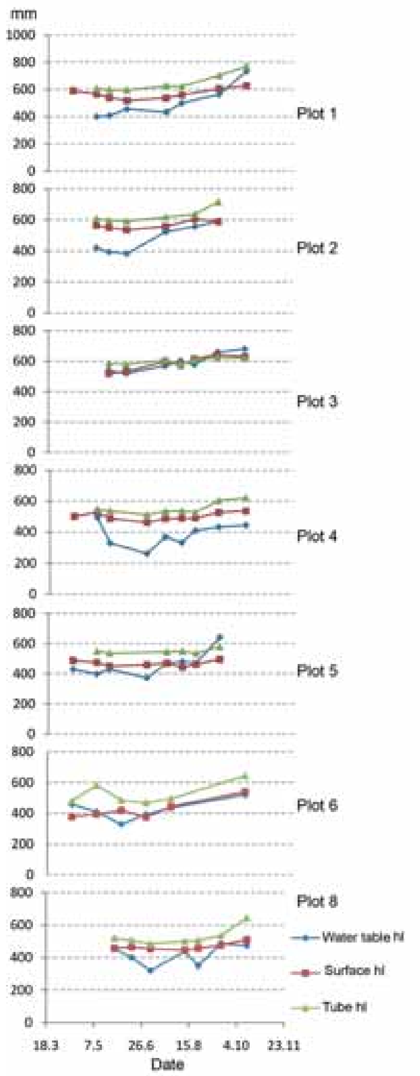

Figure 6. The effect of the amount of water in *acrotelm* (Water table hl (hollows)) on the behavior of the *acrotelm* (Tube hl) and surface marks (Surface hl)

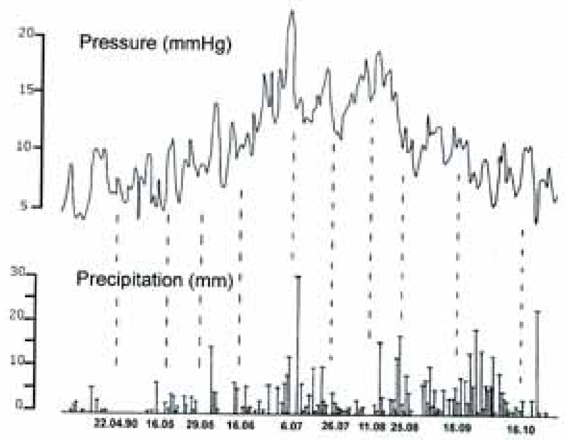

Figure 7. Changes in climatic conditions during the study period

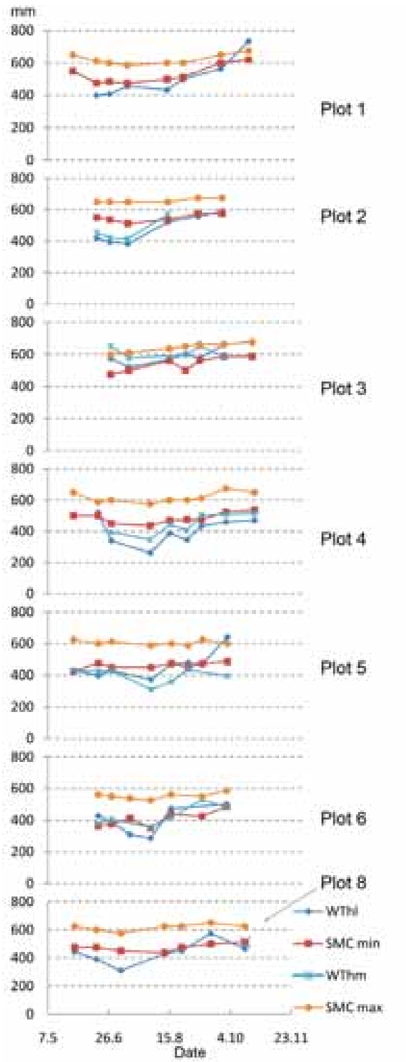

Figure 8. The effect of the amount of water in *acrotelm* (WT - Water table hl (hollows), hm (hummock)) on the behaviour of the moss cover surface maximum (SMC max) and minimum (SMC min) marks

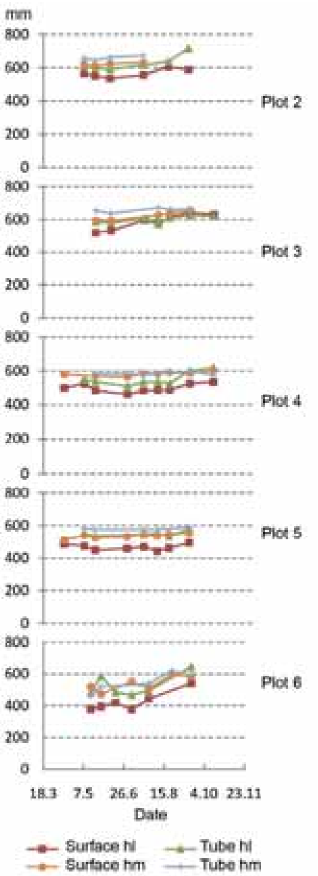

Figure 9. Relationships between the behaviour of the the moss cover surface marks (Surface hl (hollows), hm (hummock)) and *acrotelm* marks (Tube hl (hollows)), hm (hummock))

Figure 8 shows the behaviour of the maximum and minimum surface level marks. The water levels measured on the hollows and hummock slopes differ by two to eight centimetres. This difference is constant and independent of the photography technique. The mark levels vary nonsynchronously from one area to another. The maximum and minimum variation amplitudes are almost the same for each area, which suggests that the *acrotelm* has a constant shape. For the entire region, the microrelief variation range is 10 to 20 cm, independent of the mire position and surface angle. In the middle summer the moss surface level of the hollow reached that of the hummock on Area No. 3. This fact made an exclusion of the latter.

Comparison between the hollow and hummock *acrotelm* pipe variations (Fig. 9) shows that the hummock pipes get covered by moss by autumn, and the sod does not sag. On the hollows, on the contrary, the pipes elevate in parallel with the moss surface sagging. The moss stems changed their position from vertical to horizontal.
Figures 6 and 8 show water level values above the free water and moss surfaces. This should be caused by the fact that the float was high on the high water and vibrated in the wind. So, the extreme values should be equated to the moss or free water surface level.

Discussion

That is why the moss layer and *acrotelm* surface shape variations depend on the amount of water input to the mire. Some water drains from the mire (Иванов, 1953). Some water is accumulated in the *acrotelm* because of the filtration coefficient change with depth or a different filtration under hollows and hummocks (Лиштван и др., 1989). Some water saturates, laminates the peat deposit (Лиштван и др., 1989) and makes it float. As a result, changes in the surface shape cause changes in the moss layer development. Its heterogeneity gradually creates heterogeneous peat deposits (Кузьмин, 1980). And vice versa, when measuring the quantity of water in the *acrotelm*, its thickness can have different effects on the development of the moss cover.

Thus, the moss cover is building material, reflecting the increase of the irregularities in the *acrotelm*. Spatial and temporal dynamics of the irregularities in the *acrotelm* regulate movements and the development of the moss cover.

If the moss sod motion is their search for optimum existence conditions, then the humidity gradient from the hollows to the hummocks is necessary is necessary for the progressive increase of water accumulation in the mire. Fragile and loose peat deposit parts are formed in the hollows, whereas firm and dense peat deposit parts are formed in the hummocks (Кузьмин, 1980; Лиштван и др., 1989).

The behaviour of the maximum and minimum surface level marks (Fig. 8) shows that the former as a whole, the differences reflect the changes in the climatic parameters. However, the values are not parallel or synchronic in different parts of the mire. As in the case of interdependence between the changes in the water level and the surface, each study plot is individual in the scale in question.

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Plant cover of natural mires and disturbed peatlands in Meschera National Park, Russia

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Introduction

Meschera National Park was established in 1992 to preserve the nature of the Meschera lowland. The park is situated in the south-eastern part of the Vladimir region, in the Gus-Hrustal administrative district, and is bordered in the west by the Moscow region, and in the south by Meschersky National Park in the Ryazan region (Fig. 1). The total area of Meschera National Park is 118 900 hectares. Wooded lands of the Federal Forestry occupy 86 300 hectares (72.6%). Mires are today considered a distinct and important landscape within the park, although the last two centuries saw more than 1 000 hectares of mires drained for agricultural purposes and approximately 3 000 hectares for peat extraction.

Large mires have disappeared in the present territory of national park. But not less than 3 thousand hectares of open mires, mire sites and their fragments still exist. Diversity studies and preservation of mire biota are the important tasks of the park activity. The goals of our investigations were to study plant cover diversity of natural mires and disturbed peatlands (milled fields, quarries of winning peat) in Meschera National Park. The first results were published already (Антипин & Дроздова 2004; Антипин et al. 2004, 2005, 2006).

Natural mires and disturbed peatlands altogether cover 6600 ha or 5,5% of the area of national park (2700 ha natural mires and 3900 ha disturbed peatlands).

Figure 1. Location of Meschera National Park.

In 1920s and 1930s the first peat extracting companies started to work here. Peat briquettes were extracted by elevator buckets. At first, mires were drained and then excavated by dredge method using the peat deposits down to the bottom. After the peat was excavated, mires have turned into a system of quarries filled in with water and separated by peat borders. New modern peat extracting plants were built in 1960s to 1980s. Peat was cut by drum shredders. This method has required a larger area to work on. Drained mires were cut into milled fields by drain channels. Thus artificial ecosystems were formed on the place of mires.

Materials and methods

Study objects were chosen on the basis of color aerial photos in scale 1: 25000 (August 2001) and space image of territory of park (June 2004). Open natural mires, mires with sparse trees and disturbed peatlands are easy to distinguish on the photos. Most of the disturbed peatlands were covered by plants before a fire happened in 2002.

Field work was done during the summer seasons in 2003-2006. Plant cover of natural mires and disturbed peatlands (milled fields and quarries of winning peat) were inventoried. Altogether 12 natural mires and disturbed peatlands were investigated. Geobotanical descriptions of mire sites (78 descriptions) were prepared according to the traditional method (Методы исследований.., 1991). On the basis of space image Landsat, the map of the vegetation of natural mires and the disturbed peatlands of park was made.

The taxonomy of vascular plants in the text follows Черепанов (1995), and that of mosses Ignatov & Afonina (1992).

Results and discussion

Natural mires of Meschera National Park are presented by oligotrophic (25%), mesotrophic (10%) and meso-eutrophic (65%) types. Oligotrophic Sphagnum mires occur here on the southern limit of their zonal distribution. They belong to the group of magellanicum-mires typical for the southern taiga (Богдановская-Гиенэф, 1949). Most of mires are middle-Russian wooded and hummock–hollow mire types (Юрковская, 1992). Mires are situated mainly on glaciofluvial and moraine-glaciofluvial plains. Mesotrophic mires are small (2-5 ha). They lie on glaciofluvial formations and river terraces. Meso-eutrophic mires are distributed mainly in the southern part of the national park, in neighbourings of Svetloe Lake and along the Buzha River (Fig. 2).

The flora of natural mires in Meschera National Park includes 103 species: 70 vascular plants and 33 mosses (Table 1). Vascular plants are mainly presented by the families Cyperaceae (15 species), Salicaceae (6), Ericaceae (6) and Poaceae (5). The other families have 1-3 species only. 18 species are regarded as true mire species, and most of them were found on oligotrophic mires. Common mire species are *Andromeda polifolia, Chamaedaphne calyculata, Ledum palustre, Oxycoccus palustris, Vaccinium uliginosum, Eriophorum vaginatum, Carex lasiocarpa, C. limosa, Scheuchzeria palustris, Rhynchospora alba* and *Drosera rotundifolia*. Absence of bog shrubs such as *Empetrum nigrum* and *Betula nana*, as well as the rarity of *Rubus chamaemorus, Oxycoccus microcarpus* and *Carex pauciflora* were reported earlier (Исаченко & Юрковская 1973). Among the mosses, Sphagnaceae family prevails (17 species). The flora of mire bryophytes includes the following common mosses *Sphagnum angustifolium, S. magellanicum, S. fallax, S. papil-*

Figure 2. Natural meso-eutrophic herb-Sphagnum mire in Meschera National park.

losum, S. balticum, S. cuspidatum, Polytrichum strictum, Aulacomnium palustre, Dicranum scoparium and *Pleurozium schreberi*.

The following objects have a high nature conservation value:

1. Oligotrophic hummock-hollow bogs and their fragments;
2. Communities typical of the middle-Russian mires: Pinus sylvestris – Ledum palustre – Sphagnum magellanicum on bog hummocks and Eriophorum vaginatum – Sphagnum cuspidatum in bog hollows;
3. Rare communities with the presence of Sphagnum fuscum and Rhynchospora alba.

Milled peat fields have the highest number of species, 165 (133vascular plants and 32 mosses). The main vascular plant families are Poaceae (17 species), Cyperaceae (11), Asteraceae (10), Salicaceae (9) and Ericaceae (7). *Carex cinerea, C. rostrata, Eriophorum vaginatum, E. polystachion, Chamaenerion angustifolium, Phragmites australis, Juncus conglomeratus* and *Typha latifolia* are common (Fig. 3). *Chamaenerion angustifolium, Calamagrostis canescens* and *Epilobium ciliatum* grow on dry easily burning milled fields Apophyte species are *Chamaenerion angustifolium, Atriplex calotheca, Bidens cernua, Calamagrostis neglecta, Chenopodium album* and *Urtica dioica*. They grow better in disturbed biotopes. The main bryophyte families are Sphagnaceae (10), Amblystegiaceae (6), Polytrichaceae (4). Invasive species *Polytrichum juniperinum, P. piliferum, Funaria hygrometrica, Ceratodon purpureus, Dicranella cerviculata, Leptobryum pyriforme* and *Marchantia polymorpha* are the pioneers of open peat.

The flora of quarries of winning peat includes 75 species (50 vascular plants and 25 mosses). Ericaceae (8 species), Cyperaceae (7), Poaceae (6) and Salicaceae (4) families prevail. *Betula pubescens, Pinus sylvestris, Frangula alnus* and *Salix pentandra* grow on quarry borders. *Vaccinium myrtillus, V. vitis-idaea, V. uliginosum* and *Ledum palustre* are abundant. *Phragmites australis, Eriophorum vaginatum, Comarum palustre* and *Carex rostrata* are very common (Fig. 4). Among mosses Sphagnaceae family dominates (14 species). Natural regeneration of mire vegetation was observed in old quarries of former peat extraction. Flora of quarries and flora of natural mires are quite similar.

Figure 3. Plant cover of the previous milled field.

Figure 4. Plant cover of former peat quarries.

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Table 1. Vascular plants and bryophytes of natural mires and disturbed peatlands in Meschera National Park.

Species	Natural Mires	Disturbed peatlands	
		milled fields	quarries of winning peat
TREES AND SHRUBS			
Alnus glutinosa	+		+
Betula pubescens	+	+	+
Frangula alnus	+	+	+
Pinus sylvestris	+	+	+
Populus tremula	+	+	+
Salix aurita	+	+	+
S. caprea	+	+	
S. cinerea	+	+	+
S. lapponum	+		
S. myrsinifolia		+	
S. pentandra		+	+
S. rosmarinifolia	+	+	
S. starkeana		+	
S. viminalis		+	
Tilia cordata			+
DWARF SHRUBS			
Andromeda polifolia	+		+
Calluna vulgaris		+	+
Chamaedaphne calyculata	+	+	+
Ledum palustre	+	+	+
Oxycoccus palustris	+	+	+
Vaccinium myrtillus		+	+
Vaccinium uliginosum	+	+	+
Vaccinium vitis-idaea	+	+	+
SEDGE PLANTS			
Carex acuta	+	+	
C. cespitosa	+		
C. chordorrhiza	+		
C. cinerea	+	+	+
C. diandra	+		
C. elongata	+		
C. lachenalii		+	
C. lasiocarpa	+	+	
C. limosa	+		
C. nigra	+	+	

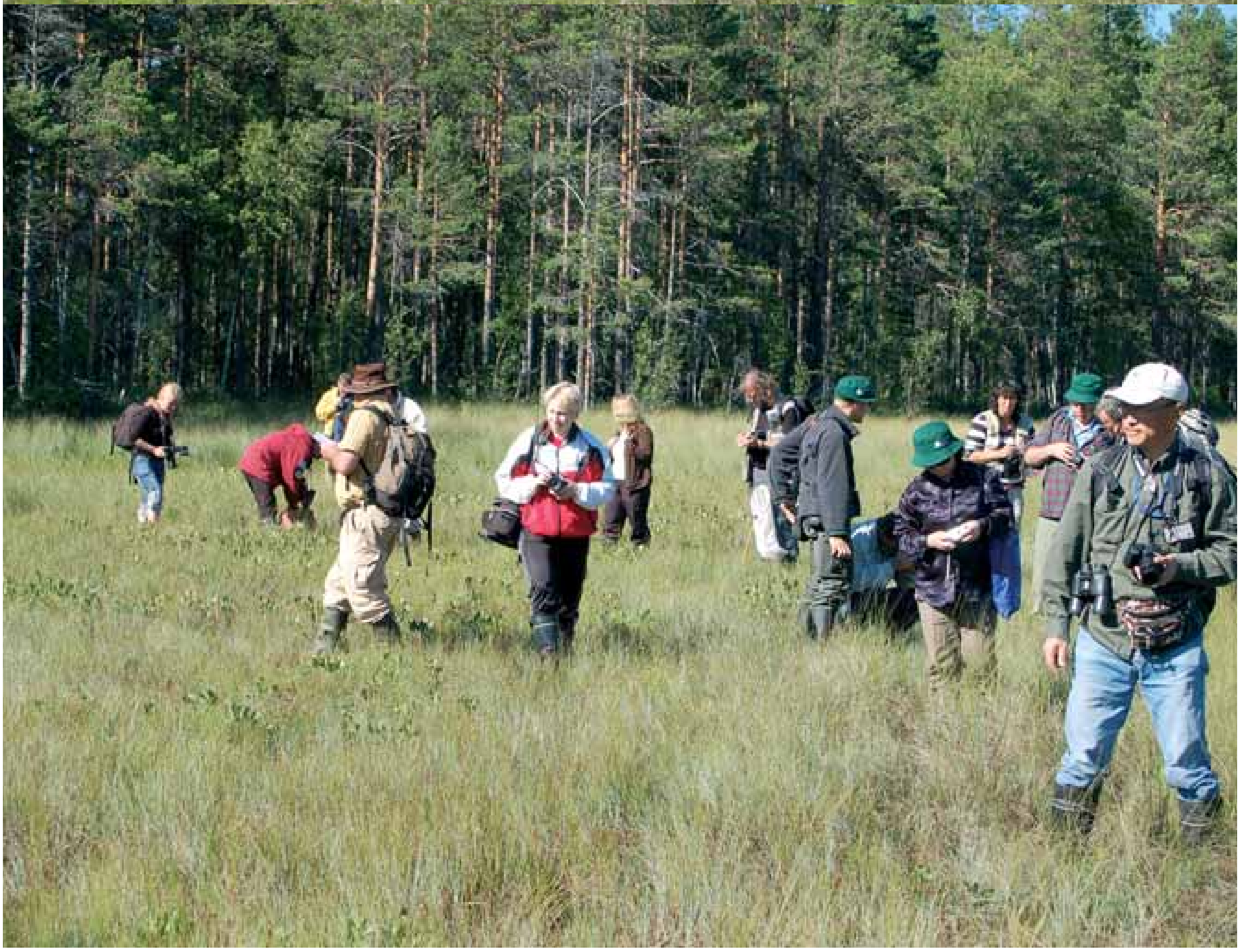
Species	Natural Mires	Disturbed peatlands	
		milled fields	quarries of winning peat
C. pseudocyperus		+	+
C. rostrata	+	+	+
C. vesicaria	+	+	
Eriophorum gracile	+		
E. polystachion	+	+	+
E. vaginatum	+	+	+
Rhynchospora alba	+		+
Scirpus sylvaticus		+	+
GRAMINEOUS PLANTS			
Agrostis canina	+	+	
A. gigantea		+	
A. stolonifera		+	
A. tenuis		+	+
Anthoxanthum odoratum		+	
Calamagrostis arundinacea		+	+
C. canescens	+	+	
C. epigeios		+	+
C. neglecta	+	+	+
Deschampsia cespitosa		+	+
Festuca pratensis		+	
F. rubra		+	
Molinia caerulea		+	
Phragmites australis	+	+	+
Poa palustris	+	+	
P. pratensis		+	
P. trivialis		+	
HERBS			
Achillea millefolium		+	
Alisma plantago-aquatica	+	+	+
Atriplex calotheca		+	
Bidens cernua		+	
B. tripartita		+	
Calla palustris	+	+	+
Caltha palustris	+		
Campanula persicifolia		+	
Cerastium holosteoides		+	
Chamaenerion angustifolium	+	+	+
Chenopodium album		+	

Species	Natural Mires	Disturbed peatlands	
		milled fields	quarries of winning peat
C. polyspermum		+	
Cicuta virosa		+	
Cirsium arvense		+	
C. palustre		+	
C. setosum		+	
Comarum palustre	+	+	+
Crepis tectorum		+	
Dactylorhiza maculata	+		
Drosera rotundifolia	+	+	+
Dryopteris carthusiana		+	+
Eleocharis palustris		+	
Epilobium ciliatum	+	+	
E. hirsutum		+	
E. montanum		+	
E. palustre	+	+	
Equisetum arvense		+	
E. fluviatile	+		
Filipendula ulmaria		+	
Galeopsis bifida		+	
Galium mollugo	+	+	
G. palustre	+	+	+
G. trifidum		+	
G. uliginosum	+	+	+
Geum rivale		+	
Hieracium umbellatum		+	
Hippuris vulgaris	+		
Hydrocharis morsus-ranae		+	+
Iris pseudacorus	+	+	
Juncus conglomeratus	+	+	+
J. effusus		+	+
J. filiformis	+	+	
J. tenuis		+	
Lemna minor		+	+
Leontodon autumnalis		+	
Linaria vulgaris		+	
Luzula multiflora		+	
Lycopodium clavatum		+	
Lycopus europaeus	+	+	+

Species	Natural Mires	Disturbed peatlands	
		milled fields	quarries of winning peat
Lysimachia vulgaris	+	+	+
Lythrum salicaria	+	+	
Mentha arvensis		+	
Menyanthes trifoliata	+		
Myosotis cespitosa		+	
M. palustris		+	
Naumburgia thyrsiflora	+	+	+
Pedicularis palustris	+	+	
Persicaria lapathifolia		+	
P. maculata		+	
Potentilla erecta		+	
P. intermedia		+	
P. norvegica	+	+	
Ptarmica vulgaris		+	
Pteridium aquilinum		+	
Ranunculus acris		+	
R. flammula	+		
R. lingua	+	+	
R. repens		+	
R. sceleratus		+	
Rorippa palustris		+	
Rubus idaeus		+	
Rumex acetosa		+	
R. acetosella		+	
Scheuchzeria palustris	+		
Scutellaria galericulata	+	+	
Solanum dulcamara		+	
Spergularia rubra		+	
Stellaria graminea		+	
S. palustris	+	+	
Steris viscaria	+		
Taraxacum officinale		+	
Thelypteris palustris		+	+
Thyselium palustre	+	+	+
Trientalis europaea		+	
Typha angustifolia	+	+	+
T. latifolia		+	+
Urtica dioica		+	

Species	Natural Mires	Disturbed peatlands	
		milled fields	quarries of winning peat
Utricularia minor		+	+
U. vulgaris		+	
Verbascum thapsus		+	
Veronica chamaedrys		+	
V. officinalis		+	
V. scutellata	+		
V. serpyllifolia		+	
Viola palustris	+	+	
HEPATICAE			
Marchantia polymorpha	+	+	+
SPHAGNIDAE			
Sphagnum angustifolium	+	+	+
S. balticum	+	+	+
S. capillifolium	+	+	
S. centrale	+		+
S. compactum			+
S. contortum	+		
S. cuspidatum	+	+	+
S. fallax	+	+	+
S. fimbriatum	+	+	+
S. flexuosum	+		
S. fuscum	+		
S. magellanicum	+	+	+
S. majus	+		+
S. obtusum	+		
S. papillosum	+		+
S. platyphyllum		+	
S. riparium		+	+
S. rubellum	+		
S. russowii			+
S. squarrosum	+	+	+
S. subsecundum	+		+
BRYIDAE			
Atrichum tenellum		+	
Aulacomnim palustre	+	+	+
Brachythecium salebrosum		+	+
Bryum pseudotriquetrum	+		
Calliergon cordifolium	+	+	

Species	Natural Mires	Disturbed peatlands	
		milled fields	quarries of winning peat
C. giganteum	+		
C. stramineum	+	+	
Ceratodon purpureus		+	
Dicranella cerviculata		+	
Dicranum scoparium	+	+	+
Drepanocladus aduncus	+	+	
Funaria hygrometrica		+	
Leptobryum pyriforme		+	
Plagiomnium ellipticum	+		
Plagiothecium denticulatum	+		+
Pleurozium schreberi	+	+	+
Pohlia nutans	+	+	+
Polytrichum commune	+	+	+
P. juniperinum		+	+
P. longisetum		+	
P. piliferum		+	
P. strictum	+		+
Sanionia uncinata		+	+
Warnstorfia exannulata	+	+	
W. fluitans	+	+	
Warnstorfia pseudostraminea		+	



Management and monitoring of three Latvian raised bogs and a fen

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Introduction

Mires are an important part of Latvian landscape and comprise 4.9% of the total land area. Peat deposits, i.e. peatlands of more than 1 ha large and with more than 0.3 m peat, cover 10,4% of the land and include, next to mires with thick peat layers, also some forest types, drained mires, and peat extraction sites. Mires are distributed throughout the country but the area covered differs among the nature regions of Latvia (Pakalne & Kalnina 2000). The largest raised bogs occur in the East and Middle Latvia Lowland and North Vidzeme Lowland. Raised bogs are most widespread, although fens occur as well.

Due to drainage and peat extraction that was carried out in Latvia between 1930s and 1980s and still continues, half of the total area of mires in Latvia is influenced by human activities. Part of the previous intact mires that included raised bogs and fens have been replaced by peat fields, agriculture lands and forestry plantations. Also many sites are threatened by drainage, peat extraction and fires.Therefore, from 2004-2008 the LIFE project "Implementation of Mire Habitat Management Plan in Latvia" was carried out. Objectives of the project included active raised bog restoration measures implemented in the 3 project sites, habitat and hydrological monitoring to ensure the successful restoration activities of these Natura 2000 sites, and mire vegetation assessment in the intact parts of the raised bogs including labyrinths of bog pools and ridges.

The LIFE project includes management actions like building of dams in the drainage ditches and rising of the water level in the raised bogs, and management of fen habitats. Habitat and hydrological monitoring is carried out in all the project sites. The rising of water level in drained parts of mire ecosystem is one of the most effective management activity for mire restoration. For the management planning and control of the success of management, the hydrological characterisation of mires is needed. As classical tools can be the catchments approach, river regime and surface runoff description (Иванов 1975; Heikkilä & al. 2001). In connection with the assessment of the catchments response to drainage, there are a lot of projects dealing with eco-hydrology, estimation of ombrotrophy-minerotrophy conditions and the hydrotopographical mire classification (Sjörs 1948; Du Rietz 1954; Eurola 1962; Sallantaus 1984; Bragg & al. 1994; Sallantaus 1995; van der Schaaf 1999; Kennedy and Murphy 2004; Sallantaus 2006), as well as process-based work at a smaller scale combined with catchments, and hillslope-scale monitoring to examine the hydrological processes and the feedback mechanisms related to water quality and changes to soil properties (McDonald & al. 2003). The electrical conductivity and the temperature of the water are used to characterize the water movement through the peat layers, and trophic gradients in mires are constructed (Verhoeven & al. 1988; van Wirdum 1991).

Since the mire restoration projects were started, the water table monitoring and comparative studies between restored and intact sites of mires have taken place in different bogs of different parts of the world (Mawby 1995; Price 1997; Jauhiainen & al. 2002). Our study shows the response of the hydrological parameters, such as the water table, to the mire restoration.

Materials and methods

Study sites

The project includes 4 protected nature areas that are also Natura 2000 sites: Cena, Stikli, Klani and Veseta Floodplain Mires**.** Three of the sites include raised bogs; only Veseta Floodplain Mire has fens. The project sites are nationally and internationally important as they include habitats and species of EU Concern as well as protected habitats and species of Latvia. Cena Mire and Stikli Mires are included in the List of Important Bird Areas of Europe. The total area of the project sites is 10 808 ha.

Cena Mire Nature Reserve is located in the Coastal Lowland. It is a specially protected nature area with the total area of 2133 ha, established in 1999. It is also an Important Bird Area (IBA) with the total area of 2826 ha (Fig. 1). Geological studies reveal that Cena Mire has started to develop about 6000–6500 years ago. At present, the peat thickness can reach almost 6 m, but the mean thickness is about 3 m.

Figure 1. Cena Mire from the air (Photo M. Pakalne).

At the beginning of the 20th century activities were carried out for the drainage of Cena Mire and were followed by peat extraction in the drained areas. Before that Cena Mire was one of the largest raised bogs in Latvia with the total area of over 8500 ha. At present, only over 2000 ha are left, from which state protected area is 2133 ha. Drainage has caused the water table lowering, favoured forest growth and separated the bog area from the agricultural lands. In the drained areas, especially in the area close to the ditches, pine forest stands have established. The ditches in Cena Mire and marginal areas are mostly shallow (about 0.5 m). However, the net of the ditches is comparatively dense and causes peat compaction that does not allow the further growth of the mire in the marginal areas. The site borders with peat extraction fields that are a threat to the intact and protected part of Cena Mire.

Stikli Mire Nature Reserve is the largest raised bog complex in the West Latvia geobotanic District, protected area since 1977. It includes 5 raised bogs. The largest raised bog is Stikli Dizpurvs Mire with the total area of area of 724 ha. The others include - Vasenieki Mire (497 ha), Vanagu Mire (354 ha), Zvagulu Mire (244 ha) and Pumpuru Mire (283 ha).

During the 1970s, the western and northern part of the Vasenieki Mire in the Stikli Mires Nature Reserve was intensively drained for the planned peat extraction that was stopped when the nature reserve was established there in 1977. In Vasenieki Mire the drainage ditches are deeper than in the other sites, even up to 2-3 m (Fig. 2). Drainage ditches in Vasenieki Mire have damaged the mire hydrological regime as the water level has been lowered. The situation has now improved after building dams in the ditches.

Figure 2. A drainage ditch in Vasenieki Mire (Photo by G. Balodis).

Klani Mire Nature Reserve is situated in the Coastal Lowland geobotanical district, protected by the state since 1977. Klani Mire Nature Reserve with the total area of 1615 ha is located in about 9-12 km south from the coast of the Baltic Sea. The site includes also Klani Lake.

Before the establishment of the nature reserve, drainage was carried out in 1950s and 1960s in the area of Klani Mire. As a result, one of the raised bogs of Klani Nature Reserve (Dziru Mire) has transformed into a forest; at least 80 ha of the mire degraded. Nowadays, the runoff from drainage systems proceeds via a channel connecting Klani and Busnieki Lakes. During the 1920-30s, a canal was dug, which caused a lowering of the water level in Klani Lake and lake terrestrialisation. The old topographical maps show that natural water flow direction was north-oriented. Also the intact part of the bog is exposed to northwest direction. Some traces of old watercourse supplying the water from lake to drainage system can also be found in northern side of Klani Lake.

Figure 3. The new river bed of Veseta (Photo M. Pakalne).

Figure 4. The old river bed of Veseta River (Photo M. Pakalne).

Veseta Floodplain Mire Nature Reserve is a specially protected nature area since 1999 with a total area of 427 ha. The site is located in Central Latvia. The mire belongs to the territory of "Scientific Research Forests" directed by State Forest Service.

In 19th century, the natural Veseta River bed was changed in the area of Veseta Floodplain Mire. It caused the overgrowing of floodplains, transition mires and spring fens by shrubs and trees (Fig.3, 4). Also forest drainage was carried out in the area and outside. These activities do not have only a negative influence, as in the new part of the natural river meanders habitats of EU importance also occur. In the old river beds many protected species are known.

Management actions

During 2005, management plans were elaborated for Cena Mire, Stikli Mires, Klani Mire and Veseta Floodplain Nature Reserves (Silamikele 2006, Reriha 2006, Baronina 2006, Bambe 2005). The main management actions in the raised bog sites include maintenance of raised bogs without any disturbance to allow the natural processes to proceed in the area, as well as restoration of the degraded raised bog habitats and those influenced by drainage by raising of the water level and building of dams in the drainage ditches Prior to management actions hydrological studies were carried out as well as technical designs elaborated for the building of dams on the drainage ditches, as well as control of the functioning of the dams. Another important task is monitoring the effects of the management actions.

In the autumn 2006, in total 180 larger and smaller dams were made by excavator and hand work in Cena Mire (Fig. 5).

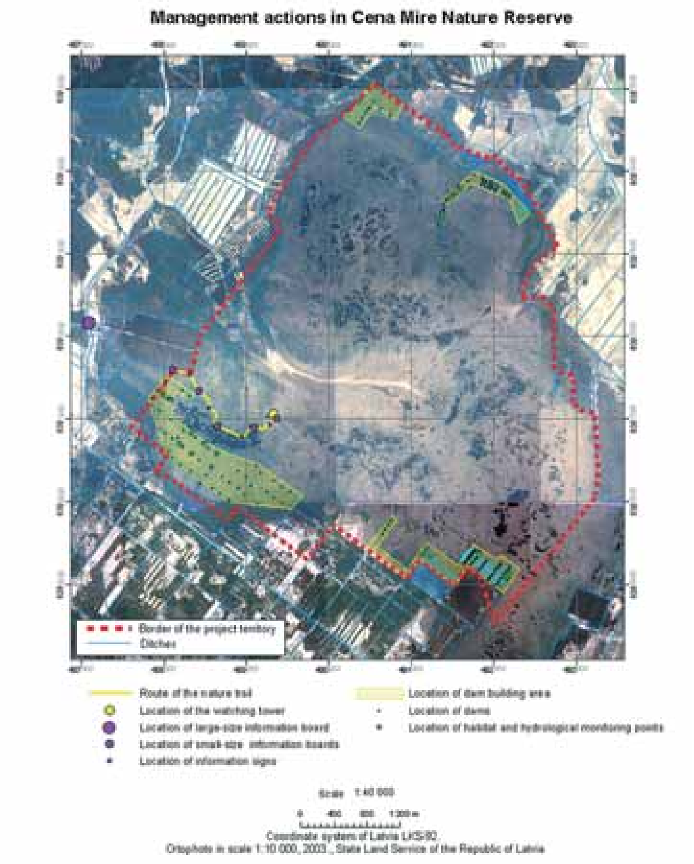

Figure 5. Management actions in Cena Mire

Figure 6. Building of dams in drainage ditches in Cena Mire (Photo M. Pakalne).

Figure 7. A dam in a drainage ditch in Vasenieki Mire (Photo M. Pakalne).

In June 2007, building of dams was started in Vasenieki Mire from Stikli Mires Nature Reserve and was completed by building 135 dams in Vasenieki Mire (Fig. 6, 7). Also in Klani Mire, 36 dams were built in the drainage ditches

Water table monitoring

In order to carry out the restoration of the active raised bog habitats in the drained parts of Cena Mire, Vasenieki Mire from Stikli Mire and Klani Mire, the raised bog hydrology was assessed. Hydrological studies were carried out in the areas where the dams were built. Estimation of groundwater flow directions in the raised bog was carried out by analyzing topographic maps and levelling of mire surface. For the measurements of elevations, a high accuracy Trimble GPS was used.

Figure 8. Water table monitoring wells in Cena Mire (Photo M. Pakalne).

In total, 227 water table observation wells were established. Out of them 101 were placed in Cena Mire, 25 in Stikli Mires, 28 in Klani Mire and 73 in Veseta Floodplain Mire. The perforated plastic tubes with lengths of 2 m and diameter of 10 cm were used as a material for the wells. Aerial photographs and GIS (Geographical Information Systems) for the site management were used as well.

For the characterization of the natural groundwater regime in Cena Mire, two transects of water table observation wells were made. In total, the water table measurement wells are placed in 8 transects. The two control transects are located in the northern part of the bog, in the intact and drained parts of Cena Mire. Transects of water table wells were installed in winter-spring season of 2005 comparably close (about 1 km) to each other. That allows the comparison of the fluctuations of water table (Fig. 8). The water table observation wells in the drained part of bog were installed on both sides of drainage ditches in the margin of the mire, and arranged in a line in east-west direction parallel to mire margin. The ditch is draining several connected bog pools and a lake. In the drained site, about 20 years ago there was a fire of several tens of hectares. In total, 10 water table observation wells were established perpendicular to the ditch flow direction (5 wells on each side of the ditch) at 10 m distance from each other. The water table observation wells in the intact part of the bog were placed near the northern raised bog dome of Cena Mire in the area of pool complex between the two raised bog pools. In total, there were 14 wells installed in a north-south directed transect, perpendicular to the bog margin with the distance of 10 m from each other.

The water table observation wells in Veseta Floodplain Mire were established in the shape of a transect across the Veseta River valley. The transect of wells crosses at least 4 different plant communities in the following order: transition mires and quaking bogs (7140), bog woodland (91D0) (dominant tree species *Pinus sylvestris* and *Betula pendula*), Fennoscandian deciduous swamp forests (9080*) (dominant tree species *Alnus glutinosa* and *Picea abies*, and the open reed field.

Vegetation studies and habitat monitoring

Vegetation studies were carried out both in the intact area of Cena Mire, Stikli Mires, Klani and also in the degraded habitats. Most detailed studies were carried out in Cena Mire Nature Reserve. To characterise the raised bog and fen vegetation in Cena Mire, a total 114 of relevès were randomly made. Vegetation relevés were described according to the Braun-Blanquet method. Vegetation studies were carried out in different mire types, which include raised bog, transitional mire vegetation adjacent the bog pools, and the transition mire vegetation placed in central part of Cena Mire. The descriptions of vegetation included the typical hollow-hummock vegetation, as well the habitats changed by the influence on hydrological regime, or fires. The size of plots is 1x1 m. For the characterization of vegetation gradients, data ordination programme DECORANA was applied using the programme package PC-ORD (Kent & Coker 1992).

To follow the effects of the management actions in all the project sites, vegetation monitoring plots were established. In the relevés all the plant species were registered and the projective coverage in percents was determined.

In 2005, a total of 130 permanent plots were established next to hydrological monitoring plots, in places where vegetation changes were most likely to occur after the management actions, which took take place in 2006. There are 38 monitoring plots in ditches in the raised bogs, 22 monitoring plots in raised bogs and 10 in the fen area. The number of permanent plots depends on the size of management area in each site. The monitoring scheme includes also control plots. There are 3-5 plots within the larger 10x10 m relevé. The wetness of the sites was recorded and it includes surface water evaluation; identification of adjacent pools and *Sphagnum* dominated vegetation.

Results and discussion

Vegetation studies

Cena Mire Nature Reserve
Vegetation studies reveal that Cena Mire includes raised bog vegetation of the classes Oxycocco-Sphagnetea and fen vegetation of the Scheuchzerio-Caricetea fuscae. The vegetation of the intact part of Cena Mire has a typical hummock - hollow complex and includes labyrinths of bog pools and ridges (Fig. 9). Bog pools have a concentric pattern and are located on both sides of the soak area that has transition mire vegetation. Cena Mire is surrounded by bog woodland and pine forests.

Cena Mire is a unique mire as it is one of the few raised bogs of Latvia that possess the features of the coastal raised bog type as it includes *Trichophorum cespitosum*, and also the features of the eastern bog type as it is a habitat for *Chamaedaphne calyculata*. Raised bog hummocks in Cena Mire are characterised by *Sphagnum* species: *Sphagnum fuscum, S. rubellum* and *S. magellanicum*, combined with *Polytrichum strictum, Oxycoccus palustris* and *Empetrum nigrum.* In some places also *Ledum palustre* occurs. There are hummocks and lawns dominated by *Sphagnum magellanicum.* On the raised bog margins there are hummocks with *Sphagnum fuscum* and *S. rubellum* accompanied by *Calluna vulgaris, Andromeda polifolia, Eriophorum vaginatum, Oxycoccus microcarpus, O. palustris, Drosera rotundifolia, Rubus chamaemorus* and *Empetrum nigrum..*

Figure 9. Raised bog pools in Cena Mire (Photo A. Indriksons).

In the hollows, the most common species are *Rhynchospora alba, Scheuchzeria palustris, Sphagnum flexuosum, S. cuspidatum* and *S. tenellum* accompanied by *Scheuchzeria palustris, Andromeda polifolia, Drosera anglica, D. rotundifolia, Oxycoccus palustris, O. microcarpus, Eriophorum vaginatum, Cladopodiella fluitans* and *Calypogeia sphagnicola.* On the margins of the labyrinths of raised bog pools, *Carex limosa, Rhynchospora alba, Warnstorfia fluitans* and *Sphagnum cuspidatum* occur.

The typical raised bog communities include Sphagnetum magellanici, Rhynchosporetum albae, as well as fen vegetation of Caricetum rostratae and Caricetum lasiocarpae.

Analysis of mire species and vegetation relevès applying DECORANA showed that the upper right corner of the diagram characterises the transition mire vegetation of Cena Mire but on the left side there are relevès characterising raised bog vegetation. A gradient from transition mire to raised bog vegetation can be observed from right to the left. On the left lower side raised bog hummock species have grouped (Fig. 10).

Cena Mire is the habitat for four protected vascular plant species of Latvia: *Betula nana*, *Dactylorhiza maculata*, *Trichophorum cespitosum* and *Eriophorum gracile,* and one bryophyte species, *Calypogeia sphagnicola*. The other rare bryophytes include *Sphagnum pulchrum* and *Splachnum ampullaceum.*

Cena Mire is of national and international importance as most of its area includes the active raised bog habitats (7110*) that is a priority habitat of EU Habitats Directive. Cena Mire is surrounded by bog woodland (91D0*), Skaists Lake and pine forests.

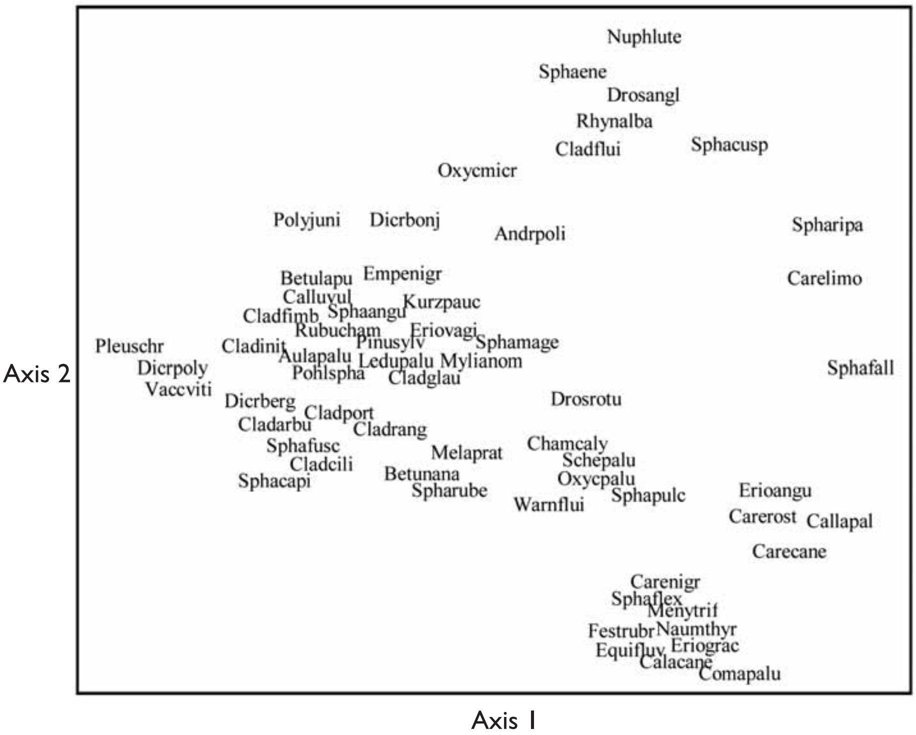

Figure 10. Species ordination of the relevès in Cena Mire

Stikli Mires Nature Reserve

The nature reserve includes 5 raised bogs, which have a typical hummock-hollow complex and the bog pool labyrinth as well as transition mire vegetation.

The Stikli Mires Nature Reserve is mostly open with sparse pine belts on the margins. The mosaic of mires with small lakes in their centre, surrounded by wet forests, has produced a large diversity of mire communities and species. The characteristic species of western bog types like *Trichophorum cespitosum* occur there. Bog hummocks are characterised by Empetro nigri–Sphagnetum fusci and Sphagnetum magellanici. In bog hollows, communities with Rhynchosporetum albae and Caricetum limosae occur. Transition mire vegetation covering rather significant areas in the marginal parts of Stikli Mires includes Caricetum rostratae. Small fen fragments with Caricetum lasiocarpae occur also on mire margins. In bog hollows, communities with Rhynchosporetum albae and Caricetum limosae occur (Pakalne & Kalnina, 2005). The rare bryophytes *Bryum cyclophyllum* and *Sphagnum lindbergii* grow in Stikli Mires.

The raised bog habitats belong to the vegetation Class Oxycocco-Sphagnetea but fen habitats to the Scheuchzerio-Caricetea fuscae. Forests include the habitats of the class of the boreal coniferous forests Vaccinio-Picetea.

Stikli Mires Nature Reserve comprises ten habitats of EC Habitats Directive including four priority habitats: active raised bog 7110*, bog woodland 91D0*, Western taiga 9010*, Alluvial forests with *Alnus glutnosa* and *Fraxinus excelsior (*Alno - Padion, Alnion incanae, Salicion albae*)* (9140*). The other habitats of EU importance include degraded raised bogs still capable of natural regeneration (7120), transition mires and quaking bogs (7140), depressions on peat substrates of the *Rhynchosporion* (7150), oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or Isoëto – Nanojuncetea (3130), natural eutrophic lakes with

Magnopotamion or Hydrochariton type vegetation (3150) and natural dystrophic lakes and ponds (3160).

Stikli Mires Nature Reserve includes raised bogs and small lakes that are the habitats for protected vascular plant species of Latvia, such as, *Lycopodiella inundata, Trichophorum cespitosum* and bryophytes *Sphagnum lindbergii, S. papillosum* and *Calypogeia sphagnicola.*

Klani Mires Nature Reserve includes 2 raised bogs (Klani Mire covers 442 ha, Punu Mire 325 ha), forests, meadows, rich and poor fens and Klani Lake (67 ha).

Klani Mires started to develop as a result of terrestrialization of Klani Lake about 6000 years ago after the regression of the Litorina Sea. At present, development of mire vegetation is still observed near Klani Lake where reed swamp and tall-sedge vegetation (Phragmitetum communis*)*, fen vegetation (Caricetum rostratae, Caricetum lasiocarpae) is present. Fen vegetation leads to raised bog communities, like Sphagnetum magellanici, Eriophoro-Trichophoretum cespitosi, Empetro nigri-Sphagnetum fusci and Rhynchosporetum albae.

On sandy shores of Klani Lake, plant communities with *Rhynchospora fusca* and *Eleocharis multicaulis* as well as *Lobelia dortmanna* are characteristic.

Klani Lake is the only locality of *Eleocharis multicaulis* in Latvia and one of the five of *Rhynchospora fusca*. *Eleocharis multicaulis* forms also mono-dominant growths near Klani Lake. Also *Myrica gale, Lythrum salicaria* and *Carex lasiocarpa* occur on lake shore.

The raised bog vegetation is characterized by bog pools and hollows. On raised-bog hummocks *Calluna vulgaris, Ledum palustre, Rubus chamaemorus, Eriophorum vaginatum, Empetrum nigrum, Oxycoccus palustris* and *Drosera rotundifolia* occur in the herb layer. *Sphagnum magellanicum, S. rubellum* and *S. fuscum* are the most common bryophytes. The other species on hummocks include *Dicranum affine, Pleurozium schreberi, Mylia anomala, Calypogeia sphagnicola, Kurzia pauciflora* and *Pohlia sphagnicola.* In hollows, *Rhynchopora alba, Andromeda polifolia, Oxycoccus palustris* and *Drosera anglica* appear, while in the bryophyte layer *Sphagnum cuspidatum, S. flexuosum* and *Cladopodiella fluitans* are common.

Klani Lake is characterised by a high habitat and species diversity. Terrestrialization of Klani Lake still takes place especially in the western part where transition mires and quaking bogs (7140) have developed. There are known over 530 vascular and 158 bryophyte species (Baronina 2006).

In total, 9 habitats of Habitats Directive Annex I (from them 4 are priority habitats (7110*, 9080*, 91D0*, 9010*) and 10 protected habitats of Latvia were found in the site. Active raised bogs cover about 25 % of the total area. Still, due to the drainage of the raised bog, vegetation has become degraded, especially near the ditches. Special value have the Fennoscandian deciduous swamp forests (9080*) as well as bog woodland (91D0*). An outstanding value has Klani Lake, where the habitat of EU concern Oligotrophic to mesotrophic standing waters with vegetation of the *Liitorelletea uniflorae* and/or *Isoëto-Nanojuncetea* (3130) with *Lobelia dortmanna* and *Myriophyllum alterniflotum* occurs. Here also the increase of rare and protected plant species, such as, *Lobelia dortmanna, Eleocharis multicaulis* and *Rhynchospora fusca* was observed. The territory includes also forest openings where 2 habitats of EU importance were found (6410, 6210).

In the Klani Mires Nature Reserve protected habitats of Latvia include stands with *Myrica gale*, calcareous fens with *Schoenus ferrugineus*, plant communities with *Lobelia dortmanna* and *Isoëtes* spp., lake shore communities with *Eleocharis multicaulis, Rhynchospora fusca* and *Myrica gale*, stands with *Nuphar pumila,* wide, not overgrowing lake shore, sandy shore ground in lakes and *Molinia meadows.*

Veseta River Floodplain Mire Nature Reserve

The site is one of the most valuable transition mire habitats in the Eastern Latvia, and it holds six plant species for which micro-reserves must be established: *Carex atherodes*, *Carex paupercula*, *Dactylorhiza russowii*, *Corallorhiza trifida*, *Trichocolea tomentella* and *Geocalyx graveolens* (Bambe 2005).

Veseta River Floodplain Mire is one of the most valuable sites in Latvia as it includes transition mires and quaking bogs (7140), Fennoscandian mineral-rich springs and spring fens (7160), as well as species of EU Habitats Directive *Saxifraga hirculus* and *Hamatocaulis vernicosus.* The peat depth of the site reaches 5 meters.

Veseta River Floodplain Mire includes the protected mire habitat of Latvia: oligotrohic springs poor in lime. Transition mires and quaking bogs (7140) belong to the vegetation class Scheuchzerio-Cariceta fuscae.

In total, eight habitats of Habitats Directive Annex I and three protected habitats of Latvia are known in the Project site. Out of them, three are priority habitats (91D0*, 9080*, 9010*). The most valuable habitat here are spring fens, although forests, transition mires (7140) and floodplain meadows occur as well. The area includes two priority habitats Bog woodland (91D0*) and alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior (*Alno-Padion, Alnion incanae, Salicion albae*)* (9140*) .

There are known 12 plant species protected by the Law "On the Protection of Species and Habitats" (2000) in the Veseta River Floodplain Mire. The flora includes seven protected vascular plant species, such as *Corallorhiza trifida, Saxifraga hirculus, Dactylorhiza russowii, Gymnadenia conopsea, Hammarbya paludosa, Carex atherodes* and *C. paupercula,* and five protected bryophytes: *Geocalyx graveolens, Hamatocaulis vernicosus, Lophozia rutheana, Paludella squarrosa* and *Trichocolea tomentella* (Bambe 2005).

In the territory, 18 protected vascular plant species and 10 protected bryophyte species were discovered, but the total number of vascular plants reaches 325 species and 112 bryophytes (Bambe 2005).

Hydrology of Cena Mire, Klani Mire, Vasenieki Mire and Veseta Floodplain Mire

The fieldwork to evaluate the hydrology of the project sites was started in late 2004. Maps of water flow directions were prepared.

Cena Mire Nature Reserve is surrounded by large drainage ditches that do not allow the further growth of the mire. The raised bog habitats in the margins are influenced by drainage and peat extraction and are degraded, but the central part of this raised bog acts like a sponge accumulating large amount of water in its body. There are more than 140 larger raised bog pools with a depth of 3 m (with an area more than one hectare) and also *Skaists* Lake with an area of 18.5 hectares. The watershed crossing Cena Mire has a semicircle-shaped form dividing the water flowing in north direc-

Figure 11. The flooded area with water table monitoring wells in Cena Mire after the building of dams (Photo A. Indriksons).

tion to Nerina and Dzilnupe Rivers; in west direction to Miglupite and Cena Rivers and south-east direction to Misa River. Historically, the flat land surface around the Mire has been favouring the bog expansion, the intensity of which can reach 10 m per year under natural conditions. However, digging of the ditches around the raised bog area has stopped the further growth of the mire. The length of natural slopes from bog centre to the margins in Cena Mire is between 1 and 2 km. The largest height difference between bog dome and margins is 7 m, but in average 3m. Since July, 2005, the surface height measurements using the Trimble GPS two-frequency equipment were carried out. The purpose of those measurements was to construct the 100 x 100 m grid for the estimation of the water flow directions.

In September and October, 2006 building of dams on the drainage ditches in Cena Mire was performed. Also in the beginning of October 2006 seven hand-made dams were established in the above-mentioned ditches that were draining the raised bog pools and Skaists Lake. The main aim of dam building was the rising of the water table and decreasing the surface run-off in the drained part of bog.

Before the dam building from January of 2005 till October 2006, the average water table in the intact site of bog was 8.6 cm and in the drained site 23.7 cm below the bog surface (Fig. 11, 12. Table 1**)**. Thus, in average, in the drained site it was at 15.1 cm or 2.8 times lower than in intact part. In the observation period after the dam building in Cena Mire the water table in the intact site of bog was 5.8 cm, and in drained site 9.7 cm below the mire surface, in average just only 3.9 cm or 1.7 times lower. The data shows that the water table differences after the dam building between the both sites have been decreased remarkably and can be considered as non-significant at present in the area where dams were built. The water table difference between the intact and drained parts of the bog has decreased by six times. In some observations days,

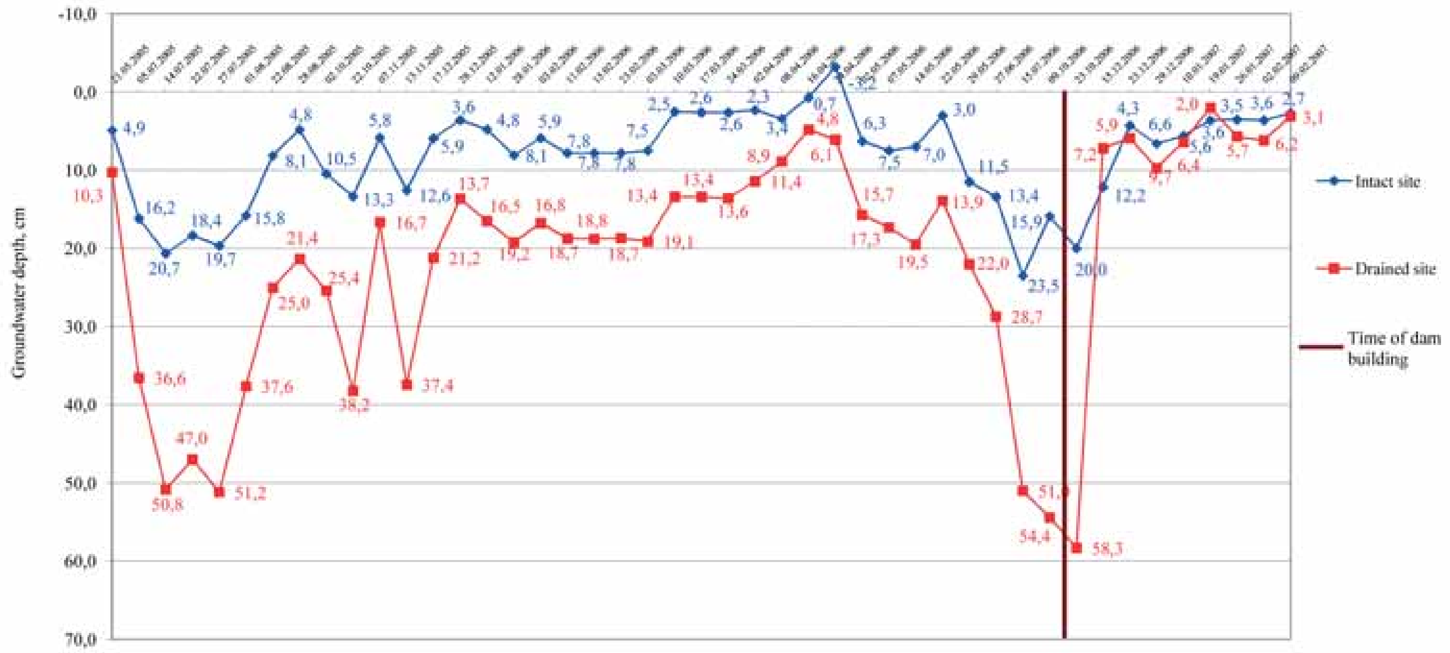

Figure 12. Fluctuation of water table in Cena Mire

thanks to the water rise in the dam areas, the water table in the former drained part was even higher. The dam building has reduced the range of water table fluctuations. Similar conclusions were obtained also in other studies (Lindholm & Markkula 1984).

The water table in the bog depends mostly on the meteorological conditions, the amount of precipitation and temperature. The incoming part of water balance in the raised bog depends only on the amount of atmospheric precipitations, but the outcoming part, mostly, on evapotranspiration, which is directly depends on air temperature, and from the bog is even higher than from open water surface. During the separate seasons, those parameters are different. Therefore, it is reasonable to compare the average values of water table in seasons of winter, spring, summer and autumn. The division of the year in seasons in hydrology is following: winter (January, February, March), spring (April, May, June), summer (July, August, September), and autumn (October, November, December). Also by analysing the average values of the water table, the periods before and after the dam building have to be analysed separately.

In the spring season before the dam building, the water table in the intact site was at an average 5.2 cm below the bog surface, but in the drained site 14.4 cm, 9.2 cm or 2.8 times lower. The spring season, especially, the middle and end of April is characterised by the highest water table in the bog. In some places of the intact part of the bog, the water level even exceeds the bog surface. For the present, we do not have data about the spring season after the dam building in Cena Mire.

The summer season is characterised by the lowest water table during the year, especially in the years with a small amount of precipitation. It can be explained by the intensive evaporation. The lower values of water table during the summer in the intact site of bog are close to 30 cm, but in drained sites even to the depth of 100 cm. In the summer season before the dam building, the depth of water table in the intact site of bog was 15.9 cm, but in a drained site 40.1 cm. Thus, the difference between the water table levels was 24.2 cm or 2.5 times.

Table 1. The average values of the groundwater level in monitoring sites. Negative values indicate water table above the soil surface.

Site	**Monitoring area in the mire**	**Average water table, cm**				
		Winter	Spring	Summer	Autumn	Average
Cena Mire before the dam building	Intact site	5.7	5.2	15.9	9.7	8.6
	Drained site	16.8	14.4	40.1	29.6	23.7
Cena Mire after the dam building	Intact site	3.3			10.8	5.8
	Drained site	4.5			20.3	9.7
Klani Mire	Intact site	-3.4		14.1	-0.8	1.6
	Drained site	27.6		54.8	26.8	33.9
Vasenieki Mire	100m between the ditches	39.8	46.3	86.0	32.3	48.7
	20 m between the ditches	51.9	52.0	73.8	40.8	53.8
Veseta Floodplain Mire	Transitional mire	5.8	7.3	19.8		8.3
	Caricoso-phragmitosa forest site type	-1.4	6.3	27.0		5.4
	Dryopterioso-caricosa forest site type	-17.4	-7.3	15.2		-9.0
	Open reed field	-19.5	-2.6	39.4		-5.0
	Average	-12.9	-1.3	28.6		-2.8

In the autumn season, especially after the dry summer, the water table in the bog stays low for a long time, in the intact part, during the observed season 20 cm deep, but in the drained part even to 60 cm and deeper. Therefore, the differences between the absolute values of water table levels are larger. Before the dam building, in the intact site of bog the water table level was 9.7 cm, but in drained site of bog 29.6 cm. The difference between the water table levels between the both sites was 19.9 cm or 3.05 times. After the dam building, in the intact site of bog, the water table level was at an average 10.8 cm, but in the drained site of bog 20.3 cm. Thus, the difference was 9.2 cm or 1.9 times. It means that the dam building has reduced the difference of water table levels between both sites in autumn season.

In the winter season, before the dam building, in the intact site of bog the water table level was at an average 5.7 cm, but in the drained site of bog 16.8 cm, or 11.1 cm lower. After the dam building, in winter season in the intact part of bog the water table was 3.3 cm below the bog surface, but in the drained part just only 4.5 cm below the bog surface. The difference was only 1.2 cm. Thus, we can to conclude that the dam building has reduced the difference between the water table levels in winter season. The water rising effect has drawn the water level in winter closer to the flood period of the spring. Similar results were found in the other studies (Mawby, 1995; Price,

Figure 13. Fluctuation of the water table in Klani Mire

1997). After the ditch blockage, the drained peat water levels did not fall back to the minimum levels experienced in previous years. However, the water table level recession was still much faster and greater than in an intact site.

In Klani and Vasenieki Mires building of dams has been carried out only recently in 2007. Therefore, the water table monitoring has been made, for the estimation of background stage of the water table level in dam building places and for comparison of this with intact site of bog.

In the **Klani Mire Nature Reserve** the water table level was monitored by using 11 water table observation wells in the intact site, placed in centre of bog, and in 8 water table wells, placed near to drainage ditches. At an average, in the entire observation period from February 2006 till March of 2007, the water table level in the intact site of bog was 1.6 cm, but in drained site 33.9 cm (Fig. 13). The difference between both sites was at an average 32.3 cm. For the present, the data about the spring season are lacking, which can change this relation.

In the winter season, in the intact site of the bog, the water table level was at an average 3.4 cm above the bog surface, but in drained site 27.6 cm below the bog surface. The difference between the water table levels was 31 cm.

In the summer season, in the intact site of bog, the water table level was 14.1 cm below the bog surface, but in drained site 54.8 cm. The difference was 40.1 cm.

In the autumn season, in the intact site of bog, the water table was at an average 0.8 cm above the bog surface, but in drained site 26.8 cm below the bog surface.

Vasenieki Mire in Stikli Mires Nature Reserve is a raised bog where the building of dams on the drainage ditches was carried out in June 2007. Hydrological studies were carried out there as well. The central part Vasenieki Mire includes also intact raised bog vegetation. The round-shaped raised bog ecosystem in its intact area is

Figure 14. Water table monitoring wells and habitat monitoring relevés in Vasenieki Mire (Photo M. Pakalne).

highly water saturated; especially wet is the northern part of the raised bog. The highest dome is placed in the central part of the raised bog. The medium size and smaller pools are distributed as a circle around the dome. The peat layer thickness at an average varies between 2 and 3 m. Under the peat layer, on the bottom of the raised bog, sand, loamy sand and clay is found. Therefore, certain possibilities for water movement via the border horizon between mineral and peat layers exist, as is observed it in the drainage ditches. The natural water flow follows the west direction. There is alsoa forested depression with a natural rivulet. The flow in drainage systems also follows the west direction. Beaver, the role of which for bog hydrology is still not fully studied, mostly blocks drainage ditches.

In Vasenieki Mire, the water table level was analysed by a comparison of the intensive and less intensive drained areas of the bog. There was measurement of the average water table level in 15 wells, placed in the shape of a transect between 100 m distant drainage ditches, and in 10 wells, placed in the shape of a transect between the 20 m distant ditches obtained, which indicates the impact of different drainage intensity on the water table. At an average, in the entire observation period, the water table level between the 100 m distant drainage ditches was 48.7 cm, but in the area with more intensive degree of drainage (distance between the ditches 20 m) 53.8 cm (Fig. 14 15. Table 1). The drainage ditches of the Vasenieki Mire differ from the other project bogs with larger dimensions and depth. In the margins of the mire they are going till the mineral bottom of the bog. Therefore, the water table levels are deep. In general, the difference between the both sites is not big, but it depends on the peculiarities of groundwater regime in separate seasons of the year. In winter, spring and autumn, the water table level is higher in less intensive drained area with bigger distance between the ditches. However, in the hot and dry summer of 2006, an opposite trend was observed. The water table was higher in the more intensive drained area, but in the site with the 100 m spaced ditches it decreased, at an average, even till 95 cm below the bog surface. It is partly explainable by the situation, that the investigated area with the bigger distance between the ditches is located closer to the bog margin

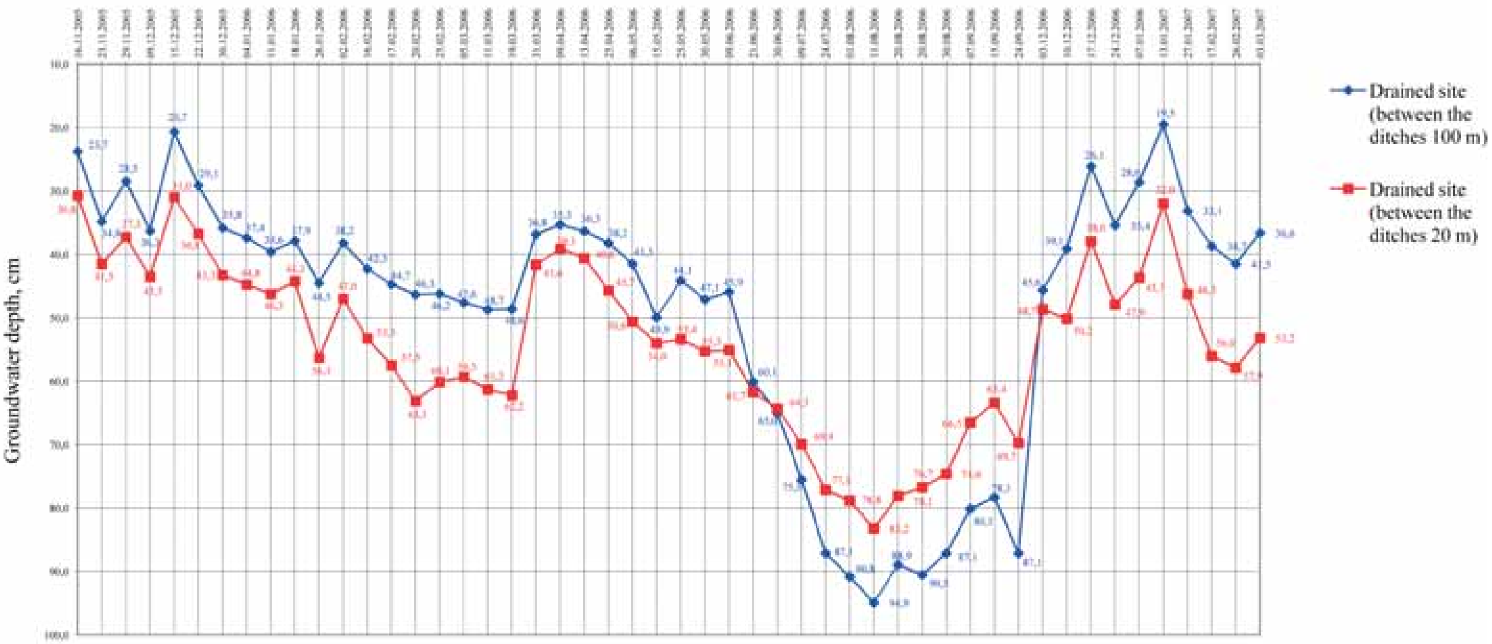

Figure 15. Fluctuation of water table in Vasenieki Mire

and is bordering with the contour ditch, but the area with the more intensive ditch network is located closer to the bog centre.

The spring season in Vasenieki Mire, similarly as in Cena Mire, characterises the almost smallest water table level difference between the investigated sites with different drainage intensity. In the site with the 100 m distant ditches, the water table level was 46.3 cm, but in site with 20 m distant ditches it was 52 cm.

However, in the summer season, the water table level was lower in the less intensively drained area, but it is, possibly, connected with the specific site peculiarities. In the site with the 100 m distant ditches, the water table level was 86 cm, but, in site with the 20 m distant ditches, it was 73.8 cm.

In the autumn season, again, the water table is higher in the less intensively drained area. In the site with 100 m distant ditches, the water table level was 32.3 cm, but, in the site with the 20 m distant ditches, it was 40.8 cm.

In the winter season, the differences between the water table levels were similar to the autumn season, only the absolute value of the difference is bigger. In the site with the 100 m distant ditches, the water table level was 39.8 cm, but, in the site with the 20 m distant ditches, it was 51.9 cm.

The monitoring of water table fluctuations was continued also in 2007 to bring new significant knowledge about the background indices of groundwater regime and the efficiency of dam building.

Since 1960s, numerous hydrological investigations were carried out in **Veseta Floodplain Mire area**, but mainly outside the present protected nature area. The floodplain as such, is influenced by river processes and has a special water flow regime. Both banks of the floodplain area are steep and project in the surrounding relief. During the last centuries Veseta River has been used also for floating of timber. At the end of

Figure 16. Water table monitoring wells in Veseta Floodplain Mire (Photo M. Pakalne).

the 19th century, the river was straightened for the timber floating purpose. An artificial island between the new and old riverbeds was established. On the banks of the old riverbed, tall-sedge fen and reed vegetation has developed. Veseta River has, at least, 5 riverbeds. The water has surface runoff over the entire river valley. In spring the water is almost totally covering the valley surface. On the left side of river, there is transition mire and spring fen vegetation with a high number of endangered plant and bryophyte species. The water level in river and groundwater regime is important for the successful management of the area. Beaver has a considerably high impact on the floodplain water regime.

The most minimal water table fluctuations are in the transition mire area (Fig. 16, 17, Table 1)**.** The average water table level there is 8.3 cm. The mire ecosystem keeps the water level stable all the year. The water level is significantly lower only during the drought period of summer. In the dry summer of 2006 it was 27.3 cm. During the spring and winter seasons, the water table level never exceeds mire surface, most likely, because of enhanced water evaporation and the hypsometrically higher placement of the mire surface in comparison with the rest of valley. In the spring, the water table is at the depth of 7.3 cm and in winter, at an average, in the depth of 5.8 cm. For the present, we do not have data about the water table in the autumn season in Veseta Floodplain.

MireThe highest water table fluctuations and range between the minimal and maximal values are obtained in the open area in the middle of the valley, overgrown with reed. The maximal values were obtained during the winter of 2007; in the period without snow cover in January, when the water table level was, at an average, 32.5 cm over the soil surface. In the dry summer of 2006, the water table level in July reached 51.0 cm below the soil surface. The sharp fluctuations of water table can be explained by the water level and discharge in Veseta River and the filtration properties of the sandy bottom of the floodplain. At an average, during the entire observation period from March, 2006 till March, 2007, the water table in the open reed field was 5.0 cm over the soil surface. In the spring season, the water table was, at an average, 2.6 cm

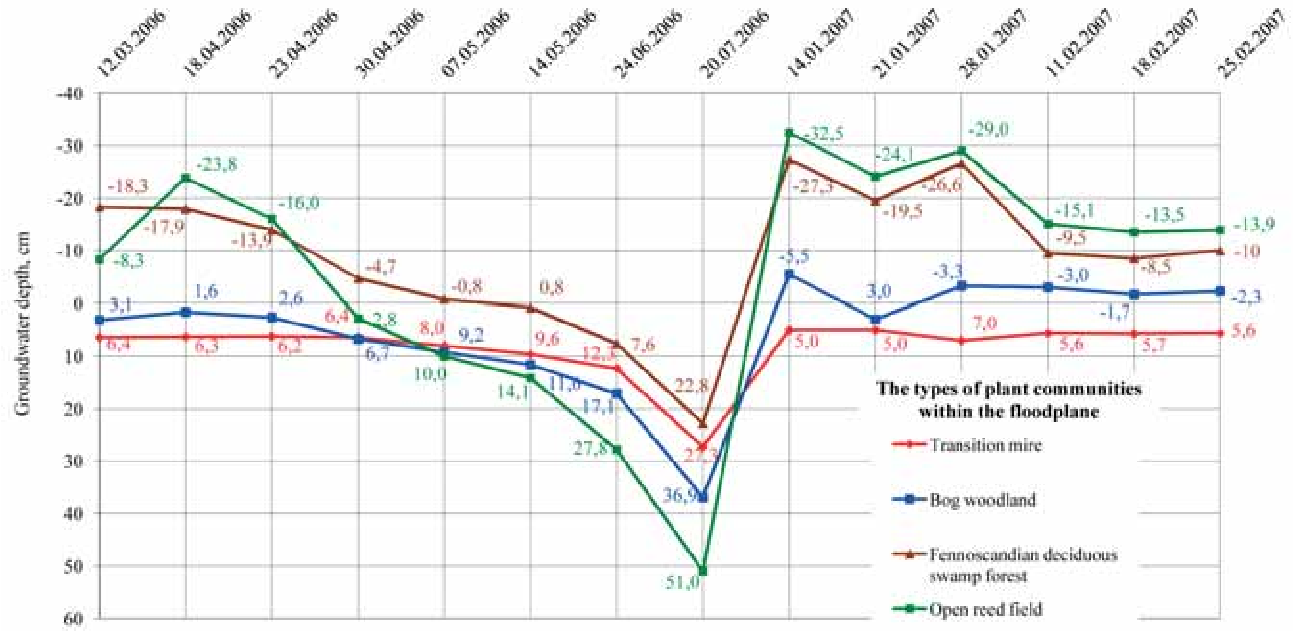

Fig. 17. Fluctuation of water table in Veseta Floodplain Mire

over the soil surface. In the summer, the average values were in the depth of 39.4 cm, but in winter 19.5 cm above the soil surface. The Veseta floodplain in winter seems like frozen water body.

Sharp water table fluctuations were observed also in deciduous swamp forest, where the average annual water table level is 9 cm above the soil surface. In the winter it reaches 17.4 cm, but in spring 7.3 cm above the soil surface. In the summer, the water table level is 15.2 cm below the soil surface. In bog woodland, being placed between transition mire and deciduous swamp forest, the water table fluctuations are larger than in the transition mire, but smaller than in the deciduous swamp forest and in open reed field. At an average, the annual water table level there was 5.4 cm below the soil surface. In spring season, the groundwater level was in the depth of 6.3 cm, in summer season 27.0 cm deep, but in winter 1.4 cm above the soil surface. The mineral soil there is covered by *Sphagnum* and reed peat.

The results of the first year observations suggest that the forest canopy detains the evaporation in the dry summer days. The soils of open reed fields in Veseta floodplain in the summer are dry places in the river valley, whereas, in winter and in wet periods in general, the most wet places. During the hot and dry summer, the water level is most shallow in the deciduous swamp forest, where, possibly, the confined aquifer water discharges and the water level is kept by beaver.

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The Origin, Development, and Modern State of Karst Mires in the Tula Region of Russia

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Introduction

Tula region is located in the center of the Russian Plain, between the heads of the rivers Don and Oka, on the boundary of the coniferous-deciduous forest, deciduous forest, and forest-steppe vegetation zones. According to N.Ya. Katz (Кац, 1971), the Tula region is located between the Moskovsko-Verhnedneprovskaya province of coniferous-deciduous forest and eutrophic and oligotrophic pine-sphagnum mires, and the Verhne-Donskaya province of forest-steppe and reed and big sedge mires. It means that the territory is characterized by different types of mires.

Climatic, geomorphological, geological, and hydrological features of the region do not promote mire formation, and the level of paludification is low in Tula region (Дымов и др., 2000).

During the years of 2000-2005, about 200 mires of all types were found and studied in this region. They differ in location, relief, geology of the depression's floor, hydrologic regime, mire vegetation, and the structure of the peat deposit. The total surface area of all types of mires is 1590 ha, which is 0.07% of the land of the Tula region (Волкова и др., 2003). Karst mires are present in different parts of the region, but they are more typical in the deciduous forest vegetation zone. All together, karst mires comprise 35% of the total number of all mires, but their total surface area is a small, about 60 ha (3.7% of the total surface area of all mires).

Based on their occurrence in karst depressions (sinkholes), karst mires have been named gap or funnel mires because they usually develop in deep, funnel-shaped, depressions (Пьявченко, 1958). Development of this type of relief in Tula region depends on the dissolution by groundwater of limestone and gypsum in Carboniferous and Devonian bedrock. This bedrock is usually covered by Jurassic and Holocene sand-clay deposits (Чикишев, 1978). In this case, dissolution results in a cavern with a bedrock roof which eventually collapses to form a sinkhole. Usually such karst depressions on the surface are comparatively deep (up to 10 meters or more, measured from the top of the depression's rim to the deepest part of its surface floor) and have a round or elliptical surface shape. These karst depressions occur in two types:

1. Dry depressions (with a water drainage system, and therefore no water accumulates on the sinkhole's surface)

2. Wet depressions (with little or no drainage system, so water collects on the surface to form lakes and mires)

The paludification of karst depressions depends on the presence of a relatively waterproof layer of clay on the floor of the depression (which prevents or greatly reduces downward drainage of water) and on the lack of a good lateral drainage system as well. For these reasons, the depressions may retain ground and surface waters. The volume of water may vary because some of the water evaporates, and some drains along the surface and even to the ground water. Therefore, karst depressions may contain different volumes of water and may paludify in several ways.

Materials and methods

In Tula region, several complexes of karst mires were found and studied during 2000-2005. This paper will show the results of the investigations of some of these mires, specifically (Fig. 1): near Ozerniy village (5 mires), Rvy village (1), Kochaki village (1), the natural reserve Yasnaya Polyana (2) and the area around it (1), and Lipki village (1). For each mire, the vegetation was described (Лавренко & Корчагин, 1964), the depth of the peat deposits were measured, and peat samples were collected from the deepest point for macrofossil analysis (Тюремнов, 1959). All this information and analyses were used to reconstruct the history of paludification for each mire.

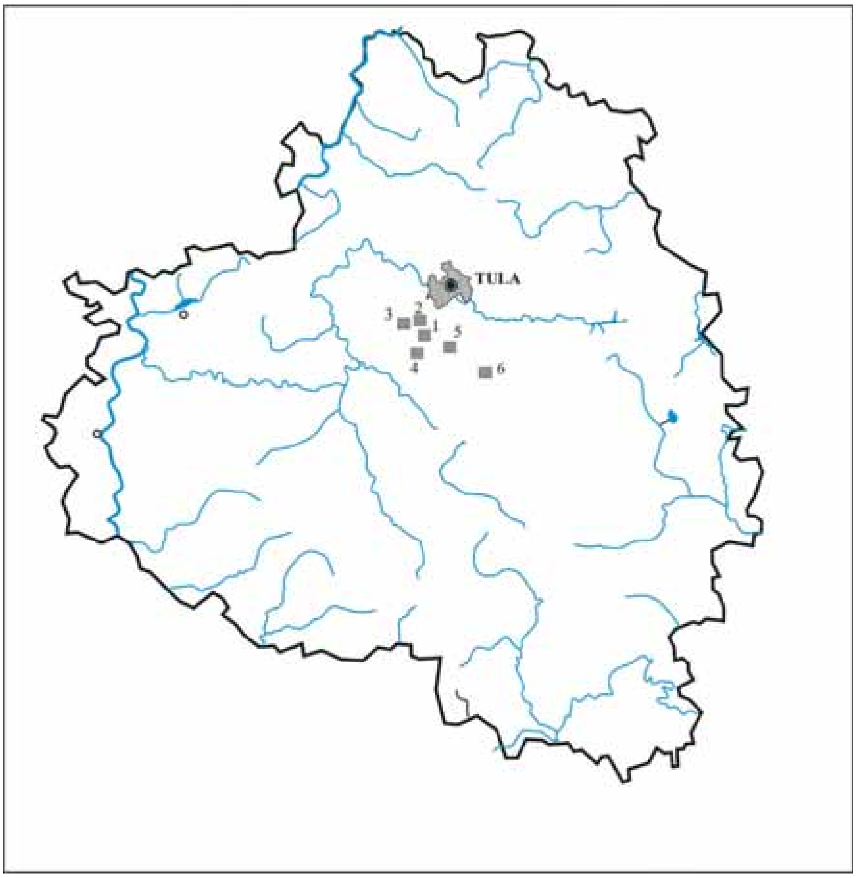

Figure 1. Locations of karst mires mentioned in this paper.
1. Near Yasnaya Polyana; 2. Natural reserve Yasnaya Polyana (mires Istochek and Volkoboinya); 3. Rvy village; 4. Kochaki village; 5. Ozerniy village (mires Chernool'shanik, Bol'shoye, Lubimoe, Glavnoye, and Voronka); 6. Lipki village

Results and discussion

Wet karst depressions in Tula region form funnel mires that range in depth from comparatively shallow (usually less than 1 meter) to relatively deep (up to 10 meters or more), and may contain different volumes of water. The results of the description of these sinkhole mires shows that paludification of wet karst depressions may develop in four ways, depending on the depth of the funnel mires.

Surface paludification of shallow karst mires

The shallowest karst depression with the thinnest peat deposit was found near Yasnaya Polyana. It is of round shape and occupies 0.03 ha. Its vegetation is of the communities Salix cinerea-Scirpus sylvaticus and Salix cinerea-Athyrium filix-femina+Dryopteris carthusiana. Its peat deposit is 30 cm of wood-sedge eutrophic peat (with *Betula* sp., *Salix cinerea*, *Carex cespitosa* and *C. vesicaria*) that shows the beginning of paludification by trees and herbs, which grew in wet conditions (Fig. 2A).

A wide and flat karst depression (0.5 ha) was found near Rvy village. Its maximum depth is 70 cm. The community Betula pubescens-Carex vesicaria+C. riparia dominates the vegetation. The mire's micro-relief is a combination of birch hummocks with *Sphagnum* mosses (*S. squarrosum, S. fallax*) and wet depressions with sedges (*Carex vesicaria, C. riparia)*. The peat deposit is 70 cm deep. The deposit was formed by wood-sedges, and woody and herbal eutrophic peats (Fig. 2B). The structure of the peat deposit shows that the formation of the mire began from a herbal community (*Calla palustris, Naumburgia thyrsiflora, Carex riparia, C. vesicaria, C. acuta*), but this stage did not last a long time, because the herbal peat formed only the bottom 20 cm of the whole peat deposit. Later, trees (*Betula* sp., *Salix cinerea*) grew on this peat layer, and they eventually formed the overlying layer of woody and wood-sedges peat.

The same type of depression was found on the land of Yasnaya Polyana. The mire Volkoboinya is located in a 90 cm deep depression. The mire has a surface area of 0.25 ha, and it is characterized by an intensive surface water flow. In the central part of the mire the vegetation community Salix cinerea-Menyanthes trifoliata+Calla palustris-Sphagnum squarrosum is present, but along the edges the community dominated by *Scirpus sylvaticus.*

The formation of the mire began on the bottom of the depression from the willow-herbal community located in the central part (Fig. 2C). Later the willows died out, but flowing surface water allowed the eutrophic herbal community (*Menyanthes trifoliata*) to remain and formed herbal peat. But at the depth of 70 cm, this peat changed to birch peat, which is 30 cm thick. This shows the invasion of birch to the mire and the existence of the birch community for a long time. Later, the abundance of trees decreased, indicated by the change from birch peat to herbal peat and then (on top) to *Sphagnum* peat.

Therefore, shallow karst depressions (less than 1 m) are characterized by peat formation on the surface of the sinkhole floor (Fig. 3). The first stages of paludification have the communities of trees (willow, birch) and herbs in wet conditions. Sometimes the vegetation changes to the *Sphagnum* stage (mosses begin to grow on birch hummocks). The stages of community succession are: Salix cinerea–Carex vesicaria+C. riparia ➨ Betula alba–Carex vesicaria or Salix cinerea–Calla palustris+Scirpus sylvestris ➨ Betula alba–Menyanthes trifoliata ➨ Betula alba–Menyanthes trifoliata–Sphagnum squarrosum

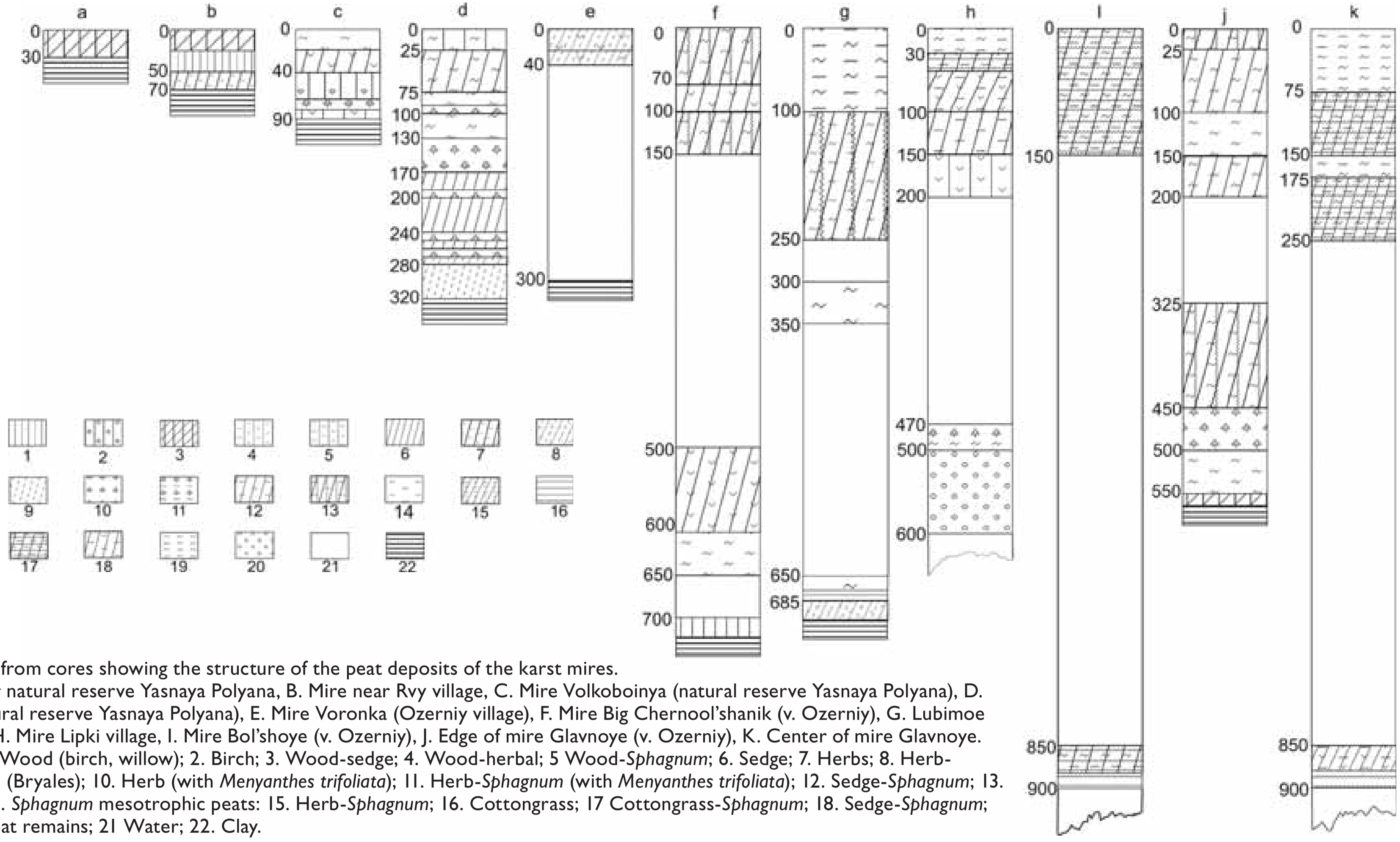

Fig.ure 2. Columns from cores showing the structure of the peat deposits of the karst mires.
Mires: A. Mire near natural reserve Yasnaya Polyana, B. Mire near Rvy village, C. Mire Volkoboinya (natural reserve Yasnaya Polyana), D. Mire Istochek (natural reserve Yasnaya Polyana), E. Mire Voronka (Ozerniy village), F. Mire Big Chernool'shanik (v. Ozerniy), G. Lubimoe mire (v. Ozerniy), H. Mire Lipki village, I. Mire Bol'shoye (v. Ozerniy), J. Edge of mire Glavnoye (v. Ozerniy), K. Center of mire Glavnoye.
Eutrophic peats: 1. Wood (birch, willow); 2. Birch; 3. Wood-sedge; 4. Wood-herbal; 5 Wood-*Sphagnum*; 6. Sedge; 7. Herbs; 8. Herb-*Hypnum*; 9. *Hypnum* (Bryales); 10. Herb (with *Menyanthes trifoliata*); 11. Herb-*Sphagnum* (with *Menyanthes trifoliata*); 12. Sedge-*Sphagnum*; 13. Herb-*Sphagnum*; 14. *Sphagnum* mesotrophic peats: 15. Herb-*Sphagnum*; 16. Cottongrass; 17 Cottongrass-*Sphagnum*; 18. Sedge-*Sphagnum*; 19 *Sphagnum;* 20 Peat remains; 21 Water; 22. Clay.

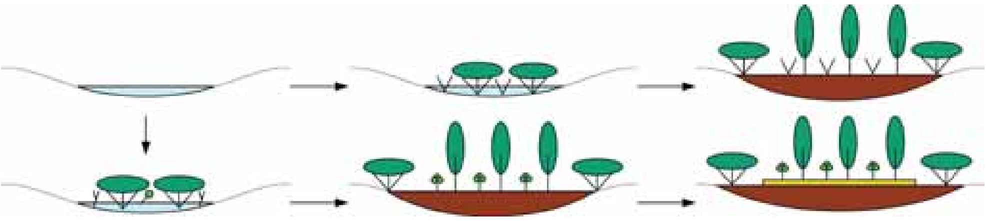

Figure 3. Paludification of shallow karst depressions with low and variably sloping sidewalls and at most a small amount of water.

Explanations for Figures 3, 4, 5, and 7:
1. Betula pubescens, 2. Alnus glutinosa, 3. Salix cinerea, 4. Scirpus sylvaticus, 5. Carex vesicaria+C. riparia, 6. Carex rostrata+C. lasiocarpa, 7. Rhynchospora alba, 8. Eriophorum vaginatum, 9. Menyanthes trifoliata, 10. Calla palustris, 11. Comarum palustre, 12. Impatiens noli-tangere, 13. Other herbs; 14. Thelypteris palustris, 15. Athyrium filix-femina; 16. Green mosses, 17. Sphagnum squarrosum+S. riparium, 18. Sphagnum fallax+S. angustifolium, 19. Sphagnum centrale+S. squarrosum, 20. Sphagnum magellanicum+S. angustifolium; 21. Water, 22. Fallen leaves, 23. Peat, 24. Broken off pieces of peat float.

Sometimes, atypically, deeper karst depressions may paludify in the same way as shallow depressions, but probably they need flowing (not stagnant) water to develop in this way.

Surface paludification deep karst mires

Deep karst depressions with steeply sloping sidewalls hold filtered ground water and flowing surface water. The volume of water is small and it depends on the age of the depression, location in relief, hydrology of the area and on the extent of the drainage system. As a result, small amount of water only stays in depression. It looks like a small pond in the bottom of the depression.

Mire Istochek on the territory of Yasnaya Polyana (0.16 ha) was formed in a deep depression. This mire has a natural drainage system to a lake and to the Arkovskiy ravine. The vegetation of the mire's central part is of the communities Betula pubescens - Menyanthes trifoliata + Calla palustris – Sphagnum centrale+S. wulfianum and Betula pubescens - Carex vesicaria+C. riparia – Sphagnum squarrosum. Along the mire's edge, the Alnus glutinosa – Athyrium filix-femina+Dryopteris carthusiana community is present

The peat deposit has a depth of 3.2 m in the center (Fig. 2D). Green moss, sedge, herb (*Menyanthes trifoliata*), *Sphagnum* and wood-*Sphagnum* eutrophic peats form this deposit. This means that the paludification of the depression began from a green mosses community (*Drepanocladus* sp., *Calliergon cordifolium*) in a small central pond. These green mosses formed a 40 cm layer of Bryales peat. On this peat sedges (*C. vesicaria, C. riparia*) and herbs (*Calla palustris, Comarum palustre, Menyanthes trifoliata*) began to grow. Later (depth 130 cm), *Sphagnum* eutrophic peat (*Sphagnum squarrosum, S. riparium*) was present. The invasion of birch to the mire was probably facilitated by the vertical peat growth. The ability of birch to grow on the *Sphagnum* carpet resulted in the formation of a wood (birch)-*Sphagnum* eutrophic peat, which is the soil medium of the modern vegetation.

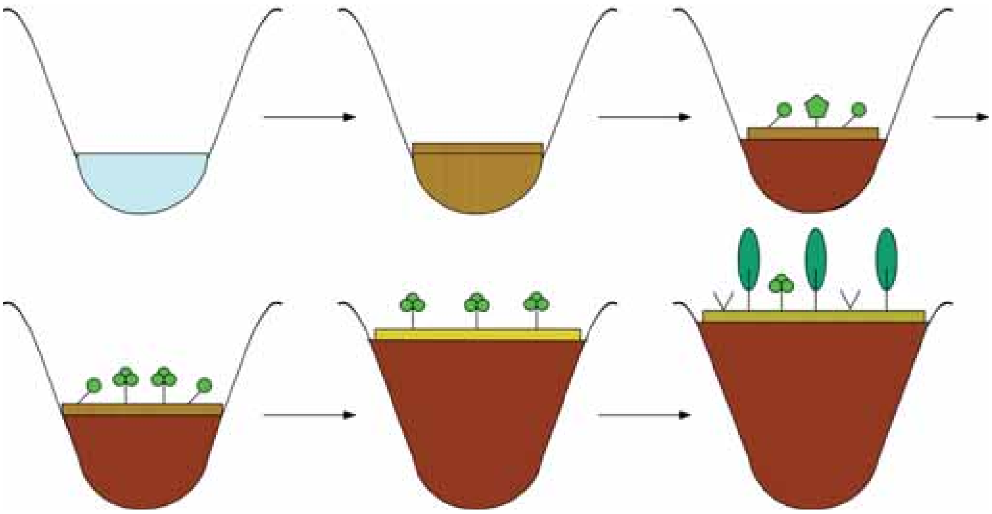

Figure 4. Paludification of deep karst depressions with high and steeply sloping side walls and a small amount of water.

Therefore, for deep karst mires such as Istochek the surface water is present in the depressions, but the water is shallow and has only a small surface area (small ponds). Peat formation begins on the surface of the depression's floor from the formation of a green mosses community (Fig. 4). After that, there is growing of herbs to form herbal peat. Changing wetness of the peat and reduced nutrition of the mire water (with increasing depth) probably facilitate the growth of *Sphagnum* mosses and birch. The stages of community succession are: green mosses community (Drepanocladus sp., Mnium, Calliergon cordifolium) ➡ Calla palustris+Comarum palustre ➡ Menyanthes trifoliata+Calla palustris ➡ Menyanthes trifoliata–Sphagnum squarrosum+S. riparium ➡ Betula alba– Sphagnum centrale+S. squarrosum.

We found several mires with the same structure of peat deposits in Tula region. The maximum depth is 8.8 m (the mire between Rvy and Gorushino villages).

Float paludification deep karst mires

Deep karst depressions with a large volume of water due to a poor water drainage system (e.g. clay layer) and with steeply sloping sidewalls paludify in another way. Stagnant water in a large pond or lake provides the conditions for the formation of floating vegetation on the water surface, which produces peat. The peat grows laterally from the center of the sinkhole to its edges. Water flowing down the steeply sloping sidewalls of the depression possibly destroys the float near the edge because the floating peat doesn't flush away near the margin zone. The structure of the peat deposit of several mires near Ozerniy village and the mire Lipki were analyzed to understand the stages of float formation.

Mire Voronka (Ozerniy village) is a karst depression (depth 7 m, area 0.05 ha) in the first stage of paludification. A vegetative float formed of fallen leaves from trees of the surrounding area has a depth of 40 cm, and it floats on the water surface. This float has remains of ferns, horsetails, some grasses, Calla palustris, and green mosses. The first true peat deposit is herbal-green mosses (Fig. 2E). Such substrate (leaves + first peat remains) is the basis for the present vegetation of the community Athyrium filix-femina+Impatiens noli-tangere. The living vegetation produces a vertical growth of the peat deposit. Therefore, the first stage of floating peat formation is from fallen leaves. The level of the float rises and falls as the water level in the depression rises or falls (seasonal fluctuation).

The mire Chernool'shanik (Ozerniy village) shows the next stages in the development of the float. The mire depth is more than 7 m, and its area is 0.07 ha. The vegetation of the central part is formed of the communities Alnus glutinosa-Athyrium filix-femina+Thelypteris palustris and Alnus glutinosa-Calla palustris.

The peat deposit is a float 1.5 m thick, formed by herbal-sphagnum and herbal eutrophic peat with a large amount of fallen leaves. Broken off parts of float peat were observed under the float at a depth of 5-6.5 m (Fig. 2F). These broken off parts contained the remains of fallen leaves.

The paludification of the karst depression evidently began after it filled up with water, and occurred by the formation of a float from fallen leaves on the water surface. On the top of these floating leaves, herbs and green and *Sphagnum* mosses began to grow, which is stage two. Nutrient-rich surface water probably was the reason for the long term existence of the second stage eutrophic herbal-Sphagnum communities, apparent from the thickness of the stratum. Increasing the float thickness provided conditions for the growth of trees (birch, black alder), which leads to the third stage in float development, the stage of the forested mire.

Lubimoe mire (Ozerniy village) has an area of 0.18 ha and is formed in a karst depression, 7 m deep. This depression is actually a series of separate interconnected depressions filled by surface water. The vegetation of the central part of the present float is the Betula pubescens-Menyanthes trifoliata-Sphagnum centale community.

The vegetation grows on the float, which is 2.0 m thick (Fig. 2G). The float was formed by herbal (sometimes with trees remains) and herbal-sphagnum eutrophic peat (with Menyanthes *trifoliata, Calla palustris, Scirpus sylvaticus, Calamagrostis* sp., *Phragmites australis, Comarum palustre, Epilobium* sp., *Carex cespitosa, Equisetum* sp., *Polytrichum* sp., and *Sphagnum centale*). Broken off pieces of the float were found below the float at a depth of 6.5-6.6 m (sphagnum eutrophic peat) and 6.6 – 6.7 m, 6.9 – 7.0 m (Bryales peat). Also, fallen leaves (with a low degree of decomposition) were found in these separated parts of float. This means that the float originally started to grow from leaf float. The floating leaves were inhabited by green mosses at first, but later *Sphagnum* mosses and herbs invaded. Therefore, paludification of the depression is similar as in the previous mire except that there is a new, fourth stage of float development: domination of birch in the tree layer and the establishment of the birch-*Sphagnum* eutrophic community.

The mire Lipki covers 0.3 ha and is located in a very deep depression (more than 12 m). The living vegetation grows on float and is of several different communities. Betula pubescens-Menyanthes trifoliata-Sphagnum riparium, Salix cinerea-Menyanthes trifoliata+Comarum palustre-Sphagnum teres, Salix cinerea-Calla palustris-Calliergon cordifolium, Menyanthes trifoliata+Comarum palustre-Sphagnum squarrosum and Carex rostrata+Comarum palustre-Sphagnum teres are all near the edge of the float.

The central part of the float has hummocks with wide flat areas (carpets) between them. The hummocks have the Eriophorum polystachion-Sphagnum magellanicum community. Between them on the carpets are the communities Carex rostrata+C.

lasiocarpa-Sphagnum angustifolium+S. fallax and Rhynchospora alba+Carex rostrata-Sphagnum magellanicum+S. angustifolium (more oligotrophic conditions).

The float (2.5 m) has *Sphagnum*, cottongrass-*Sphagnum*, and herbal-*Sphagnum* mesotrophic peats and wood-herbal eutrophic peat (Fig. 2H). The lowest part of the float is wood-herbal eutrophic peat. Under the float (5 m), a separate layer of broken off pieces of herbal-sphagnum peat (with *Menyanthes trifoliata*) was found. Such a structure of the peat deposits means that the peat float passed the eutrophic stage of development (with willow, birch, *Menyanthes, Carex vesicaria, Phragmites australis, Equisetum*). The vertical growth of peat changed the hydrologic features of the float and provided conditions for the invasion of oligotrophic species of *Sphagnum*. The abundance of *Betula pubescens* and *Menyanthes trifoliata* decreased, whereas *Oxycoccus palustris, Carex rostrata, Rhynchospora alba* increased. These new communities formed mesotrophic peats (*Sphagnum*, cottongrass-*Sphagnum* and herbal-*Sphagnum*), that form the modern surface peat. Therefore, this mire is characterized by the change of vegetation from eutrophic to mesotrophic types and the formation of the fifth stage of development of float.

The same large karst depression near Ozerniy village contained the mire Bol'shoye, which was also paludified by float formation. The communities near the edges are Betula pubescens-Carex acuta, Betula pubescens-Carex vesicaria, Betula pubescens-Scirpus sylvaticus, Betula pubescens-Calamagrostis neglecta -Calliergon cordifolium. The central part of the mire is of an Eriophorum vaginatum – Sphagnum magellanucum+S. angustifolium community, which is formed on the float (1.5 m thick) and has cottongrass-*Sphagnum* mesotrophic peat (Fig. 2I). Under the float (8.5-9.0 m), separate broken off pieces of float (cottongrass-*Sphagnum* peat also) were found. This means that the mire passed through five stages of float development and is now characterized by the sixth stage.

The analyses of the vegetation and peat deposits of these karst mires resulted in some ideas about the stages of development of peat float (Fig. 5). The first stage is formed by fallen tree leaves. This substrate is then inhabited by green mosses and "pioneer" herbs (*Athyrium filix-femina, Impatiens noli-tangere*). Increasing thickness of the float (1-1.5 m) provides for the growth of other herbs (*Menyanthes trifoliata, Calla palustris, Comarum palustris, Scirpus sylvaticus*), shrubs (*Salix cinerea*) and trees. Black alder begins to grow in more wet and nutrient rich conditions, and birch invades later. Sometimes these tree species may grow together, however the vertical growth of the peat means that it becomes more dependent on nutrient-poor rain water rather than nutrient-rich lake water, and this decreases the nutrition of the root layer. This is the reason for the death of alder and the domination of birch, which is more typical in nutrient poor conditions. When the float becomes more than 2 m. thick and its top layers begin to use rain water, *Sphagnum* mosses begin to grow (*Sphagnum squarrosum, S. riparia, S. centrale*). Increasing float thickness and decreasing nutrition of the water result in the change of vegetation: meso- and oligotrophic species of *Sphagnum* (*S. fallax, S. angustifolium, S. magellanicum), Carex rostrata, C. lasiocarpa, Rhynchospora alba* and *Eriophorum vaginatum* begin to grow.

The peat formation begins from dead vegetative material (leaves, etc.) floating on the water surface in the center of the lake or pond. Then peat grows laterally from the center of the depression to its side walls, which are steeply sloping, and the thickness of the peat increases also. However, the peat is floating, and therefore it normally has a thickness of not more than 2-3 meters, because the lowest layer of the peat usually

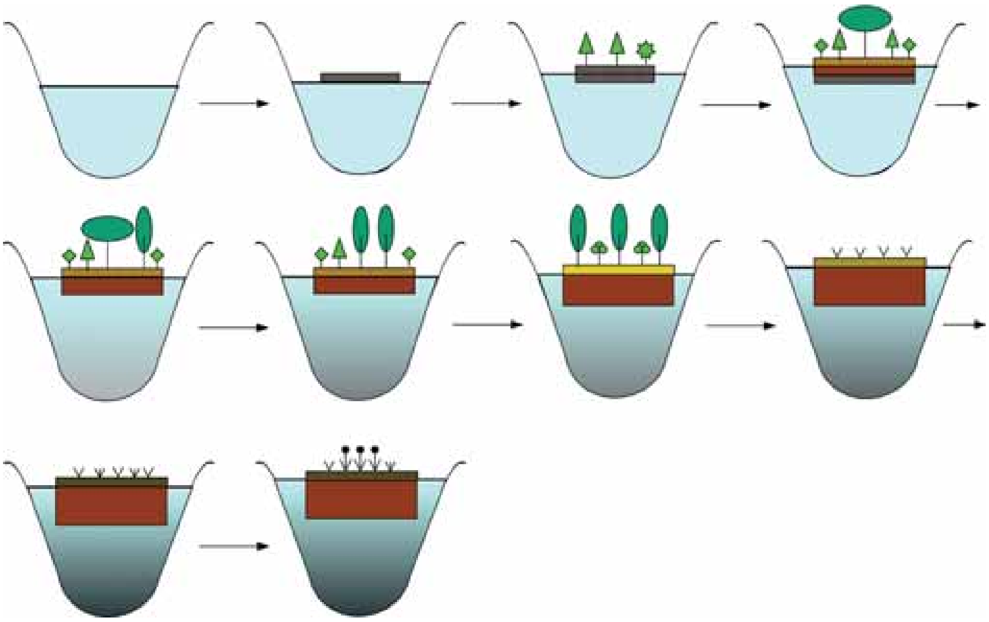

Figure 5. Paludification of deep karst depressions with high and steeply sloping side walls and a large amount of water.

breaks off and sinks down to the bottom of the pond. During this time, the vegetation may change from eutrophic to mesotrophic type.

Based on the data given above, and on the basis of data about other mires not discussed here, the succession of vegetation may be shown as follows: fallen leaves on water surface ➡ Athyrium filix-femina+Impatiens noli-tangere ➡ Alnus glutinosa–Athyrium filix-femina+Thelypteris palustris ➡ Betula alba+Alnus glutinosa–Athyrium filix-femina+Thelypteris palustris ➡ Betula alba–Thelypteris palustris ➡ Betula alba–Menyanthes trifoliata–Sphagnum squarrosum ➡ Carex rostrata+C. lasiocarpa–Sphagnum fallax ➡ Rhynchospora alba+Carex rostrata–Sphagnum magellanicum+S. angustifolium ➡ Eriophorum vaginatum–Sphagnum magellanicum.

Therefore, peat growth and increasing float thickness results in the separation of the lower layer of the float, which sinks down on the floor of the depression. Sometimes, however, after this lower layer separates it remains suspended in the water above the floor. Permanent separation of the lower layer is the reason that the maximum thickness of the float is only 2.5-3 m. The top of the float is on the water surface, whereas the lower parts are submerged in the water.

The formation of the peat float coincides with a rising water level in the karst depression, due to surface and ground waters flowing together. In this case, the level of the float in the depression will also rise. During different seasons the water level is different: usually it is higher in spring and fall and lower in summer (Вислогузова, 2007). The level of the float changes also. In general, depressions maintain both flowing surface water and ground water, and every year the depressions have a greater volume of water than before. This means that every year the float level will be higher.

Sometimes the forest mire stage of development of the float could not be found. For example, the order of vegetation stages for Kochaki mire is: leaf float ➡ growing green mosses (*Drepanocladus* sp.) and some herbs (*Scirpus sylvaticus, Calla palustris, Comarum palustre, Equisetum* sp.) ➡ invasion and increasing abundance of eutrophic

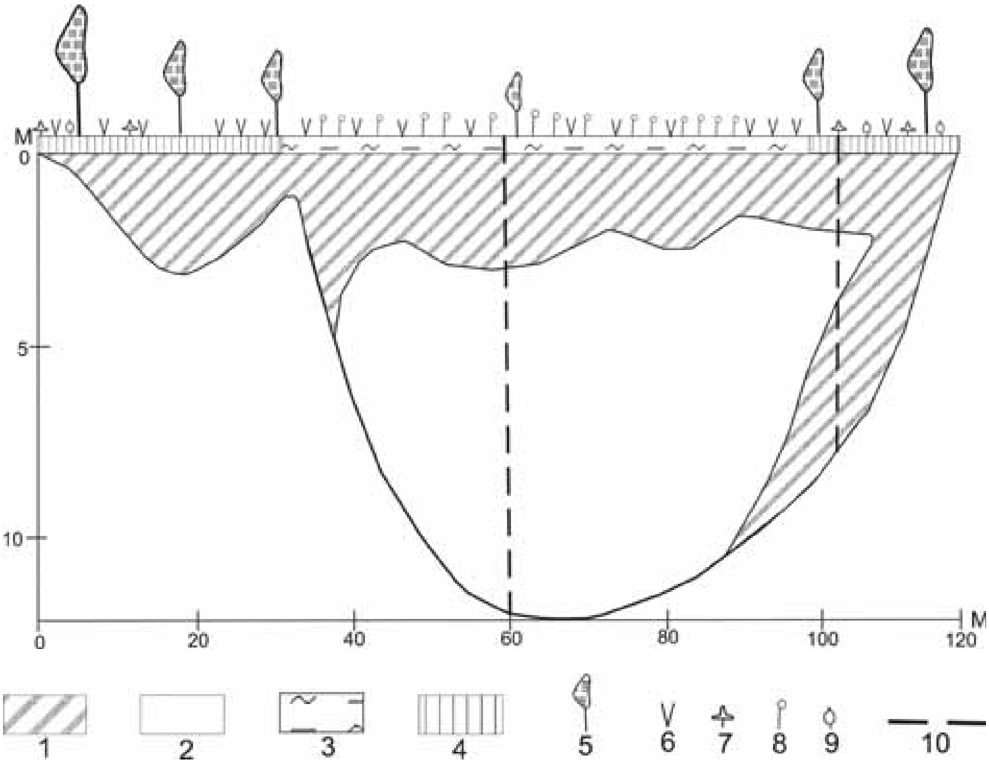

Figure 6. Profile of mire Glavnoye, Ozerniy village.
1. Peat, 2. Water, 3. Sphagnum angustifolium + S. fallax, 4. Sphagnum riparium + S. squarrosum, 5. Betula pubescens, 6. Carex rostrata, 7. Menyanthes trifoliata, 8. Rhynchospora alba, 9. Calla palustris, 10. peat coring points.

Sphagnum mosses (*Sphagnum riparium, S. teres, S. subsecundum)* ➡ increasing float thickness and use of rain water ➡ invasion of meso- and oligotrophic species (*Sphagnum magellanicum, S. angustifolium, S. balticum*) on which grow the modern vegetation communities Eriophorum polystachion+Carex rostrata-Sphagnum angustifolium, Rhynchospora alba+Carex rostrata-Sphagnum angustifolium, Chamaedaphne calyculata+Oxycoccus palustris-Sphagnum magellanicum+S. angustifolium, and Andromeda polyfolia-Sphagnum magellanicum+S. angustifolium.

Float and marginal paludification of deep karst mires

Paludification of deep and wide karst depressions with gently sloping sidewalls usually occurs by a combination of two ways. Mire Glavnoye is a good example of this. The mire (area more than 1 ha) arises in a huge linear depression (depth more 12 m) which is a series of small and separate but interconnected depressions filled by surface water (Fig. 6). The edges of the mire are characterized by the eutrophic communities Scirpus sylvaticus-Calla palustris, Salix cinerea-Scirpus sylvaticus, Betula pubescens-Carex acutiformis, Betula pubescens-Thelypteris palustris, Betula pubescens-Menyanthes trifoliata-Sphagnum riparium. At the edges the thickness of the peat deposit is 4-6 m. The edge deposit may be complete from bottom to top (non-floating), or it may be floating with broken off pieces underneath. In the latter case, vegetation grows on the float (2 m thick), which is herbal-*Sphagnum* and sedge-*Sphagnum* eutrophic peat (Fig. 2J; Fig. 6). Under the float there is a layer of water (2.0 – 3.2 m), which covers the peat that was formed on the depression's floor. This part of the peat deposit at the edges has herbal-*Sphagnum* (3.2-5.0 m), *Sphagnum* (5.0-5.5 m) and wood-sedge (5.5-5.6 m) eutrophic peat.

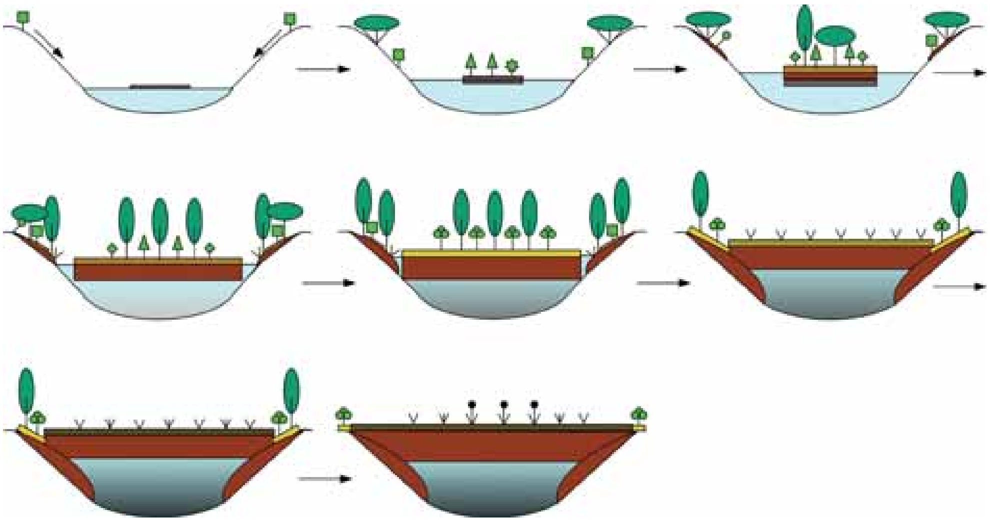

Figure 7. Paludification of deep and wide karst depressions with high but gently (not steeply) sloping side walls and a large amount of water.

The mesotrophic vegetation of the mire is a carpet with rare hummocks. The vegetation of the carpets is of the Rhynchospora alba-Carex rostrata-Sphagnum magellanicum+S. fallax and Rhynchospora alba-Carex rostrata-Sphagnum fallax+S. angustifolium communities. *Sphagnum magellanicum* and *S. angustifolium* grow on the hummocks, as do young trees of *Betula pubescens* (height 3-4 m) and *Oxycoccus palustris*. Between the mesotrophic center and the eutrophic edge, the Betula pubescens-Carex lasiocarpa+C. rostrata-Sphagnum fallax community is present. This vegetation is typical for the central part and is characteristic for float (2.5-3.0 m thick). Cottongrass-*Sphagnum* and *Sphagnum* mesotrophic kinds of peat form this float. Broken off parts of the float were found to a depth of 8-9 m. They are formed by herbal-sphagnum and cottongrass peat (Fig. 2K; Fig. 6).

The analysis of the structure of the peat deposits in different parts of the mire resulted in the discovery of two ways of paludification depending on location: on the slopes of the depression, and in its central part (Fig. 7). The paludification of the gently sloping sidewalls of the depression began from the formation of communities with trees (willow, birch), sedges (*C. rostrata, C. cinerea*), some herbs (*Calla palustris, Menyanthes trifoliata, Phragmites australis, Calamagrostis* sp.) and *Sphagnum* mosses (less than 20%). The accumulation of water in the depression resulted in the decrease of the trees and in an increase in the abundance of herbs and *Sphagnum* mosses (*Sphagnum centrale, S. squarrosum, S. fimbriatum*).

At the same time, on the water surface in the central part of the depression, a float began to form. The stages of the development were the same as with previously discussed floating mires, and the vegetation changed from eutrophic to mesotrophic types. The accumulation of surface and ground waters produced a rising higher water level in the depression, which in turn resulted in both the rising of the level of the float and the covering of previously produced peat deposit on the sidewall slopes. The rising water caused parts of this previous deposit to become disturbed, and their top parts began to rise to the surface of the water.

Some plants began to grow on this different kind of float. The lateral growth of the first float from the center to the edges resulted in the two types of float combining into one. In this way, a layer of water was formed between two parts of the overall peat deposits (combined peat float and peat deposit on the bottom of the depression's sidewalls) near the edge of the mire. This evidently is the reason why the present float is characterized by mesotrophic vegetation in its center and eutrophic vegetation near its edges.

Conclusion

Karst mires originate and further develop in funnel-shaped karst depressions (sinkholes) which are formed through processes of dissolution by groundwater of limestone in bedrock. The depths of the depressions vary from less than 1 to 10 or more meters.

The ages of the karst depressions are different (Чикишев, 1978), but the age of the beginning of paludification for most mires is Boreal time of the Holocene (Гребенщикова, 1939; Хмелев, 1975). Mire formation in karst depressions occurred by surface paludification and by float formation. The same ways have been found for kettle-hole mires also (Andreas and Bryan, 1990; Gaudig et al., 2006; Krisai, 2006). Additional detailed analyses of peat stratigraphy of karst-hole mires in the Tula region have allowed the determination of four different ways of paludification:

1. Paludification of shallow karst depressions with low and variably sloping sidewalls and at most a small amount of water. This provides conditions for the growth of trees (willow, birch) and the formation of woody peat on the surface of the depression floor.

2. Paludification of deep karst depressions with high and steeply sloping side walls and a small amount of water. The shallow water has only a small surface area. Peat formation begins on the surface of the depression floor from the green mosses community. Later, other plants (herbs, trees) begin to grow on the green-mosses-peat. The accumulation of peat and the change of hydrologic regime provides for the invasion of *Sphagnum* mosses. The vegetation is of the eutrophic type.

3. Paludification of deep karst depressions with high and steeply sloping side walls and a large amount of water. The water forms large ponds and lakes. Peat formation begins from dead vegetative material (leaves, etc.) floating on the water's surface in the center of the lake. The peat grows laterally from the center of the depression to its edges, which may be almost vertical, and the thickness of the peat also increases. However, the peat is floating, and therefore it normally has a thickness of only 2-3 meters, because the lower layer of the peat usually breaks off and sinks down to the bottom of the lake. During this time, the vegetation may change from eutrophic to mesotrophic type.

4. Paludification of deep and wide karst depressions with high but gently (not steeply) sloping side walls and a large amount of water. The sidewalls of the depression begin to paludificate by way № 1 because surface waters moisten this area enough to provide good conditions for the growth of trees (willow, birch) and herbs. The central part is a depression with water on the floor (deeper and wider than in № 2), and float begins to form there (as in № 3). Surface waters flow into the pond, raising its water level. This results in a lifting up of the floating peat. When the centrally-located float raises high enough to reach the same level as the sidewalls of the depression, it will begin to grow in width and cover the already-existing peat on the gently sloping sidewalls. Ultimately, therefore, the edges of the sinkhole have peat produced by two ways: (1 and 3).

In Tula region, we have found karst mires that are characterized by different ways and different stages of paludification. These mires are important elements of the regional landscape and significant centers of biological diversity, because many regionally rare species of plants are growing there, such as *Salix lapponum* L., *S. myrtilloides* L., *S. rosmarinifolia* L., *Andromeda polifolia* L., *Chamaedaphne calyculata* L, *Oxycoccus palustris* Pers., *Hammarbya paludosa* (L.) O. Kuntze, *Molinia caerulea* (L.) Moench, *Eriophorum vaginatum* L., *Rhynchospora alba* (L.) Vahl., *Carex limosa* L., *C. lasiocarpa* Ehrh., *C. atherodes* Spreng., *Scheuchzeria palustris* L., *Drosera rotundifolia* L., *D. anglica* Huds., *D. obovata* Mert.et Koch., *Helodium blandowii* (Web.et Mohr.) Warnst., *Sphagnum magellanicum* Brid., *S. subsecundum* Nees., *S. obtusum* Warnst, *S. fimbriatum* Wils., *S. wulfianum* Girg., S. flexuosum Dozy et Molk., *S. girgensohnii* Russ.

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SALAMAJÄRVI
HEIKINJÄRVENNEVA – LINTUSUO

Subsidence in bogs

Moving catchment boundaries, changing flow paths and slopes, self-sealing and effects on drying and natural rewetting

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Introduction

This text is based on experience in the Irish-Dutch Raised Bog Study with field work in two Irish raised bogs, Raheenmore Bog and Clara Bog in the Irish Midlands, during 1989-1993 and 2002-2003 and on research on bog remnants in the framework of the Dutch Survival Plan for Forest and Nature (OBN). In Ireland hydrological, geological and ecological field campaigns were carried out. Subsidence turned out to be one of the key processes in the development of both bogs over the past 200 years.

In Dutch nature conservation, the question whether changes in the hydrological system in the immediate surroundings of a raised bog remnant would have a substantial effect on hydrological and ecological conditions in the bog itself, has been discussed for a long time. The practical background was, whether or not nature conservancy should invest in creating hydrological buffer zones around raised bog nature reserves. The reader should be aware that in the Netherlands no natural raised bogs exist anymore. There are only relatively small remnants; most of them cut-over or almost cutaway and positioned in a landscape where the groundwater table has been lowered considerably. The lowering is often about as much as the thickness of the removed peat layers plus current drainage depth in the reclaimed cut-away.

A lowering of the groundwater level in the surrounding area will inevitably create a lowering of the piezometric level in the mineral layers below the peat body. A possible direct effect would be an increased downward seepage with a subsequent lowering and/or increased fluctuation of the phreatic water table in the bog. An indirect effect may be created by surface subsidence and a resulting change in surface slope, which would negatively affect the possibilities for the growth of bog vegetation. The latter was studied in Ireland.

In this paper effects of subsidence on flow patterns and ecological conditions in raised bogs will be discussed. A supporting theoretical basis for bog subsidence will be developed in a largely informal way. A more formal approach, including a numerical model, will be published elsewhere.

Theory

The process of subsidence

Peat in an undisturbed raised bog in the strongly Atlantic climate zone of western Europe contains a volume fraction of water of 0.95 – 0.96, averaged over the entire profile. Hence the average volume fraction of solid matter is 0.04 – 0.05, if the gas fraction is neglected. This shows that the main constituent of a bog soil is water, not solid matter.

As a result of the processes of gradual decay, subsequent loss of fibre elasticity and some compaction, the volume fraction of solid matter tends to increase downwards. An example from Clara Bog, Ireland, is shown in Figure 1. It shows an increasing trend of the volume fraction of solid matter with depth, from approximately 0.03 at a depth of half a metre to 0.05-0.06 at the peat bottom at a depth of nearly 10 m. This means a volume reduction by 40-50% if effects of decay on the volume are neglected.

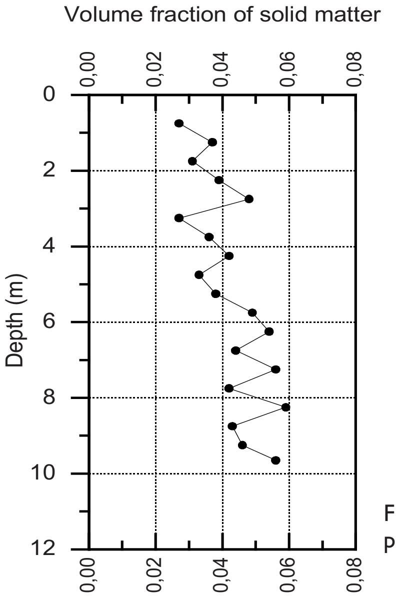

Figure 1. Volume fraction of solid matter against depth in a profile in Clara Bog, Ireland.

Because the forces that cause the volume reduction are basically vertical, the shrinkage of peat layers means reduced thickness and hence surface subsidence. In pristine mires, subsidence is usually more than compensated for by a net production of fresh organic matter, *i.e.* although the surface of year *a* subsides, in year *a*+1 a new surface is formed, which lies on average a little higher than the surface level of year a. However, if the system dries out temporarily or permanently, for example during one or more dry years or as a result of changed drainage conditions, either of natural or of anthropogenic origin, the bog may lose extra water and thus subside more than by its average rate. Wet years and wet summers in particular have an opposite effect.

The rate of subsidence depends on the difference between pore water pressure -or briefly pore pressure- and total soil pressure. In soil mechanics this difference is called stress. This physical quantity may be new to many readers and therefore requires some explanation.

Let us consider the simplest possible case, a peat profile without vertical flow, which is water-saturated below the phreatic water table. Then the pore pressure at any depth z is equal to the pressure exerted by the vertical water column from the phreatic water table to z. Note that in the peat above the water table the pressure is negative. Sometimes negative pressure is called suction.

The soil pressure is the pressure of the soil column, including both soil material and water, from the soil surface to z. The stress is the difference between soil pressure and pore pressure. One may visualize stress as the apparent weight per horizontal area of a soil column with the part below the phreatic water table submerged in water. This looks similar to Archimedes' principle and actually it is. In soil mechanics, stress is often denoted by the symbol σ'. In SI units it is expressed in kPa (= kNm^{-2}).

Stress is related to hydraulic head h via the components of pore pressure and vertical position z. In a profile without vertical flow, h is the same at any depth, because pore pressure and z compensate each other. In a field situation without vertical flow component, piezometers installed at different depths show equal inside water levels. However, if vertical flow occurs, the hydraulic head in a profile decreases in the direction of flow. Because z does not change, pore pressure does. Hence a decrease in hydraulic head in an otherwise unchanged profile means a decrease in pore pressure and thus an increase in stress.

Terzaghi (1925) found that vertical compaction of a soil, caused by a permanent increase in stress, is approximately proportional to the logarithm of the ratio (not the difference!) of the old and the new stress. Hence, for soil compaction, it makes no difference whether the stress changes from 1 to 2 kPa or from 10 to 20 kPa. The proportionality constant depends on the soil and denotes the soil's compressibility. The compressibility of peat soils is usually large, contrary to *e.g.* sands, where it may be very small. The process is only partially irreversible, *i.e.* if the original stress is restored, the soil surface does not go back to its original level, but it will usually regain a small part of the loss. On the other hand, returning the stress back to its increased level after a release will not create additional compaction. If the stress is increased further, the compaction process will continue according to Terzaghi's theory. We deliberately neglect the so-called secular subsidence, which is a very slow subsidence that continues after the level predicted by Terzaghi's theory has been reached. Neither shall we take into account the time involved in the process. For the scope of this text, it is sufficient to note that surface subsidence means loss of water from the soil profile and that the speed of the outflow roughly depends on the soil's hydraulic conductivity, layer thickness and internal friction. Hence soils consisting of sediments with a low hydraulic conductivity will subside slower than soils of very permeable material, even though both may eventually end up with the same subsidence, which depends on their compressibility.

In peat soils in particular, there is a complicating factor: the strong decrease of the hydraulic conductivity k with increasing compaction. For both Clara Bog and Raheenmore Bog, an approximate relationship was found, where log k roughly had a linear proportionality with a change of the volume fraction of organic matter (Van der Schaaf 1999). A doubling of the volume fraction of organic matter, which is equivalent to a volume reduction by 50%, caused a decrease of k by a factor between 10 and 100. As a consequence, the speed of the process slows down much more than predicted by "classic" subsidence theory (but continues longer).

Subsidence caused by internal drainage and by drainage via the subsoil

Internal drainage

Internal drainage may be anything from man-made open drains or tube drains to surface runoff by an increased slope on a bog margin or even well inside a bog. The latter may be the result of unequal subsidence of a bog's surface. This implies that subsidence in one place may create secondary subsidence elsewhere.

The common result is a lowered phreatic level. We shall consider a simple example of a peat profile, 5 m deep and an average volume fraction of solid matter of 0.05. If we assume a specific mass of the solid matter of 1400 kg m^{-3}, based on work by Skempton and Petley (1970) and Galvin (1976), the specific mass of the saturated peat is approximately 1020 kg m^{-3}. If a gravity of 9.81 m s^{-2} is assumed, such a peat causes a soil pressure of 50.02 kPa at a depth of 5 m. A column of water of 10 ºC would cause a pressure of 49.04 kPa at the same depth. The difference, nearly 1 kPa, is the stress at the bottom of a peat column, where the phreatic water table is at the surface and without a vertical flow component.

The stress versus depth is shown in profile (a) of Figure 2. The increase of the stress with depth coincides rather well with the increase in volume fraction of solid matter shown in Figure 1, but should not be regarded as a full explanation, because of the complexity of the processes that occur during the ageing of peat. Profile (b) shows the stress if both the water table and the hydraulic head at the peat bottom change from surface level to 20 cm below it. The additional assumption as to the profile section above the water table is a volume fraction of water of 0.5, which implies that 45% of the volume is air. Profile (c) shows the log of the stress ratio, which, according to Terzaghi's theory, is proportional to compaction. Although compared to a real situation Figure 1 is somewhat exaggerated, profile (c) shows perfectly well that in a situation with superficial drainage resulting in a lowered phreatic water table, the compaction or shrinkage of the peat is concentrated in the upper part of the peat as, for example, described by Uhden (1960) and Eggelsmann (1990).

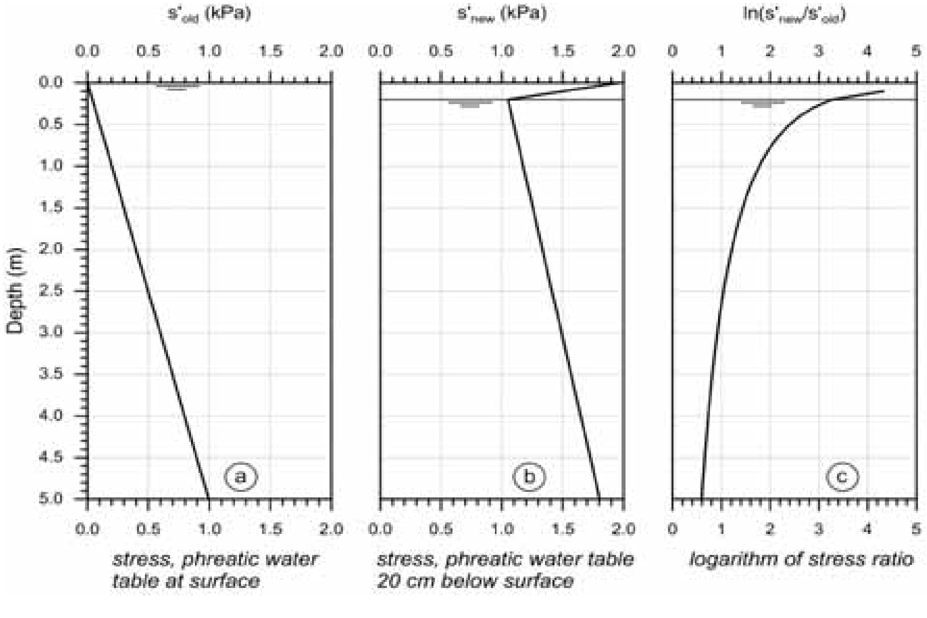

Figure 2. Stress in a 5 m deep peat profile, (a) phreatic the water table at the surface, (b) phreatic water table 20 cm below the surface, (c) the log of the stress ratio ln(ó^2'new/ó^2'old) of (a) and (b).

The subsidence effect of internal drainage itself has been described as early as 1749 (Linnaeus 1749). More extensive descriptions are given by Hausding (1917), Hallakorpi (1936), Segeberg (1951), Uhden (1960), Eggelsmann (1990) and many others.

Because the hydraulic conductivity in the upper peat layer of a raised bog is relatively high, the subsidence process is fast and because of the large stress ratio, the total subsidence is usually large. Eggelsmann (1990) mentioned a subsidence of 1 m in 100 days and 1.4 m in 200 days after drainage in a deep bog in Holstein. However, such figures are extremes. The deep subsidence is not necessarily caused by such deep drains, but because the bottom of an open drain subsides with the bog surface, it may eventually cause a subsidence, considerably larger than the actual drain depth.

Because during the subsidence process the hydraulic conductivity of the compacted upper peat decreases considerably, the effect of the drainage on the hydraulic head and the stress will be increasingly concentrated in the upper peat and thus to some extent prevents the compaction process from affecting the lower peat. This is one of the many examples of feedback mechanisms in mires.
Water loss through the subsoil

Loss of water via the mineral subsoil may be caused by a lowered groundwater level in the surroundings of a bog that propagates into the underlying mineral layers. The change of the hydraulic head below the bog body depends on the geohydrological conditions in the area. A permeable subsoil is likely to cause a larger effect than an impervious one. As a result of bog growth, the difference between the phreatic water level in a bog and the hydraulic head in underlying soil layers also increases gradually, because a bog grows higher above its surroundings. There is no basic difference with the artificial process, except that the natural process is generally much slower. Figure 3 (a) shows that the downward increase of the stress becomes larger with depth in a situation with a downward decreasing hydraulic conductivity and downward

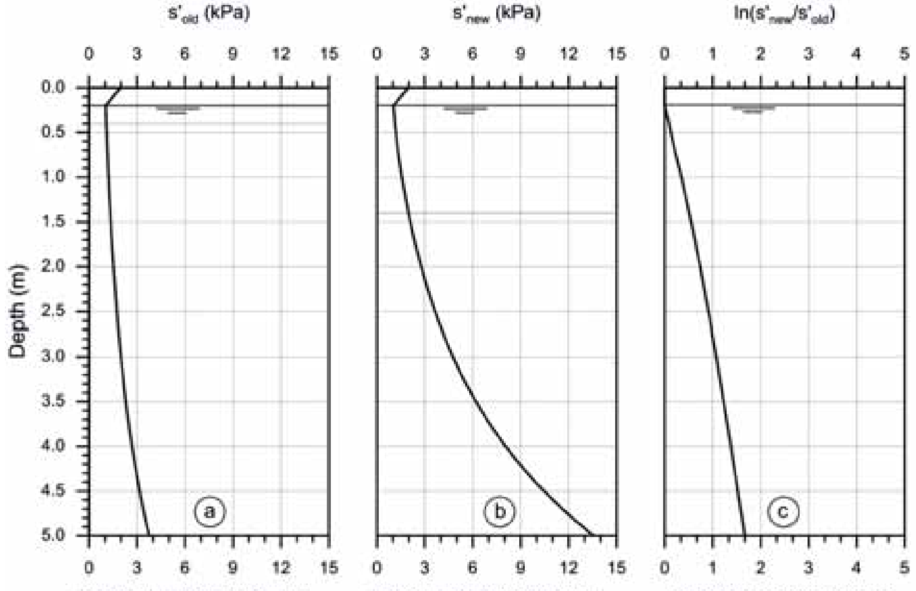

Figure 3. Stress in a 5 m deep peat profile, phreatic water table at 20 cm below surface, a linear increase of the volume fraction of solid matter of 0.03 at the surface to 0.05 at the peat bottom, saturated hydraulic conductivity decreases downwards logarithmically from 0.1 m d-1 at the surface to 0.004 m d-1 at the bottom. (a) hydraulic head at the bottom 40 cm below the surface (dashed line), (b) hydraulic head at the bottom 140 cm below the surface (dashed line), (c) the log of the stress ratio ln(σ’new/σ’old) of (a) and (b).

seepage, caused by the lower hydraulic head at the bottom of the peat. The situation as shown in profile (a) is rather normal in an undisturbed raised bog. Profile (b) shows the same situation, but with a hydraulic head at the bottom of the peat, which is 1 m lower than in (a). The water table has been kept at a constant level of 20 cm below the surface. The dashed lines in (a) and (b) show the level of the hydraulic head at the bottom of the peat.

The curve of the stress ratio in (c) shows that, contrary to curve (c) in Figure 2, the ratio increases downwards, which implies a downward increase of the shrinkage.

The water loss is now from the deepest peat, which means a slower subsidence process than in the case of superficial drainage. Because the drainage level does not subside with the peat surface, the subsidence caused by external drainage may also be smaller than subsidence resulting from internal drainage. However, this also depends on how much the hydraulic head at the peat bottom has been lowered.

A limiting factor is the decrease of the hydraulic conductivity, which is caused by the compaction. This decrease is strongest where compaction is largest, i.e. in the deepest peat. Consequently, the decrease in hydraulic head is more and more concentrated in the deepest peat, which shrinks more, etc. This is yet another example of a feedback phenomenon, which eventually more or less seals off the upper peat from being affected by drainage in the near surroundings of a bog. An extreme result from the Netherlands is shown in Figure 4.

Even this kind of subsidence may pose a threat to ecological conditions. If it causes an increase of the surface slope, local conditions could become drier. It could even cause such an increase of the surface drainage, that shrinkage of the upper peat might be a result. In fact, this would be a form of superficial drainage. Most sensitive to such changes are zones close to artificial bog margins (face banks) created by marginal peat cutting, where lateral outflow of water may enhance the process (Ten Heggeler *et al.*, 2005).

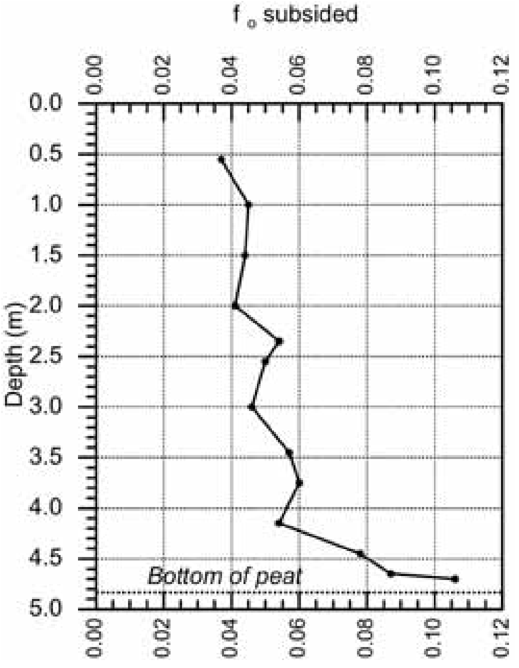

Figure 4. Meerstalblok (Netherlands) subsided bog profile with volume fraction of solid matter φ_0 versus depth. The average hydraulic head at the peat bottom has sunk below the peat bottom level due to agricultural drainage in the adjacent cut-away area.

Effects of bog subsidence on ecological conditions

Processes

Because subsidence is related to water loss from the peat, an apparently logical consequence would be drying out of a bog's surface. In the case of superficial internal drainage, regardless of whether it is natural or artificial, the immediate effect is a lowering of the phreatic water table, which has a strong impact on vegetation development. A related and equally important direct effect is shortening of flow paths (Bogaart and Troch, 2006). The role of flow paths in bog hydrology may need some explanation.

In the acrotelm-catotelm concept, the acrotelm is the one and only aquifer of a raised bog. According to Darcy's law, the flow rate[1] q [L^2T^{-1}] across any point on a bog is directly related to two quantities, transmissivity[2] T[L^2T^{-1}] and the hydraulic gradient $\frac{dH}{ds}$ [1], which is approximately equal to the surface slope I [1]. Thus we have

$$q = -T\frac{dH}{ds} \approx TI \quad (1)$$

Note that in (1) the minus sign disappears because of a convenient definition of I. In a bog, T adjusts itself to the value needed to accommodate q at a given slope I. The adjusting mechanism is the changing phreatic water level (Ivanov 1953, 1957 cited in Romanov 1968; Ivanov, 1981). However, q also depends on specific discharge[3] v [LT^{-1}], and flow path length L_u [L] upslope from the point and the flow pattern. In a radially diverging flow pattern, q is twice as small compared to a parallel pattern with the same v and in a diverging pattern it is larger. Hence a dimensionless shape factor f is needed in the relationship of q, v and L_u (Ivanov, 1965; Van der Schaaf, 2002b): $q = vL_u f$ (2)

Combining Eqs. (14) and (15), we can derive $\frac{T}{v} = \frac{L_u}{fI}$ (3)

Eq. (3) shows that the ratio of T and v may also be expressed in topographical terms. It has the dimension length [L] and may be used as an indicator of wetness and ecological potential (Van der Schaaf and Streefkerk, 2003). It is related to the so-called TWI (Topographical Wetness Index), a common quantity in hillslope hydrology, which is the logarithm of the same ratio (Beven and Kirkby, 1979).

The largest ratios tend to coincide with loose and deep acrotelms, normally associated with wet places. Smaller ratios may lead to a large proportion of hummocks, and larger ratios to a larger proportion of hollows or even the formation of endotelmic pools. However, the value $\frac{T}{v}$ (or) $\frac{L_u}{fI}$ is only meaningful in relation to climatic conditions, in particular evapotranspiration, rainfall sums, their variability and their distribution over the year. For the Irish Midlands, a value of 50 km (equivalent to, for example, a flow path length of 500 m and a local slope of 1:100) is probably a reasonable minimum for natural bog growth (Van der Schaaf and Streefkerk, 2002), but in other parts of the world different values might be applicable.

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[1] Flow rate may be expressed in volume per time or, in this case, volume per time per flow path width.

[2] Transmissivity is the integral of hydraulic conductivity over the saturated depth of the aquifer.

[3] Specific discharge is discharge in volume per time per area, which is equivalent to length per time (for example, mm per day). Thus rainfall expressed in such a unit may be regarded as specific recharge. The advantage of using these concepts is that they are independent of area size.

If subsidence is spatially unequal -which it usually is- it affects both I and L_u and possibly also f in Eq. (3). This creates an indirect effect of subsidence on ecological conditions on a raised bog, because of changing surface slopes, flow path lengths and flow patterns.

The simplest case is -again- drainage by shallow drains. If for example the drain distance is 20 m, the average L_u is reduced from several hundred m to approximately 5 m. In a real situation, a change in I can impossibly compensate for this. Actually, in most cases I will increase, worsening the situation even further. Changes in f are nearly always negligible compared changes in L_u as described.

In the area close to the water divide, in a raised bog the vicinity of the apex, $\frac{L_u}{fI}$ is especially sensitive to minor changes in the surface topography, because both L_u and I are small. Consequently, conditions in the centre of a bog may be easily affected by subsidence, either caused by changes in the internal drainage, even if it is some distance from a lowered piezometric head in the mineral layers below the peat body.

Subsidence caused by a decreased piezometric head below the peat does not necessarily cause extra water losses to the mineral subsoil, because of the sealing effect of the compressed peat at the bottom. However, it does change the flow pattern and often with it the position of the internal water divide. The result is not always drier conditions. Locally a bog may become wetter as a result of increased flow path length, a decreased surface slope, or even both. Three examples with subsidence effects on their internal flow system will be discussed below. They are Raheenmore Bog, Clara Bog West and Clara Bog East.

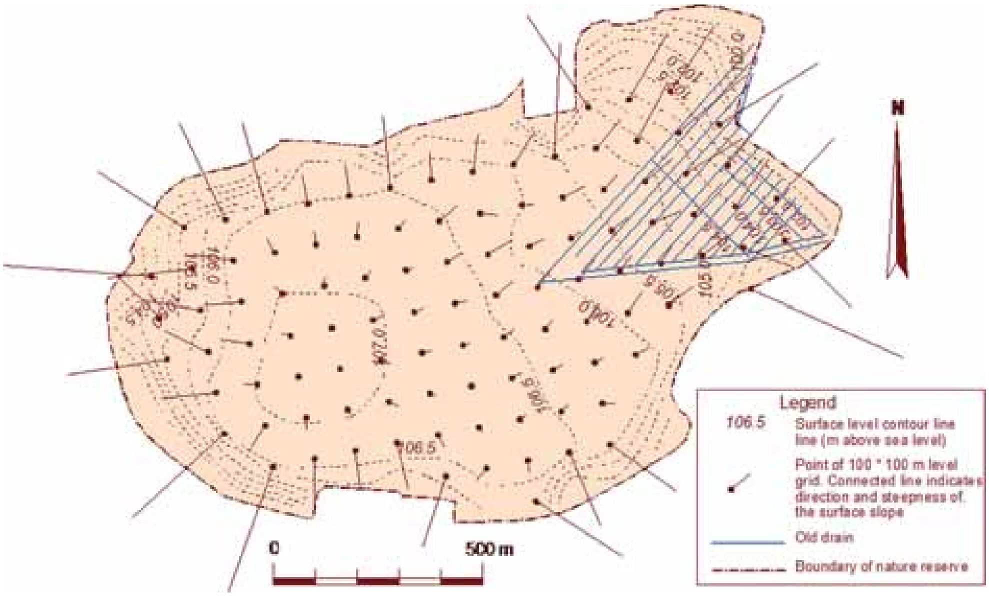

Figure 5. Raheenmore Bog, County Offaly, Ireland.

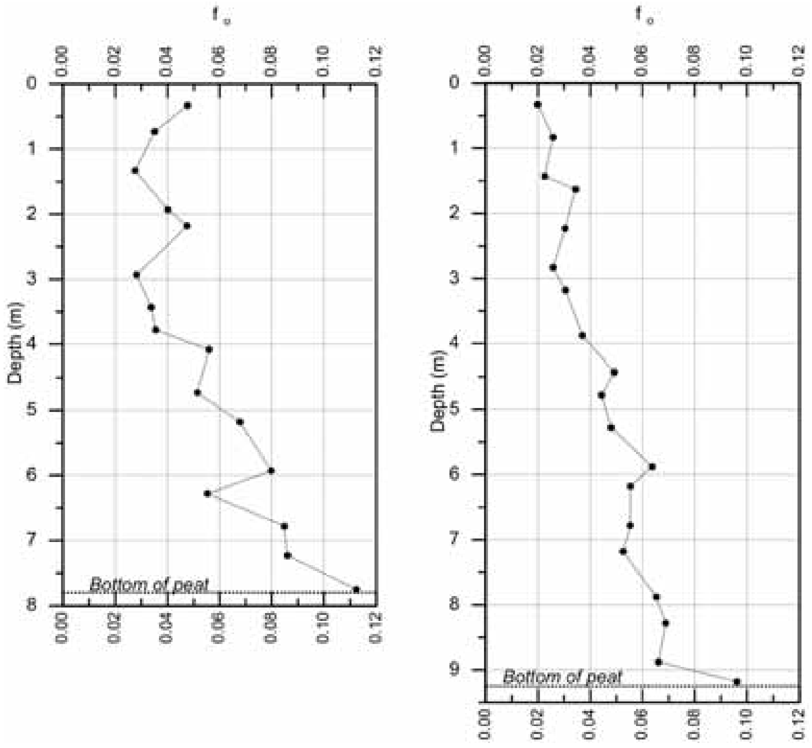

Figure 6. Profile of volume fraction of solid matter φ o, about 80 m from the southern margin of Raheenmore Bog (left). Surface peat influenced by peat margin slope, bottom peat affected by margin drain and at 150 m (right) only bottom peat affected.

Examples

Raheenmore Bog

Raheenmore Bog in Co. Offaly, Ireland, is a clearly convex raised bog. In the past it has suffered from a system of shallow drains of unknown age, probably 150 years or more, in its north-eastern part (Figure 5). These drains had a strong impact on the bog's hydrology. Peat cutting along the margin, although mostly in a zone less than 100 m wide, has also harmed the bog ecosystem. A deep margin drain around the bog may have added to subsidence in a narrow margin zone. Thus the bog slope close to the margin was steepened, which has probably led to additional subsidence and a widening of the margin zone (Van der Schaaf, 1999). A typical profile, sampled at about 80 m from the southern margin, is shown in Figure 6 (left hand profile). It shows compaction at the peat bottom and near the surface, indicating the effects of superficial drainage caused by both the increased surface slope and of a lowered piezometric head at the peat bottom. The right hand profile in Figure 6 was sampled about 70 m further from the margin. It only shows compaction at the bottom.

On the bog, terrestrialised small pools occur, most of them in the order of 10 m^2 in size. There are no open pools anymore. This may be another sign of hydrological disturbance, but the exact mechanism behind the phenomenon is unclear.

Although in 1990 the drains had terrestrialised to an extent that they were nearly invisible to the inexperienced eye, they still carried rather substantial amounts of water. They were blocked in 1995 by a system of peat dams. The effect on the acrotelm was significantly positive eight years later (Ten Heggeler *et al.*, 2005), but because the process of subsidence is almost irreversible, the surface levels have not changed substantially.

A tentative reconstruction of original surface levels in the north-east of the bog, based on }western point of the drain system and the current north-eastern bog margin, which was between 0.5 and 3 m, with the largest values towards the north-east (Van der Schaaf, 1999).

The subsidence has undoubtedly been caused by the surface drainage shown in Figure 5, possibly with a superimposed effect of the lowered piezometric head along the north-eastern boundary, caused by the deep margin drain surrounding the bog and possibly some peat extraction from the same zone in the past.

As a result of the subsidence, the apex of the bog must have shifted gradually towards the west (a basic law is that the position of the water divide moves away from the subsiding part). Thus the flow paths towards the north-east have gradually increased their length at the expense of the flow system in the west. Thus the shifted water divide caused drier and less favourable conditions for bog growth in the west. In the latter area, hummock species still thrive reasonably well, but in most hollows the typical *Sphagnum cuspidatum* is still lacking and little new acrotelm material is formed (Ten Heggeler *et al.,* 2005). In the east the drain blocking caused a measurable acrotelm growth, probably helped by the long flow paths. In this way the subsidence in the north-east now affects the western side of the bog, opposite the drain system that initially caused the changes.

To summarise the processes and their consequences:

1. The margin slopes of Raheenmore Bog have become steeper as a combined result of a deep margin drain and marginal peat cutting. The margin drain has probably caused (additional) compaction in the bottom peat, resulting in a steeper margin slope. The subsidence along the margin caused additional surface drainage and compaction of

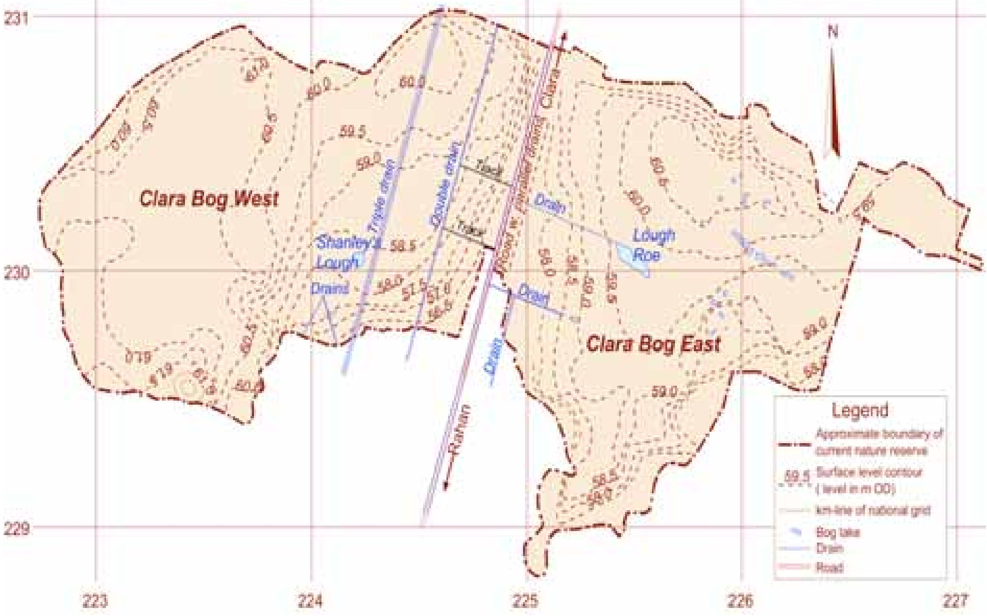

Figure 7. Clara Bog with bog road, main drains and other features.

the upper peat and thus spread into the bog. This resulted in a reduction of the $\frac{L_u}{fI}$ ratio (increase of I) and thus in a deterioration of ecological conditions in a margin zone, perhaps 100 m wide, but possibly more, which may be indicated by the disappearance of the bog pools.

2. The superficial drainage system in the north-east, which was possibly created in middle of the 19th century, has caused a shift of the water divide towards the west. Thus the flow paths to the north-east have become longer, those in the west shorter. The result is natural rewetting in the north-east, which is now helped by drain blocking, and poorer peat-forming conditions in the west, opposite the area, which was drained.

Clara Bog

Clara Bog Nature Reserve, also in Co. Offaly, Ireland, comprises 460 ha of state-owned raised bog with some privately owned bog area outside its boundary. It is bisected by a road (Figure 7), which was probably built across the bog at the beginning of the 19th century.

The bog has developed in a glacial basin of the Weichselian (usually called Midlandian in Ireland). It is surrounded by a glacial landscape with an esker in the north and an undulating landscape with a layer of till of varying texture and a depth of 1-18 m at the surface (Warren *et al.,* 2002) at its other sides.

Clara Bog contains two bog lakes, Shanley's Lough in the western half and Lough Roe, with a number of small pools in the eastern half. In 1990, many of the smaller pools were still open, as was a small part of Lough Roe; in 2002 almost all open water

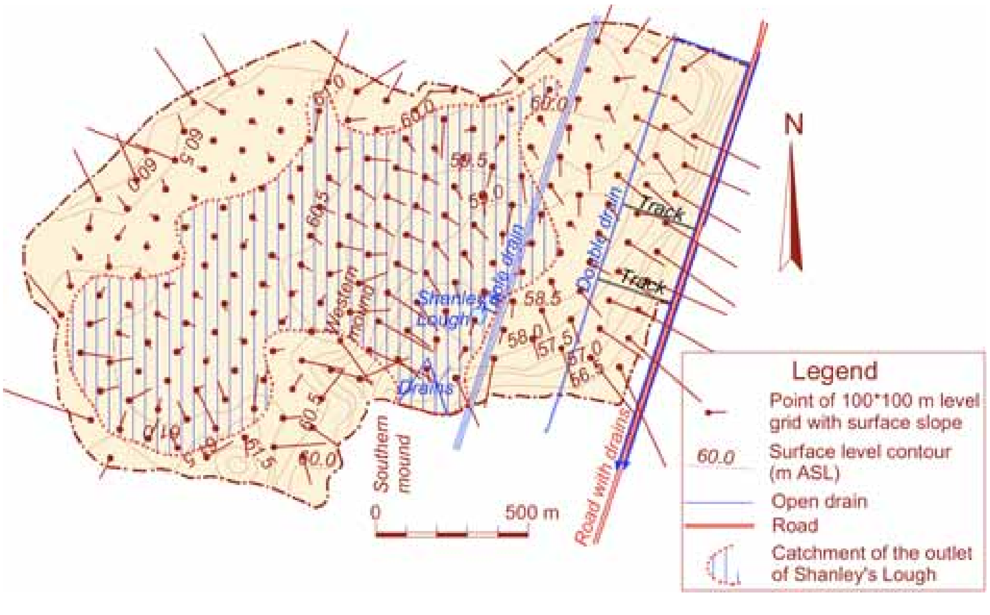

Figure 8. Clara Bog West with catchment resulting from subsidence caused by the road drains and the Triple and Double drain.

had disappeared because of terrestrialisation. In 1983, Clara Bog East was drained by Bord na Móna in preparation of peat extraction. In 1987 it became a nature reserve by law. Industrial peat extraction never took place. However, some private peat cutting at the bog margin, except in the north, has continued until 2000 or later.

During the research done in the framework of the Irish-Dutch Raised Bog Study in 1989-1993, it became clear that subsidence has shaped much of the present-day bog. Extreme subsidence has been caused by the bog road's associated drains on Clara Bog West (the drains immediately alongside the road and the Triple and Double drain on the map of Figure 7). The presence of so many road-associated drains on Clara West suggests that the original apex of the bog dome was to the west of the road and that the drains were made to deviate the flow of bog water towards the subsiding road. Peat cutting along the eastern, southern and western margin, the superficial drainage of 1983 on Clara Bog East and the deep drainage in the cut-away in the South have also caused substantial subsidence (Van der Schaaf, 1999; Ten Heggeler *et al.*, 2005).

The subsidence near the road was estimated by comparing profiles of the volume fraction of solid matter close to the road with profiles in the westernmost part of the bog. Apart from loss by oxidation, burning and superficial peat cutting along the road, the lowering of the surface level by subsidence alone was estimated at 3-5 m, depending on whether or not subsidence in the reference profiles was taken into account. The total reduction of peat depth along the road has probably been between 6 and 9 m, the latter being the more likely figure (Van der Schaaf, 1999). The remaining peat layer at the road is about 4 m deep.

The two long drain systems on Clara Bog West, marked "Triple drain" and "Double drain" in Figure 7 and Figure 8 were cut in the early 19th century. They caused subsidence in addition to the effect of the drains immediately alongside the road. This turned Clara Bog West into a partly concave instead of a convex bog. The resulting catchment is shown in Figure 8. In the south two other drains occur. These probably

Figure 9. The western mound on Clara Bog (December 1990). The bright vegetation is Molinia caerulea. Dominant occurrence of Molinia caerulea in Irish Midland bogs is usually an indication of rheotrophic conditions, which may also explain the presence of Betula pubescens stands (Photo Sake van der Schaaf).

are of a much younger age, because in 1990 they had not terrestrialised to the extent of the triple and double drains. They still were partly open.

Most likely, the narrow outlet to the south of Shanley's Lough is the result of a special subsidence process, caused by the local topography of the mineral subsoil (Van der Schaaf, 1999; Connolly *et al.,* 2002). Two till mounds occur to the west and southwest of Shanley's Lough. They are marked "Western mound" and "Southern mound" in Figure 8. The southern mound now lies in the southern cutaway, but on maps of the early 20th century it is shown inside the bog and marked as a mound. The other mound is now clearly visible in the bog as an elevated part with the slope beginning at about 200 m west of Shanley's Lough (Figure 9). It is entirely covered by peat –with fen peat on top- suggesting a considerable local subsidence. As the bog subsided and the shallow peat on the mounds subsided less than the deeper peat elsewhere, a higher zone in the bog formed. It diverted the flow from the more western part of Clara Bog West towards the drains and the road to the north and perhaps also to the south, where the bog has now been cut away.

This probably resulted in drier conditions in the region of today's Shanley's Lough than elsewhere and consequently a stronger subsidence. Most of the diverted flow was carried off by the Double and Triple drains. As these drains terrestrialised in the 19th century, the flow would have gone more southward over the bog itself, causing a natural rewetting of the area of Shanley's Lough. This might even be the origin of the lough itself, which means it is most likely man-induced. In the last decade of the 19th century, the terrestrialisation was probably sufficient to let the drains flow over. From palaeobotanic research, Van der Molen et al. (1992) suggested a minor climate change causing the regrowth of a hummock-hollow complex across the Triple drain in the late 19th century, but it seems more likely that this regrowth was caused by terrestrialisation of the drains and subsequent rewetting of the adjoining area (Van der Schaaf, 1999). As the drains terrestrialised, the flow was diverted to the then lower part of Shanley's Lough. Today's extremely wet conditions in this part of the bog are

Figure 10. Shanley's Lough: a bog pool probably caused by subsidence and natural rewetting (October 1990) (Photo Sake van der Schaaf).

directly related to the long flow paths and the flow pattern of a large catchment discharging through a relatively narrow strip of bog. This means a large L_u and a small f in the ratio $\frac{L_u}{fI}$ and thus a relatively low sensitivity to the surface slope I. Figure 8 indeed shows relatively large surface slopes in the area. In spite of the slope, the lower part of the area had a well-developed acrotelm (Van der Schaaf, 1998).

Because of the flow rate in the narrow zone of Shanley's Lough, the vegetation with *Betula pubescens, Myrica gale* and *Molinia caerulea* suggests slightly minerotrophic conditions, even though the ionic content of the water (predominantly Na^+ and Cl^-) tends to be slightly lower than more upstream in the catchment where a typical bog vegetation occurs (Kelly and Schouten, 2002). Probably the concept of rheotrophy, where water with a low ionic content is replaced rapidly, thus allowing the uptake by the vegetation of more ions than in stagnant water with the same ionic composition, is applicable.

Thus a cycle of drying and subsequent rewetting occurred over about the last 200 years, which even created a bog lake. This process is now repeating itself on the same bog, because as a result of increased subsidence, induced by continuing peat cutting at the southern bog margin and drainage of the cut-away, some new lakes have formed around 2000, one of almost the same size of Shanley's Lough (Ten Heggeler *et al.*, 2005). Indications are that the new lakes formed on places where the hydraulic conductivity of the mineral subsoil was larger than elsewhere, which would have caused some "extra" subsidence. However, this hypothesis was only supported by samples from the upper few dm of the mineral subsoil, because no equipment was available to drill deeper.

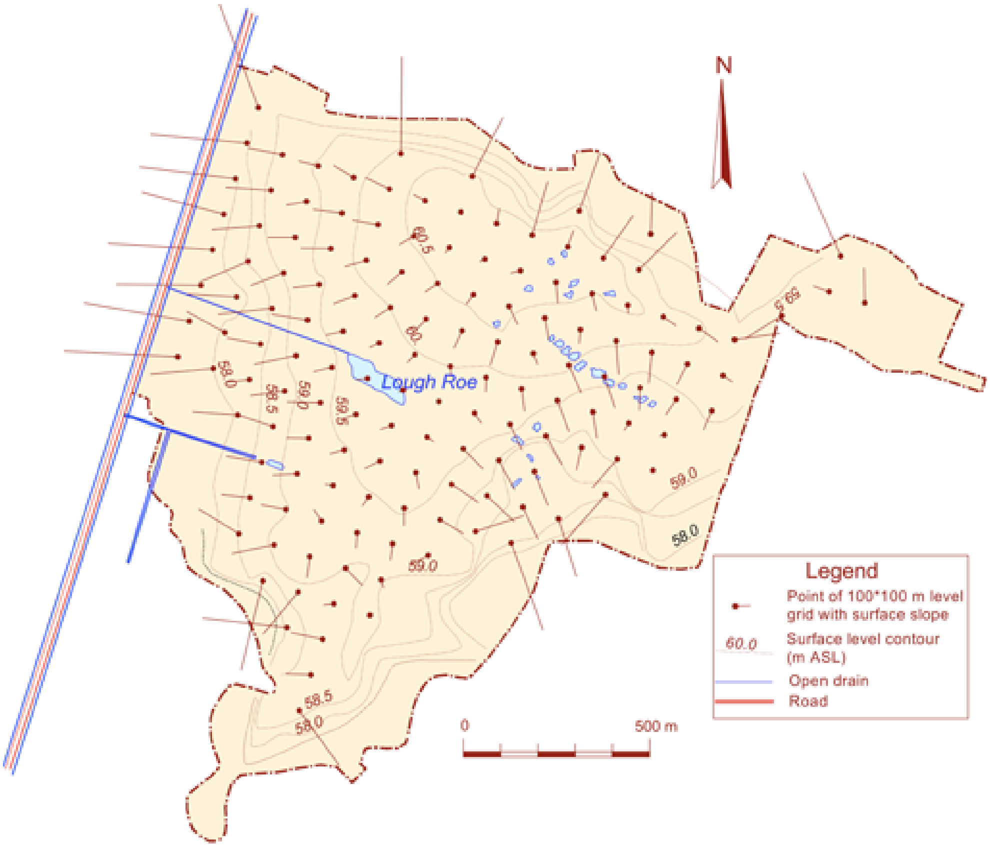

Figure 11. Clara Bog East.

The subsidence on Clara Bog West created a curve-shaped water divide along much of the margin. Thus the flow paths towards the bog margin have become short and the vegetation in the margin zone is now mostly dominated by *Calluna vulgaris* instead of *Sphagnum* species (Kelly and Schouten, 2002), even though the margin profiles show predominantly Sphagnum peat (Van der Schaaf, 1999). Like all Irish Midland raised bogs, Clara Bog must originally have been dome-shaped with a single apex in the centre and a diverging radial flow system. On the map of Figure 8, two small radial flow systems in the north can still be distinguished.

On Clara Bog East, no drains, associated with the bog road have been made and its flow system is still more or less radial.

However, the water divide lies rather eccentric in the north of the bog (Figure 11). Because neither from peat depth and stratigraphy (Bloetjes and Van der Meer, 1992), nor from the surface topography of the mineral subsoil (Warren *et al.,* 2002) any indication can be found that Clara Bog once consisted of two peat domes, a single dome must be assumed, which was at first forced into two domes by the hydrological impact of the bog road. Because much of the southern part of the bog has been cut away, subsidence probably caused the water divide to move northwards; a similar process as inferred for Raheenmore Bog. The northward movement of the water divide has stopped only recently after the drainage network, installed on Clara Bog East around 1983, was blocked in 1995 and 1996. From a comparison of surface levelling data of 1982 and 1990, it could be concluded that the water divide of Clara Bog East had moved northwards by about 100 m in less than 10 years. Measurements by the author at three benchmarks on different positions on the bog showed no significant subsidence from 1996 until 2002, whereas between 1982 and 1990 the average subsidence rate of the bog surface was about 4 cm per year (Van der Schaaf, 1999, 2002a).

Conclusions

Both theoretical considerations and observations show that bog subsidence, caused by superficial drainage, which not only includes artificial open drains or tube drains, but also drainage caused by an increased surface slope, often is a fast process in the beginning and may continue during a long time, because the drainage base subsides with the bog surface. Thus a large total subsidence may result. The compaction of the peat occurs mainly in the upper part.

Bog subsidence caused by increased loss of water to the mineral subsoil causes a compaction of the peat in the lower part of the profile and as a result of a strong decrease of the hydraulic conductivity in the compacted peat, the resulting feedback system causes the process of compaction to be more and more concentrated at the bottom of the peat. Consequently, this process of subsidence generally causes a smaller subsidence than the process mentioned under 1. It causes a dense peat layer with a very low hydraulic conductivity, that may eventually reduce water loss to the underlying mineral layers.

Subsidence causes changes in the surface slope and thus in the horizontal flow pattern of a bog, causing changing flow path lengths and wetness conditions, which themselves may create additional subsidence if a part of a bog becomes drier.

As a result of subsidence, water divides may change position, disappear and be replaced by new water divides, for example as shown in the example of Clara Bog West.

A water divide always moves away from the area of largest subsidence. Thus flow parts towards the subsided part may become longer and the catchment larger, resulting in drier conditions in parts that have not subsided, as shown in the example of Raheenmore Bog and Clara Bog East.

Subsided parts may eventually be rewetted as a result of ongoing changes in the flow pattern, as shown in the example of Shanley’s Lough, The forming of new bog lakes in this process could possibly be related to patches of larger hydraulic conductivity in the mineral subsoil, if a considerable part of the subsidence is caused by increased water loss to the mineral subsoil.

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The importance of gradual changes and landscape heterogeneity for aquatic macroinvertebrate diversity in mire restoration management

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Relict populations in degraded bogs

Raised bogs are threatened ecosystems, especially in Western Europe (Joosten & Clarke 2002) and temperate North America (Poulin & Pellerin 2001), due to drainage, afforestation, peat extraction and increased atmospheric nitrogen deposition. As *Sphagnum* growth is a necessary prerequisite for the restoration of peat-accumulating raised bogs, restoration measures in degraded bogs mainly focus on creating suitable hydrological conditions for re-colonization and growth of *Sphagnum* by blocking drainage ditches and building dams to retain rainwater and decrease fluctuations of the water table (e.g., Rochefort *et al.* 2003, Smolders *et al*. 2003, Vasander *et al.* 2003). Only in a few cases do measures focus on restoring suitable conditions for the animal species that depend on bog habitats. Recovery of characteristic fauna is often assumed to follow automatically in the course of time. Although animals, especially invertebrates, make up an important part of the total species diversity, relatively little attention has been paid to how restoration measures affect the fauna, both in raised bog remnants and other ecosystems (Longcore 2003, Van Duinen *et al.* 2003, Desrochers & Van Duinen 2006, Van Kleef *et al.* 2006).

To study whether raised bog restoration measures rehabilitate faunal diversity, we studied the aquatic invertebrate assemblages in degraded bog remnants in the Netherlands. Study sites were divided into two groups: 1) 27 sampling sites in bog remnants that where rewetted 1–29 years ago (rewetted sites), and 2) 20 sampling sites in non-rewetted Dutch bog remnants (remnant sites). These remnant sites were water bodies in bog remnants that had not been subject to large-scale restoration measures; rather, with the cessation of bog use (which was practised prior to 1950), the remnant sites continued to remain in forms such as abandoned water-filled hand peat cuttings and trenches used in buckwheat agriculture. The comparison between the rewetted and non-rewetted sites showed that the cumulative species richness for macroinvertebrates (like water beetles and larvae of dragonflies or midges) was lower at rewetted sites than at non-rewetted sites, both for total species richness and for characteristic species (Fig. 1; Van Duinen *et al.* 2003). In this study species were classified as characteristic of raised bogs if they were listed in literature as acidophilous, acidobiontic, tyrphophilous, tyrphobiontic or typical of raised bogs. This indicates that degraded bog remnants, with little or no botanical value, can still harbour many animal species, including characteristic and rare species.

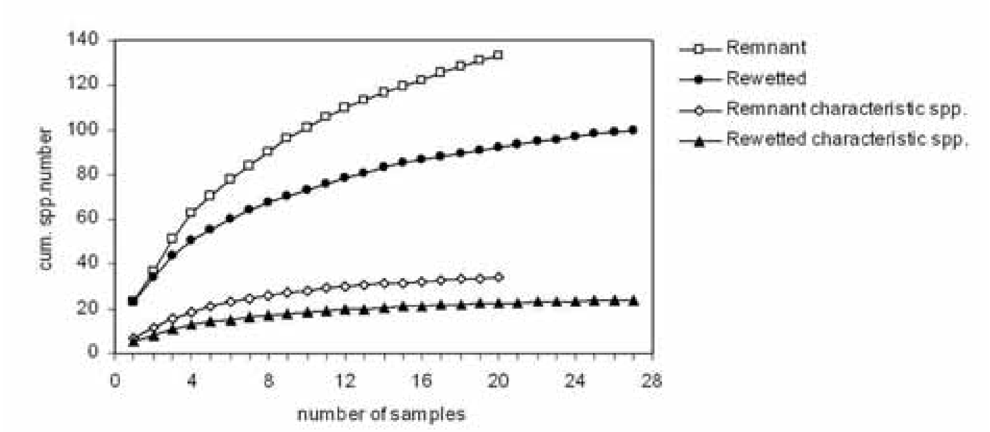

Figure 1. Cumulative species richness curves for all species and for characteristic species of macroinvertebrates in rewetted and (non-rewetted) remnant sampling sites in Dutch bog reserves. The curves are composed of averages of 250 random sorts of the sampling sites, with all samples taken at one sampling site pooled (modified from: Van Duinen et al. 2003).

Effects of rewetting measures

Since most restoration projects do not include a monitoring programme for invertebrates, their effect on the fauna, whether positive or negative, is generally unknown. Our comparative study between the rewetted and remnant (non-rewetted) sites showed considerable differences in the macroinvertebrate species assemblage (Fig. 2). Surface water quality and vegetation composition could not explain the observed differences in aquatic macroinvertebrate assemblages between these two groups of sites (Van Duinen *et al.* 2003). In addition, the variation in species composition between sites (Beta diversity) was much lower in rewetted sites, suggesting that rewetting measures have a homogenizing effect.

This comparative research provides a strong indication that there may be risks involved in the restoration of remnants, where rare and characteristic species are still present. This indication was confirmed in a study where aquatic invertebrates were studied in the *same* peatland area before and after measures took effect (Verberk *et al.* 2006a; Verberk 2008). These risks are twofold: 1) *rapid* changes causing a disturbance (shock effects) that species cannot cope with; and 2) *similar* changes, but on a large-scale, leading to a loss of variation between patches within one peatland (loss of heterogeneity), and consequently to a loss of species. In a subsequent study, we showed habitat heterogeneity to be a driver of mire biodiversity (Verberk *et al.* 2006b, Verberk 2008). These risks are faced particularly by characteristic species because many of these species occur either in low densities, or very locally in just a few sites, or both (thus contributing to the need to take restoration measures focussing on both flora and fauna), and because these species usually depend, within a peatland, on patches with specific characteristics.

Persistence and re-colonization

In order to inhabit restored areas, species either have to persist in the area during the process of degradation and restoration, or they have to re-colonize the restored area from source populations. Concerning persistence, aquatic macroinvertebrate species, which are characteristic for raised bogs, usually have slow growth and high tolerance

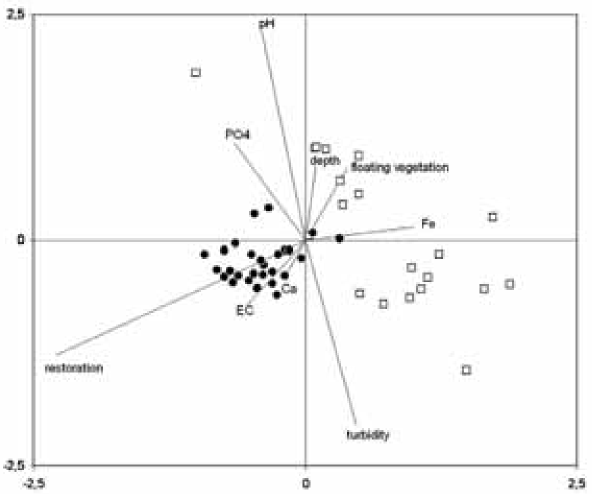

Figure 2. Correspondence Analysis plot of sampling sites based on presence/absence data of macroinvertebrate species. Significant environmental variables of surface water quality and vegetation are shown as lines. Filled circles represent rewetted sites, and open squares represent (non-rewetted) remnant sites in Dutch bog reserves (from: Van Duinen et al. 2003).

to drought and acidity. Due to their high tolerance, a number of species have been able to persist in the degraded bog remnants by surviving the slow process of degradation. However, many of these bog characteristic species have proved to be unable to cope with the rewetting of sites, most likely because the process of rewetting is much more rapid ("shocking") than the process of degradation. Other than this, rewetting tends to be large-scale and has the effect of lowering habitat diversity.

Moreover, in a study of natural and man-made bog pools in Canada, Mazerolle *et al.* (2006) concluded that some aquatic invertebrate species, including bog-associated species, readily colonize man-made bog pools created in a raised bog that had been mined for peat and where no aquatic invertebrates could have persisted. This conclusion is apparently valid for vagile aquatic beetle species of the genera *Acilius, Colymbetes, Dytiscus* and others found in the man-made bog pools in Canada, but probably not for more sedentary aquatic invertebrates, such as smaller water beetles, caddisflies, damselflies and aquatic oligochaetes (Van Duinen *et al.* 2007). Recolonization by these species is thought to be low, as many species that are adapted to life in the non-dynamic bog ecosystem are incapable or not inclined to disperse over long distances. For example some beetles have reduced flight muscles or non-functional wings, having established their current distribution in historic times when more marshland existed (Jackson 1955).

Due to cultivation and habitat deterioration, the distance between remaining bog habitats has increased. This may have reduced colonization rates of bog-associated macroinvertebrates even further. In our comparative study, many rare and characteristic species were still absent in rewetted sites after 30 years, even though source populations were present nearby, sometimes even in the same bog remnant. This may be attributed to the above mentioned low dispersal capacity of characteristic species, or, more alarmingly, to an incomplete restoration of the conditions needed by these species.

In contrast to aquatic macroinvertebrates, species assemblage and species richness of micro-crustaceans and rotifers (including bog-associated species) did not differ bet-

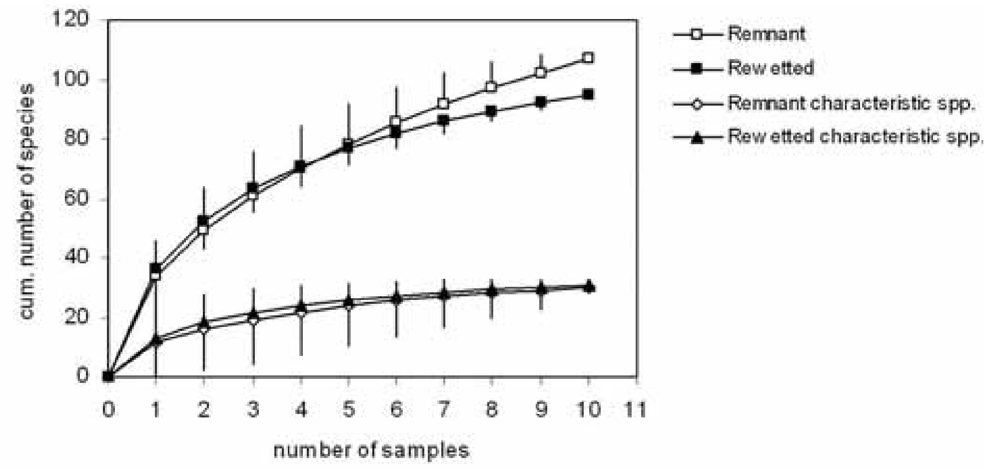

Figure 3. Cumulative species richness curves (± standard deviation) for all species and for characteristic species of microinvertebrates sampled in rewetted and (non-rewetted) remnant sampling sites in Dutch bog reserves. The curves are composed of averages of 250 random sorts of the sampling sites, with all samples taken at one sampling site pooled (from: Van Duinen et al. 2006).

ween rewetted and non-rewetted sites in Dutch bog remnants (Fig. 3; Van Duinen *et al.* 2006). Unlike that of many aquatic macroinvertebrates, the lifecycle of these microinvertebrates does not include different life stages with different habitat demands; furthermore, their development time is generally shorter. Therefore, microinvertebrates may have less strict demands on their environment regarding, e.g. vegetation structure and the combination of habitat elements (heterogeneity). In addition, the high (passive) dispersal rate of micro-crustaceans and rotifers (easy dispersal by wind and animal vectors [Cáceres & Soluk 2002; Cohen & Shurin 2003]), may explain this difference in the response of macroinvertebrates and microinvertebrates.

Importance of landscape heterogeneity

Intact bog landscapes have a high landscape heterogeneity with bog margins, transitional mires and lagg zones between the raised bog centre (mire expanse) and the surrounding mineral soil (Wheeler & Proctor 2000; Schouten 2002). Even within the raised bog centre, there is much variation between bog pools in terms of size and depth, vegetation structure, water flow and nutrient availability (Smits *et al*. 2002). Our study on aquatic macroinvertebrates in the Estonian raised bog system Nigula showed that these differences, both within the landscape and within the raised bog centre, were exploited by the species present. Characteristic bog species did not occur just anywhere in the bog, but showed distinct distribution patterns. Certain characteristic species preferred locations with either lower or higher concentrations of nutrients and minerals (Smits *et al.* 2002). Minerotrophic, hydrologically stable transitions supported many characteristic species (Fig. 4). A study in a Dutch degraded bog remnant showed that several characteristic species selectively reproduced in temporary pools and others in permanent pools (Van Duinen *et al.* 2004). Even though the average number of species per water body was lower in Estonia than in the Dutch bog remnants, the Estonian species accumulation curve was more steep than the curve for rewetted sites, indicating a higher β-diversity (heterogeneity) in intact raised bog systems (Van Duinen *et al.* 2002).

Figure 4. Female Northern emerald (*Somatochlora arctica*) just after ecdysis. For its larval development (which can take up to 5 years), this species typically selects very shallow puddles, with a slight water flow, which guarantees stable moisture conditions. Adults prefer open areas surrounded by trees. These reproduction waters are usually situated at bog margins within transitional mires (Photo W.C.E.P. Verberk).

Implications for conservation and restoration

The conservation of aquatic macroinvertebrates requires the avoidance of both temporary and permanent loss of water types or rapid shifts in the spatial configuration (also emphasised in Van Duinen *et al.* 2003). In nature reserves of high ecological value, a first priority of restoration management is the conservation of relict populations of characteristic species and landscape heterogeneity. A second priority is the strengthening of landscape heterogeneity by improving the quality of the various parts of the landscape (raised bog centre, lagg zone, transitional mire) and their transitions. Improving growing conditions for *Sphagnum* species is but a single goal, albeit important in the *long term* for restoring the acrotelm layer, and thereby, the internal hydrology of raised bogs. In the *short term*, conserving present nature values and improving their situation is important, particularly given the low re-colonization observed. Because influence of calcareous groundwater can also stimulate *Sphagnum* growth (Lamers *et al.* 1999), these goals can be reconciled when measures aim at improving the regional hydrology. These management goals can be achieved by taking measures outside the reserve, for example, reducing drainage (filling in ditches) and increasing infiltration (by logging trees). Should internal measures still be necessary, changes resulting from restoration measures should be slow and reversible, allowing species to gradually redistribute in response to the changes (Van Duinen *et al.* 2004). In addition, phased implementation of the measures, i.e. changing only small parts at a time, may allow local populations to recover from disturbance or re-colonize from adjacent unchanged locations. In sum, restoration measures should be directed at *gradually* improving growth conditions for *Sphagnum* and increasing the heterogeneity of the landscape, within the raised bog centre as well as transitions to the surrounding mineral soil (or agricultural or forested surroundings). This requires more attention to the landscape scale in bog restoration projects.

Tailor-made designs

Bog remnants differ in their geomorphological setting, remnant area and peat extraction history, therefore requiring tailor-made designs. Some significant questions to consider are: 1) what baseline inventories are necessary to assess the present species diversity, key processes in ecosystem functioning and factors limiting perspectives for restoration? 2) how can information from the different disciplines (hydrology, biogeochemistry, vegetation and animal ecology) be integrated for the optimal restoration strategy to be performed in a specific project area? 3) how can monitoring and interpreting the response of the species to restoration measures be used as a tool for "fine-tuning" the measures? Within the framework of the LIFE Nature Co-op project, "Dissemination of ecological knowledge and practical experiences for sound planning and management in raised bogs and sea dunes", two workshops were organised to facilitate international exchange of expertise to help with optimizing nature conservation and restoration measures. Based on common sense and experience, the PROMME approach was adopted by the participants of the workshops as a useful framework for the set up of restoration projects. PROMME is meant to check for pitfalls in the restoration process. This decision support system is freely available on the LIFE Co-op project website, www.barger.science.ru.nl/life, and further described and illustrated in Brouwer et al. (2005).

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Mires in Slovakia - present status and conservation

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Introduction

Mires are recognised as one of the most threatened habitats in Slovakia. Although their size is small (and they have never been widely distributed in the country), they are of high importance for biodiversity, conservation and ecological functions.

Slovakia (area 49 036 km^2; population 5,324 million) is located on the border between the Carpathian Mountains and the Pannonian Plain. The number of vascular plant species exceeds 3200, the highest diversity in the Central European countries. This fact is also reflected by the diversity of Slovakian mires, especially rich Carpathian fens. They contribute significantly to Slovakia's biodiversity and contain a high number of threatened species and plant communities.

Classification

Classification of the mire communities is rather complicated. There are several classification systems used in Europe. The first and comprehensive vegetation survey of mire communities of the former Czechoslovakia was published by Rybníček & al. (1984) and followed by detailed studies by Rybníček (1985). The authors adopted a combined classification approach: combination of diagnostic plant species with special emphasize on bryophytes reflecting the trophic level and other ecological and dynamical aspects of mire habitats. The survey of mire communities by Valachovič (2001) is based on an earlier survey by Rybníček & al. (1984). However, it contains some simplifications (leaving out some of the alliances and associations).

Three main types of mires can be described:
a) raised bogs (*Oxycocco-Sphagnetea, Sphagnetalia medii*; *Scheuchzerio-Caricetea fuscae*, *Scheuchzerietalia palustris*) (Fig. 1);
b) transition mires (*Schechuzerio-Caricetea fuscae*, *Scheuchzerietalia palustris*, *Caricetalia fuscae*);
c) rich and poor fens (*Scheuchzerio-Caricetea fuscae*, *Caricetalia davallianae*, *Molinio-Arrhenatheretea*, *Molinietalia*) (Fig. 2).

Figure 1. Raised bog near Temnosmrečinové pleso in the High Tatras (Photo Daniel Dítě).

These three main types cover also forested peatlands:

- Fen Alder Woods (*Alnetea glutinosae*, *Alnetalia glutinosae*, *Alnion glutinosae*)
- Willow Fens (*Alnetea glutinosae*, *Salicetalia auritae*, *Salicion cineraeae*)
- Birch Fens (*Vaccinio-Piceetea*, *Piceetalia excelsae*, *Betulion pubescentis*)
- Spruce Bogs (*Vaccinio-Piceetea*, *Piceetalia excelsae*, *Eu-Vaccinio-Piceenion*).

However, the classification of forest mires has not been published yet, it is still the subject of detailed studies.

Distribution of mires

Mires have been spread almost all over Slovakia. Most frequently they can be found in the mountains (the sub-mountain to lower alpine zone of the Tatras), and in the regions of Orava, Liptov, Turiec, Spiš and Pohronie). They are rare in lowlands (Záhorská Lowland and Podunajská Lowland). One can encounter raised bogs in the High and Low Tatras (the sub-mountain to lower alpine zone), Orava and sub-Tatra basins. The bogs represent an important refuge for boreal flora in Central Europe and the southern boundary of bog distribution lies in Slovakia due to climate conditions. Fens occur also at lower altitudes.

First inventory of mires in Slovakia, with the focus on the mapping of non-forested mires for exploitation purposes and for the conservation of some selected sites, started in 1958 and took several years, until 1968. The main results (Table 1) were published by Raučina & Janota (1963) and Raučina (1968). Dohnal (1965) presents regional distribution of mires in former Czechoslovakia.

The Geobotanical map of Czechoslovakia, part Slovakia (Michalko & al. 1986) is a result of long term vegetation mapping and presents the reconstructed natural vegetation, i.e. the vegetation that would occur in the absence of human activities during historic times. According to that map, mires were distributed almost on the area of

Figure 2. Rich Carpathian fen Vysoká bazička near Spišská Belá (Photo Daniel Dítě).

26 000 ha, which is 0,57 % of the total area of Slovakia (Stanová 2000). For mapping purposes, an area with the depth of peat layer more than 40 cm was considered as a mire. The potential area of different types of mires is presented in Table 2.

There was no recent mire inventory in Slovakia up to the late 1990s, when Wetlands International Central European Peatland Project started (1999-2001). According to the database, which was made as a part of the project, the area of mires was estimated to be 2575 ha (the estimation was based not on mapping but only on expert judgement). So the loss of mire habitats was about 90% of the initial area.

Another project - Conservation and Sustainable Use of Peatlands in Slovakia (2001 – 2003), which was supported by the Danish Cooperation for Environment in Eastern Europe (DANCEE), brought up detailed mapping of mires: 1213 sites were mapped with the area of 2747 ha. The results first of all were used for NATURA 2000 sites designation.

Recently, in 2005 a new project Conservation, Restoration and Wise Use of Rich Fens in the Slovak Republic was started. The duration of the project was 2005 - 2009 and it was supported by UNDP/Global Environment Facility (GEF). The project was aimed at the conservation of Carpathian peatland biodiversity, with a focus on calcareous fens, a unique ecosystem with its center of distribution in Slovakia.

Conservation

The area covered by mires in Slovakia initially was very limited, the sites with mire habitats are often small and the loss of almost 90 % of mire habitats underpins the strong need for their protection.

The first national park in Slovakia, the High Tatras, was established in 1948 and mires have been protected as one of the features of the vegetation cover since. The oldest

Table 1. Distribution of non-forested mires in Slovakia by Raučina & Janota (1963) and Raučina (1968).

Geographical region	Number of localities	Area (ha)	Type
Podunajská nížina Lowland	80	4506	fens
Záhorská nížina Lowland	37	511	fens, transition mires
Orava region	27	312	raised bogs, transition mires
Liptovská and Turčianska kotlina hollows	83	271	all types
Tatra Mts.	81	557	all types
Spiš region	9	167	fens, transition mires
River Hron valley	19	26	fens, transition mires
Total	336	6350	

Table 2. The area of different types of mires in Slovakia according to the Geobotanical map by Michalko & al. (1986).

Type of peatland	Area (ha)
Fen Alder Woods (*Alnetea glutinosae*)	1827
Birch Fens (*Molinio-Betuletum*)	2243
Spruce bogs (*Eu-Vaccinio-Piceenion*)	8434
Calcareous Fens (*Caricetalia davallianae, Molinion coeruleae*)	11764
Raised bogs and transition mires (*Oxycocco-Sphagnetea, Scheuchzerietalia palustris, Caricetalia fuscae*)	1695
Total	25963

small scale mire protected area is Nature Reserve Rojkovské rašelinisko, which came under protection in 1950.

The current Slovak legislation, Act on Nature and Landscape Protection from 2002, ensures protection of nature and landscape, with five different levels of protection, following IUCN criteria.

For mire areas with no special protection (first level of protection), approval of the Nature Conservation Body (Regional Environmental Office) is required for any activity changing state of wetlands (including mires).

The most important mires have been given special protection (from second to fifth level of protection) and they create a national network of protected areas. The total network of protected areas including buffer zones covers more than 22 % of the Slovak territory. 2773 ha of wetlands are protected by law, contained in 115 small scale protected areas (Protected Sites, Nature Reserves, Nature Monuments). 13 areas are bogs (445 ha), 93 are fens (1,994 ha) and 9 are mixed mires (335 ha). On the large scale, Protected Landscape Area Horná Orava was established for the protection of all types of mires in 1979.

Four localities have been included in the List of Internationally Important Wetlands under the Ramsar Convention: Šúr, Rudava River Valley, Turiec wetlands and Wetlands of the Orava Basin. Mires have been protected as one of the features of the vegetation of these sites and it is estimated that mires cover about 1500 ha within these sites.

NATURA 2000

Since May 1st, 2004, when Slovakia became a member state of the European Union, many mire sites became protected under the Birds Directive within Special Protection Areas (SPAs) and/or under the Habitats Directive as proposed Sites of Community Interest (pSCIs).

Birds Directive

The National List of proposed Special Protection Areas was approved by the Resolution No. 636/2003 of the Slovak Government in June 2003. 38 SPAs were listed and they cover 1 236 545 ha (25.2 %) of the territory of Slovakia (Králiková & Gojdičová 2004). The overlap of SPAs with the national network of protected areas is 55.15 %.

Habitats Directive

The National List of proposed Sites of Community Interest was approved by the Resolution No. 239/2004 of the Slovak Government in March 2004. 382 pSCIs were listed and they cover 574 110 ha (11.7 %) of the territory of Slovakia (Králiková & Gojdičová 2004). The overlap of pSCIs with the national network of protected areas is 86 % (Fig. 3).

The habitats and species listed in the Habitats Directive Annexes, which occur in Slovakia are as follows:
51 flora species (Annex II: 49, Annex IV: 40);
160 fauna species (Annex II: 106, Annex IV: 119);

66 types of habitats in Annex I occur in Slovakia, from which 19 are forest habitats (forests cover more than 40% of Slovakia); 17 are grasslands (grasslands cover about 15% of Slovakia); seven are mire habitats (see Table 3)**;** and 23 are other non-forest habitats (rocks, shrubs etc.(they cover ca. 5% of Slovakia). Stanová and Valachovič (2002) gave a detailed description of all types of habitats.

According to the conclusions of the Alpine and Pannonian biogeographical seminars held in 2005, the Slovak National List of pSCIs was evaluated on 66,3 % in the Alpine zone and on 59 % in the Pannonian zone as sufficient (no further sites needed) or insufficient (more sites required but habitats are present on sites already proposed for other habitats/species). However, it is necessary to complete the national list with sites covering the following habitats: transition mires and quaking bogs (7140), petrifying springs with tufa formation (7220*) and alkaline fens (7230) (Fig. 4).

Table 3. Mire habitats (Annex I of the Habitat Directive) occurring in Slovakia.

NATURA 2000 Code	Habitat type	Area/ha in SK	Area/ha covered by pSCI
7110*	Active raised bogs	95	78
7120	Degraded raised bogs	17	10
7140	Transition mires and quaking bogs	710	370
7150	Depression on peat substrates of the *Rynchosporion*	5	2.3
7210*	Calcareous fens with *Cladium maricsus* and species of the *Caricion davallianae*	3	2
7220*	Petryfying springs with tufa formation	7	7
7230	Alkaline fens	902	350

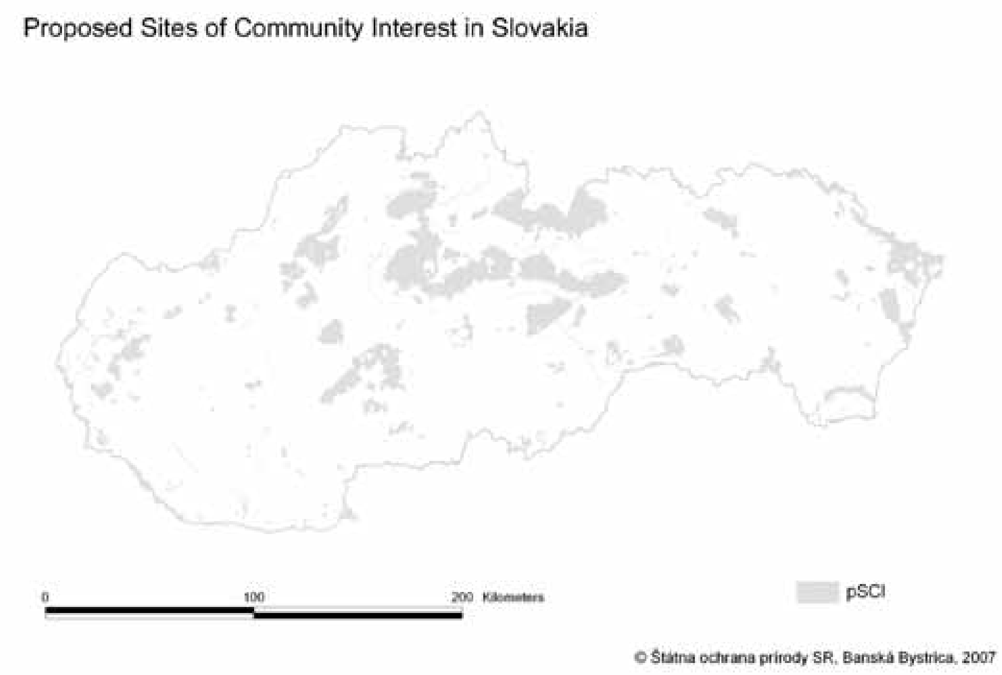

Figure 3. Distribution of proposed sites of Community Interest in Slovakia. Author: Želmíra Šípková.

Species diversity

Mire habitats contribute significantly to the biodiversity of Slovakia and contain a high number of threatened species and community types. For example, in the Nature Reserve Rojkovské rašelinisko, 160 plant species and 17 plant communities have been recorded within an area of 2.9 ha (Háberová & Fajmonová 1995). In the National Nature Reserve Abrod with the area of 92 ha, 480 vascular plant species have been recorded, of which 18 % are rare and threatened (Stanová 2000).

Several endangered species of Slovakia (Feráková et al. 2001) are restricted to the mire habitats, e.g. *Calla palustris, Carex chordorrhiza, C. limosa, C. lasiocarpa, Cladium mariscus, Ledum palustre, Rhynchospora alba, Schoenus nigricans, Sesleria uliginosa, Pedicularis sceptrum-carolinum, Salix myrtilloides, Liparis loeselii* and the bryophytes *Bryum marratii* and *Campylium elodes*. The scientific names of plant species follow Marhold and Hindák (1998).

Some of the rare glacial relict moss species (Kubínska et al. 2001) *Calliergon trifarium, Catoscopium nigritum, Helodium blandowii, Hypnum pratense, Meesia triquetra, Paludella squarrosa, Scorpidium scorpioides* and *Tomenthypnum nitens,* have their southern distribution limit in Slovakia.

The rare *Sphagnum balticum* and some of rare vascular plants, e. g. *Carex pauciflora, Scheuchzeria palustris* and *Drosera anglica*, are mainly found in raised bogs and transitional mires.

Mapping of the mire habitats has contributed not only to the knowledge on their recent distribution but some new localities of threatened plant species have been recorded, e.g. *Scheuchzeria palustris* in Kubínska hol`a (Dítě & Kubandová 2005), *Carex magellanica* in Surdíky, Orava (Dítě & Pukajová, 2003) and *Drosera anglica* in Strážovské vrchy (Dítě & al. 2006).

Figure 4. Distribution of alkaline fens in Slovakia. Author: Želmíra Šípková.

Threats to and present status of mires

The use of mires in the territory of Slovakia goes back in the past as far as the Middle Ages. However, the use was mostly at the local level and not very intensive. Traditional use included small-scale grazing and mowing, berry-picking and in some regions peat was used as a fuel. The importance of peat increased in the 19th century when it was used in balneotherapy and as a fertilizer in agriculture and for horticultural purposes. The use of peat as a raw material for industry has never been significant (Dohnal 1965).

The period of 1950s and 1960s brought more interest in peat extraction, which in 1970s and 1980s was followed by intensive drainage of mire areas and their conversion either into grasslands or arable land, or were simply destroyed by construction activities. The country development thus resulted into a dramatic loss of mires. Efforts to give special protection to mires were not always successful. Nevertheless, some valuable mires have been protected by law within the national network of protected areas or nowadays there are also protected by NATURA 2000 network. However, in many cases the habitats are not in a favourable conservation status. In the past they were very often drained or were affected by some melioration activities. Disturbance of the water regime and water chemistry in a mire or in its surroundings means significant threat to the habitat.

Many mires, especially fen habitats have been used by man for centuries and they depend on management, mainly on hand mowing or mowing with light machinery. In spite of the fact that after 1990 the land-ownership changed and now, besides the state as an owner, there are many private owners (individuals, churches, various companies and societies). The new land owners are not interested in the management and traditional use of mires which includes small scale mowing, and cutting of overgrowing trees and shrubs. Currently, this management is not economically profitable and majority of mire localities is not managed. Accumulation of biomass then leads to the secondary succession.

In many cases inappropriate forest management practices, development of recreation resorts and other construction activities or intensive agriculture interfere with the objectives of mire conservation. The most recent example is Slovakia's most important site with the occurrence of *Cladium mariscus* (Nature Reserve and pSCI Močiar) that was damaged by some construction activities in 2006.

Fortunately, in mountain areas, mostly in the High Tatras, there are still some small-scale localities with the occurrence of raised bog plant communities that are in favourable conservation status (Polák & Saxa 2005) and they do not require special management measures.

Outcomes of the recent UNDP/GEF project should demonstrate best practices in restoration and management of fens and further they should be applied in the maintenance of favourable conservation status of NATURA 2000 sites with the mire habitats.

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Status and Protection of Heilongjiang Wetlands in North-eastern China

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Introduction

Heilongjiang province is famous in China for its wetlands. The area of Natural wetlands is 4,34 million ha, accounting for 8.22% of the whole province area, and accounting for 8.78% of the country's wetlands. It is distributed mainly in Sanjiang plain, Songnen plain, Daxing'anling and Xiaoxing'anling. 41 wetland reserves have been established in Heilongjiang province, and the total protected area is 1,42 million ha, accounting for 32.7% of the whole province's wetlands. They include 5 national reserves: Zhalong, Xingkaihu, Sanjiang, Honghe and Qixinghe reserves, and their total area is 621 thousand ha. There are also 12 provincial reserves, covering 566 thousand ha, and 24 town reserves covering 233 thousand ha. Regarded as internationally important wetlands (RAMSAR areas) are Zhalong, Lake Xingkai, Honghe and Sanjiang wetlands. 13 wetlands are included in the checklist of nationally important wetlands, e.g. Qixing River, Naoli River valley, Jingpo Lake wetland, Tangwang River valley wetland and Nenjiang headwaters wetland.

The wetlands are affluent in wildlife resources and have a high number of species including 800 wetland plants, 558 vertebrates (50 mammals, 361 Birds, 11 amphibians, 16 reptiles and 120 fishes), and 991 plankton species.

Materials and methods

To collect data on the biodiversity of wetlands we have worked with topographic maps, GPS, telescope, fish and bird illustrated handbooks, and field guides to mammals and plants. The method to study wetland vegetation has been analysis of sample plots. Fish investigations use catch method. For birds, amphibious animals, reptiles and mammals we have used sample and transect census methods. The length of transects are 3-5 kilometres. The width of transects is about 500 metres. We observed and recorded the species and their numbers on the both sides of the transect line. The nomenclature of birds in this article follows Dickinson (2003).

Results

Zhalong wetland

Zhalong wetland is located in the lower reaches of Wuyuer river in Songnen plain (Fig. 1), and it is an important wetland that now is the biggest protected wetland area with the most high biodiversity. Its geographic coordinates are 123°51.5′-124°37.5′ E, 46°48′-47°31.5′ N, and total area is 210 thousand ha.

Zhalong wetland is an inland swampy wetland that developed in the alluvium of Wuyuer River and Shuangyang River Fig. 2. When water runs to Zhalong wetland, it has lost visible riverbed. Instead, there is a wide freshwater swampy wetland. The major protected object is marsh ecology and rare endangered species of waterfowl, such as Red-crowned Crane (*Grus japonensis*). According to the investigation, Zhalong wetland includes 648 vascular plant species (67 families), 22 mammal species (9 families), 6 amphibian species (4 families), 6 reptile species (2 families), 46 fish species (9 families), and 269 bird species (48 families). Among them, national category I protected birds include Oriental White Stork (*Ciconia boyciana*), Golden Eagle

Figure 1. The location of the studied wetlands in Heilongjiang province: 1. Zhalong, 2. Honghe, 3. Sanjiang, 4. Xingkai.

Figure 2. A view over Zhalong wetland (Photo Raimo Heikkilä).

(*Aquila chrysaetos*), Red-crowned Crane (Figure 3), Siberian Crane (*Grus leucogeranus*), Hooded Crane (*Grus monacha*) and Great bustard (*Otis tarda*). National category II for protected birds includes 36 species, such as White-naped Crane (*Grus vipio*), Eurasian Spoonbill (*Platalea leucocordia)* and Whooper Swan (*Cygnus cygnus*). Crane resource is the most abundant here. There are 10 species in China of all the 15 crane species of the world, and Zhalong has 7 species. Red-crowned Crane (Fig. 3), White-naped Crane, Common Crane (*Grus grus*) and Demoiselle Crane (*Anthropoides virgo*) are breeding here. Siberian Crane, Hooded Crane and Sandhill Crane (*Grus canadensis*) migrate through Zhalong and stay for some time in migrating season. The amount of breeding Red-crowned Crane has reached 200 pairs. The number of breeding Red-crowned Crane accounts for 1/6 of the world population, and Zhalong is the biggest Red-crowned Crane breeding base, and is well-known in the world.

Honghe wetland

Honghe wetland is located in the northeastern part of Sanjiang plain. The geographic coordinates are 133°34′38″-133°46′29″ E and 47°42′18″-47°52′ N. It is unique in Sanjiang plain, and even in other similar biogeographical regions in the world. The area contains nearly all species of Sanjiang plain, including lots of endangered, vulnerable or rare species internationally and nationally. It covers 21836 ha. The topography is smooth, and the flat alluvial plain is wide. The penetrability of the soil is weak, and the river waters spread over the plain during flood periods. It retains Sanjiang plain's typical natural marsh ecosystems. The vegetation in the reserve is in natural state, mainly including mire and aquatic vegetation, and has some forest islands.

The fauna and flora are diverse and rich in the area. There are 284 species of wildlife, including 32 families and 174 species of birds. There are 10 endangered bird species being protected by the country such as Oriental White Stork, Black Stork (*Ciconia nigra*), Red-crowned Crane, White-naped Crane, Mandarin Duck (*Aix galericulata*), Whooper Swan, White-tailed Sea Eagle (*Haliaeetus albicilla*), Steller's Sea Eagle (*Haliaeetus pelagicus*), Greater Spotted Eagle (*Aquila clanga*) and Black-billed Capercaillie

Figure 3. A couple of Red-crowned Crane in Zhalong wetland (Photo Raimo Heikkilä).

(*Tetrao parvirostris*). There are 1012 plant species in the area, including 6 endangered species: Wild Soybean (*Glycine soja*), Manchurian Ash (*Fraxinus mandshurica*), Manchurian Walnut (*Juglans mandshurica*), Amur Corktree (*Phellodendron amurense*), Siberian ginseng (*Acanthopanax senticosus*) and Milk-vetch root (*Astragalus membranaceus*). Protecting the Honghe wetland has established a permanent gene bank for China, and it has a remarkable practical significance.

In 1996 the area was promoted for the state-level nature reserve, and in 2002 it was included in the list of internationally important wetlands.

Sanjiang wetland

Sanjiang wetland is located in the northern part of Sanjiang plains. It is in the connection of the Heilongjiang River and Wusulijiang River, and near the towns Fuyuan and Tongjiang . The geographic coordinates of the reserve are 133°43′20″-134°46′40″ E and 47°26′-48°22′50″ N, and the area of the reserve is 198100 hectares. In 2002 it was included in the list of internationally important wetlands.

Sanjiang reserve belongs to the type of inland wetlands and water ecosystems. The vegetation in the reserve is mainly marsh meadow, and there are some forest islands, which are in natural state. The water system of Heilongjiang River and Wusulijiang River feed the reserve, and lakes spread all over. In the reserve there are 57 rivers, 201 lakes, and 26 islands in the lakes. According to primary investigation, there are 291 vertebrate species, which include 37 species of mammals, 167 species of birds, 5 species of amphibians, 5 species of reptiles and 77 species of fish. In addition, 126 species of insects have been recorded so far. There are 9 species of Category I nationally protected animals such as Oriental White Stork, Red-crowned Crane and White-tailed Sea Eagle, and 32 species of national category II protected animal species such as Whooper Swan, White-naped Crane, Common Otter (*Lutra lutra*) and Lynx (*Lynx lynx*). The resources of wild plants are rich, there are 992 species of vascular plant,

Figure 4. Sanjiang wetland (Photo Li Lin).

which include some nationally protected plants like Wild Soybean, Amur Corktree and Manchurian Ash. It is also an important channel and resting area for the migration of Northeastern Asia birds.

Xingkai Lake wetland

Xingkai Lake wetland is located on the border between China and Russia in the southeastern end of Sanjiang wetland. It is the most typical and biggest wetland area in Sanjiang plain. The geographic coordinates of the reserve are 133°43′20″- 134°46′40″ E and 47°26′48″- 48°22′50″ N.

Its major protective objects are Red-crowned Crane, Oriental White Stork，White-tailed Sea Eagle and Xingkai Lake Pine (*Pinus ussuriensis*). Its total area is 222 488 ha. There is a wide lake and a great deal of rivers and marshes, a large area of forests, and all of these form a complex and steady ecosystem, and have a rich biodiversity. According to the primary statistics, it includes 690 vascular plant species, such as Xingkai Lake Pine and Amur Linden (*Tilia amurensis*). There are 10 nationally rare endangered plant species. The fauna consists of 341 vertebrates that contain 68 fish, 7 amphibian, 7 reptile and 39 mammal species. Japanese deer (*Cervus nippon*) is the national Category I protected animal. Asiatic black Bear (*Selenarctos thibetanus*), Common Otter, Snow Hare (*Lepus timidus*) and red deer (*Cervus elaphus*) are the national category II protected animals. Among amphibians, Soft-shelled Turtle (*Trionyx sinensis*) is a globally endangered animal. The most typical wildlife resource is birds. According to the statistics, there are 232 species including 50 national keystone protected species. Red-crowned Crane, Siberian Crane, Hooded Crane, Oriental White Stork, Scaly-sided Merganser (*Mergus squamatus*), White-tailed Sea Eagle, Golden Eagle, Steller′s Sea Eagle and Eastern Imperial Eagle (*Aquila heliaca*) are the national category I protected Birds. 41 species such as Whooper Swan, Tundra Swan (*Cygnus columbianus*), Greater White-fronted Goose (*Anser albifrons*), White-naped Crane and Mandarin Duck are national category II protected birds. There are 14 globally endan-

Figure 5. Extensive fen in Xingkai wetland with a couple of Oriental White Storks (Photo Raimo Heikkilä)

gered bird species. Populations of more common bird species inhabiting the reserve such as wild geese, ducks, snipes and gulls are totally over 40 thousand individuals. The number of breeding Red-crowned Cranes is about 100 pairs, and makes it the second biggest wild Red-crowned Crane breeding population. Xingkai Lake is not only the biggest waterfowl breeding base in Sanjiang plain, but the biggest resting area during the migration. Account of migration has reached 500 thousand individuals just in the eastern non-frozen water of the lake. Every year during spring and autumn over 2 million birds migrate through Xingkai lake.

Xingkai Lake reserve has been included in the ***Ramsar Convention***, and became one of the most important of the 21 world keystone wetlands in China.

Threats and possible solutions

At present, Zhalong wetland has faced the problem of lacking water. Due to the Shengli reservoir in the headwater of Wuyuer river, and using of agriculture development, the water capacity of Zhalong wetland is lacking badly. Every year the water capacity of Zhalong wetland lacks 300 million cubic metres. Because of lacking water, over ten years a part of reed marsh has degenerated into swampy meadow. Government and wetland management department has taken measures to supply water, so as to relax the pressure of Red-crowned Crane breeding for lacking water.

The most important problem of Honghe wetland is the exploitation of agriculture around the wetland several years ago. The exploitation was done with the channel drain manner and the level of water around the wetland has descended, then turns the wetland to farmland, so that the level of wetland descends and the original wetlands are partly destroyed. In recent years the protection and management section has adopted guaranteesfor the water and the impoundment. Measures like rising up water to the wetland by constructing dams in the canals have worked for recovering the wetland.

The major threat came from agriculture development in Sanjiang wetland as well. Excessive opening up arable land in the wetland has destroyed the original features and its integrality, and it has destroyed the wetland resource more or less. The government has taken available measures to stop it.

The most serious problem is caused by the Xingkai Lake farm company settlement in the core of the wetland area. It threatens the whole wetland protection, and has destroyed the integrality of the wetland. Furthermore, development of fishery and tourism has also threatened the protection of wetland. At present, the government has carried out a migration plan for the farm gradually to decrease the threat.

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Experimental grazing management on peatlands of the French Basque Land

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Introduction

Peatlands of the Basque mountains experience very high grazing pressure, in contrast to wetlands on the plain hills which are affected by the abandonment of farmlands (Fig. 1). This has also been studied on a longer time scale, considering the evolution of human impact on these mountains (Galop 1999). Nowadays, concentrated or repeated trampling by livestock on these wetlands can result in a degradation of peaty substrates and alteration of natural habitats and populations of valuable species (Fig. 2).

Our first focus is on management experiments on Mondarrain Massif that test different types of fencing devices for small spring and slope mires. These experiments have been conducted since 1996, led by CREN Aquitaine (Conservatoire Régional d'Espaces Naturels d'Aquitaine) (Gansoinat 1996). We try to draw lessons from the results of these experiments.

Secondly, we consider how this experience can be adapted for other mires of the Basque Land Mountains. For this, we also consider the 2006 diagnosis of Archilondo mire made by CREN Aquitaine (Le Moal 2006) during its leadership of a network of wetland managers intended for technical assistance.

The experiment of fencing and monitoring peat areas on Mondarrain Massif

During a regional inventory of accessible peatlands conducted in 1994 (Junique 1994), CREN Aquitaine identified the peat areas of Mondarrain Massif as sites where urgent protection measures were required, considering the natural habitats present, the protected plant species found here (noted in Royaud 1996), and the overgrazing that seems to alter this natural heritage. Therefore, in 1996, CREN Aquitaine implemented research, (Gansoinat 1996) conservation management and public awareness measures, which were included in a 'LIFE Nature' programme called "Tourbières de France", co-ordinated by the French Federation of Natural Areas Conservancies (FCEN). in addition, the inventory of peatlands of the Pyrénées-Atlantiques district (Royad 1996) recognised the Mondarrain Massif mires*"as remarkable and in need of urgent intervention"*. This motivated the French State to include these peatlands in the preliminary inventory of proposed Sites of Community Importance (DIREN Aquitaine 1996).

Figure 1. Peat patch overtrampled by cattle and horses, Mondarrain, Pyrénées-Atlantiques, France (Photo by CREN).

Figure 2. Regular livestock traverse causes damages, Mondarrain, Pyrénées-Atlantiques, France (Photo by CREN).

The slope and spring mires, located at an altitude of less than 800 m, have an area of 10 to 3000 m^2 and a depth of peat never exceeding 40 cm. Thus, these wetlands were called 'placages tourbeux', which can be translated as 'leptic peatlands'. These peatlands are furthermore characterised by the oceanic influence of the climate, with high rainfall averages (1483 mm yearly in Biarritz at sea level, and higher at higher altitudes), and rather high annual mean temperatures (13.7°C). They include several habitats of community interest, some of them priority habitats (*), such as Sphagnum hummocks*, *Narthecium ossifragum* Western heaths, *Rhynchospora alba* pioneer communities, Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix** and with *Sphagnum*, associated with many other wet natural habitats, and with meadows and mesophile heaths.

The following plant species, typical of these wetlands, are present, and are protected at a national or a regional scale: *Lycopodiella inundata, Drosera intermedia, D. rotundifolia* and *Narthecium ossifragum*. Seven species of *Sphagnum* have been identified. In 1996, during the LIFE Programme "Tourbières de France", CREN Aquitaine acquired rights to 320 ha of land when a conservation and management agreement was signed with the communities of Itxassou (Itsasu in the Basque language) and Espelette (Ezpeleta). The same year, a management plan was developed (Gansoinat 1996) concerning the main peat patches of the massif, with an area estimated to be about 20 ha. Grazing on these leptic peatlands appears to be necessary to maintain a structure of vegetation open enough to maintain the highest botanical diversity. Nevertheless, the concentration of livestock on these areas, even temporarily, may physically damage or destroy the vegetation typical of mires, and erode the peat substrate.

Furthermore, the presence of these animals leads to nitrogen enrichment of the soils and alters the type of vegetation in favour of more common species. Four kinds of animals graze on the heaths of Massif du Mondarrain: 'Pottok' (Basque ponies), dairy ewes of 'Monech' and 'Basco-béarnaise' breeds, 'Betisu' (Betisoak or Betisuak) half-feral rustic cows (Fig. 3), and Pyrenean goats. Mainly horses and sheep graze on Mondarrain, but peatland degradation is first caused by the repeated trampling of horses and cattle.

Figure 3. 'Betissu' cattle on Mondarrain, Pyrénées-Atlantiques, France (Photo by CREN).

On this basis, three types of livestock management were tested and monitored, so as to compare their efficiency for the conservation of the natural habitat :

- total fencing on one peat patch: the fence completely prevents all farm animals from entering the wetlands;
- selective fencing on two peat patches: the fences allow free access for sheep only, but prevents horses and cattle from entering (Fig. 4);
- free access for all animals on a fourth peat patch.

At the same time, four drinking troughs were provided downstream of the peat areas, to compensate for the reduced water availability resulting from the fencing.

Two types of phytosociological relevés were implemented in 1999, 2000 and 2001:

- 7 quadrats, on the four peat areas. The species found on the relevés were listed according to their preferential habitat, according to "Catalogue of Natural Habitats" (CATMINAT) nomenclature by Julve (2009). Then, the abundance-dominance coefficient following Braun-Blanquet was converted into an average cover percentage for each species. Finally, for each optimal habitat, the Specific Contribution (SC) was calculated, which enables us to precisely determinate the main habitat for each relevé and the evolution between successive relevés.

$$SC = \frac{\text{Mean cover percentage of the species for the habitat considered}}{\text{Total of the mean cover percentage of all species}}$$

- One transect was completed for each peat area. The presence/absence of species and their relative positions along the transects were noted.

Figure 4. Selective fencing on leptic peatlands, leaving passage for sheep, with *Lycopodiella inundata* station, Mondarrain, Pyrénées-Atlantiques, France (Photo by CREN Aquitaine).

Following these first relevés, we made three hypotheses:

1. Total fencing seems to lead to a decrease of Sphagnum and species restricted to leptic peatlands, in favour of *Anthoxantum odoratum* and *Juncus acutiflorus* which become the dominant species. The cause could be a lack of grazing.
2. On the reference peat patch, over trampling seems to discourage development of vegetation characteristic of these areas. Nevertheless, the erosion of the substrate creates conditions suitable for the extension of valuable pioneer species like *Drosera intermedia* and *D. rotundifolia*.
3. Selective fencing shows encouraging results: species restricted to leptic peatlands and *Sphagnum sp*. show a stable or increasing population. For certain habitats, there is even re-colonisation by *Sphagnum*, as well as an increase of the Specific Contribution of *Lycopodiella inundata*. Thus, sheep grazing on these two areas does not seem to be an obstacle to the conservation of remarkable habitats and species.

In 2003, a new inventory counted 72 leptic peatlands for the entire massif. In 2005, a new conservation agreement was signed with the community of Itxassou in order to protect new peat areas, which resulted in CREN Aquitaine managing an area of about 350 ha.

Having gathered this new knowledge and data during the first years of monitoring, CREN adapted the monitoring protocol and levels of intervention according to the natural value (presence of protected plant species, natural habitats of community interest especially priority habitats, and the importance of the *Sphagnum* cover) and the degree of degradation of each peat area (Arlon & Deprez 2004)

Thus, 25 priority peat areas were regularly monitored in 2006 (Le Moal 2006), using the quadrats method (13 sites) and photographs taken 6-monthly (12 sites). Meanwhile, regarding the protection status and the rarity of *Lycopodiella inundata* in SW France, a specific monitoring of this species has been implemented as well. The number of butts and their repartition have been regularly evaluated: 300 were counted in 2006. A 16 m^2 quadrat was installed in the *Lycopodiella* area, in order to precisely monitor its spatial repartition. This monitoring seems to confirm the hypotheses made after the studies from 1999 to 2001. But they will have to be compared with the results of the three forthcoming years, to formulate reliable conclusions.

Adapting the fencing experience from Mondarrain Massif for other sites of the Basque Land : The case of Archilondo mire.

We tried to assess the wetlands of the Basque Land on a larger scale (Laporte & Le Moal 2002). Archilondo mire is one of the mires included in the 2002 inventory by CREN Aquitaine, but this wetland was known previously by many naturalists and acknowledged as having a great scientific value.

It spreads over 17.5 ha, in a landscape of pastures, with Commission Syndicale du Pays de Cize as land manager. The catchment area covers about 2.6 km^2. Several springs emerge in it and their waters cross the wetlands before joining the main creeks. A special characteristic of this catchment is that it feeds Rio Irati, located in Spain.

This mire shelters very diverse plant communities. Especially noticeable are communities of acid and neutro-alkaline fens, and also wet meadow communities with *Juncus* and *Poacaea*, as well as Atlantic wet heaths (Dupey1998).

A large part of the wetland is very hydromorphic, and composed i.e. by fens covered with *Sphagnum*, *Carex* communities and floating mats. These formations spread over 2 ha, about 1/8th of the wetland. Water supply is mainly topogenous at the bottom of the valley, but also ombrogenous where raised bogs and *Sphagnum* hummocks appear, and limnogenous near floating mats (Fig. 5).

These wetlands shelter 33 natural habitats, organised in mosaics, 24 of them of Community Interest (14 priority ones) according to the European Habitat Directive (CE 92/43). 131 plant species had been identified by 2006: 5 lichens, 36 bryophytes (12 *Sphagnum*) and 90 Pteridophytes or Angiosperms. 5 plant species are protected, 3 at a national level (*Drosera rotundifolia, D. intermedia* and *Daboecia cantabrica*) and 2 at a

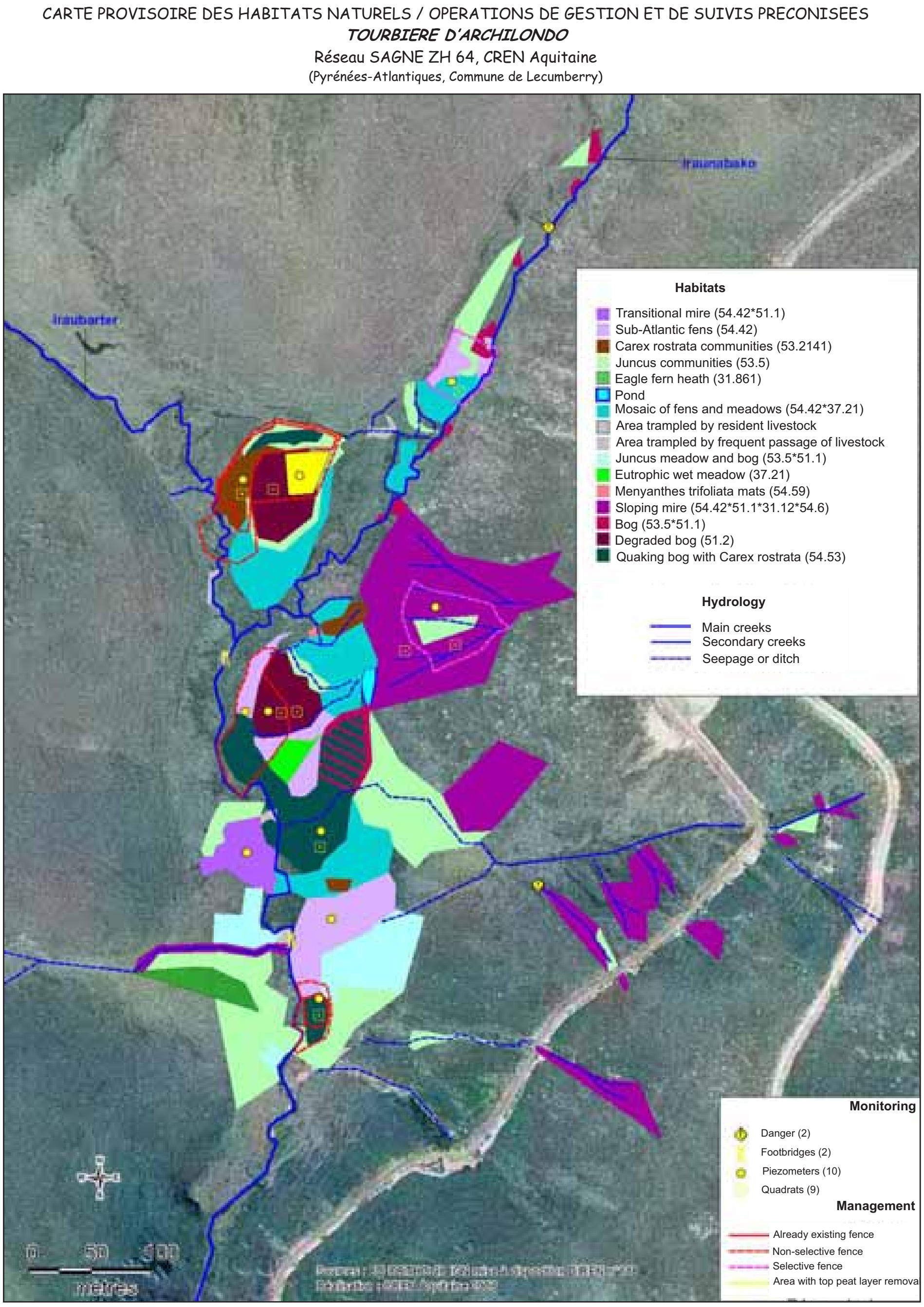

Figure 5 : Map of natural habitats and proposed management, Archilondo mire (Pyrénées-Atlantiques, France). By CREN Aquitaine

Figure 6. Archilondo mire, general view Pyrénées-Atlantiques, France (Photo by CREN Aquitaine).

regional level (*Juncus squarrosus* and *Narthecium ossifragum*). Furthermore, 2 species of *Sphagnum* (*S. russowii*, *S. molle*), inventoried by Royaud (1996) are regionally protected.

The general condition of the ecosystem appears to be satisfactory, regarding the following indicators:

- Many wetland habitats and a high specific diversity;
- Sphagnum carpets and hummocks rather well conserved and showing only local erosion effects or signs of toxification, probably related to nitrogen enrichment.

Nevertheless, considering the high ecological potential of the site, some management measures could help to ensure the conservation of the most vulnerable habitats, and increase plant diversity (Fig. 6).

The mire and its catchment area offer an important fodder resource for livestock, especially in times of drought. Some horses are resident all year long, while a 21 cattle herd and two herds of about 700 sheep stay on site in the summertime, between about 10th May and 10th October (or beginning of November for sheep). To complement grazing, the pastures are burnt every 2 or 3 years in winter during southern winds. This is an initiative of the shepherds that decreases scrubby vegetation (of the fern and *Ericacaea* heaths) and maintains grasslands.

Considering the high level of moisture in the mire, it is highly appreciated by both resident and traversing animals, as they drink or rest in the cool. But they sometimes take heavy risks when they enter the wettest parts (floating mats) and sink in (Fig. 7). Thus, shepherds regularly deplore loss of their livestock. This is why two of the wettest areas were already fenced fifteen years ago. Nowadays, these fences are no longer effective and require complete restoration.

Outside of these dangerous areas, other wetlands suffer more from the high grazing pressure. This includes especially topogenous fens uphill of the site, and spring mires

Figure 7. An ewe sank into a quaking bog, Archilondo Pyrénées-Atlantiques, France (Photo by CREN Aquitaine).

located on the slopes. In these areas, over-trampling by cattle or horses is noted, and causes either significant erosion or a packing down of the soil. These mechanical effects, combined with browsing, lead to an alteration of remarkable biotopes such as ombrotrophic *Sphagnum* hummocks. Another consequence of the presence of animals seems to be nitrogen enrichment and an impoverishment of the vegetation. Nevertheless, this type of open range grazing enables the conservation of a high diversity of habitats and species on most of the site.

With knowledge of these aspects of land use, CREN Aquitaine defined the following goals:

- Protect livestock from the risks of sinking and getting stuck in wet areas, and leave these areas to evolve naturally. In 2007, the three wettest and most dangerous areas should thus be fenced.
- Conserve the current peat area, the mosaics of natural habitats and the valuable species and habitats, whilst maintaining a mixed free range grazing, without increasing the number of animals, while conducting the herds, and monitoring the effects of grazing. Shepherds and technicians of the assistance network should follow a simple grazing plan.
- Restore the habitats that are on the verge of degradation, preventing horse and cattle grazing on fens and spring and slope mires. These areas will be selectively fenced and only sheep will be able to enter them. Experimental removal of the upper peat layer and pond creation measures are furthermore projected in two raised bogs that are currently superficially mineralised, and this may lead to the reappearance of species and habitats typical of bogs.
- Evaluate the impact of management measures, through the monitoring of natural indicators. CREN Aquitaine will implement 9 one square metre quadrats, combined with digital photographs, a complementary description and inventory of natural habitats, entomological inventories and monitoring, implementation of 10 piezometers, and an inventory and localisation of bryophytes and lichens.

Other fencing operations of the same type are foreseen on other mires of Iraty Massif, close to Archilondo: Sourzay and Iraty. Even if the management principles are fairly identical to those applied on Mondarrain, the contexts are very different. Archilondo mires and most mires in Irraty Massif are mainly topogenous and have peat depths higher than 50 cm (up to 3.6 m in Archilondo). Their surfaces are much larger than the peat patches in Mondarrain Massif. Total fencing in the quaking bogs of Archilondo is not likely to have the same a priori very negative effect on vegetation that was observed on the only patch on Mondarrain's where it was applied.

And further on...

CREN Aquitaine will try to follow these experiments, keeping in mind that, depending on the type of mire and the context, one fencing system may not be systematically transferable to another mire, but should be adapted. Implementing accurate indicators, able to measure the impact of management operations, or even of non-intervention, appears to be a short and middle term priority. It will also be indispensable to deepen our efforts to inform and communicate with farmers, explaining to them the importance of the conservation of peatlands of the Basque Land.

To broaden our knowledge and contacts, meetings were organised in 2006 with representatives and land managers of the Spanish Basque Land (i.e. on behalf of Diputación de Guipuzcoa) and we held a workshop in September 2006 in the Eastern Pyrenees, especially focusing on the questions of grazing in the Pyrenees Mountains.

Some questions raised were:

- Defining positive and negative aspects of this type of management in mires;
- What are the 'contra-indications' of grazing on certain types or contexts of mires?
- How to define overgrazing on different types of mires?
- Proposing proper grazing processes where grazing appears useful.

The accurate recommendations for monitoring sites and providing the right indicators, able to show if management or restoration actions are successful, were discussed on the Pyrenean scale during a seminar held in June 2009 in Pau.

More generally, the French Mire Resource Centre proposes to focus on mires of southern Europe and to encourage scientists and land managers of such mires to join in the work, to examine the specific situation and problems they pose, which are quite different from those faced farther north in our hemisphere. An (informal) working group could be constituted in the IMCG.

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Hydrogeochemical Investigation of Peatlands and related Vegetation Complexes in Minamidobu and Kitadobu mires in Central Japan

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Introduction

The wetland classifications are based on several approaches such as floristic association, soil types, trophic levels, and so on. The peatland classification in Japan is primarily based on the "Braun-Blanquet" phytosociological method i.e. plant species compositions in the area. The variation of environmental gradients within fens and bogs are responsible for the distinction of peatland types. The main environmental factors are groundwater level and a combination of pH, calcium content, and the nutrient status of water and soils (Rydin and Jeglum 2006). In addition, the area of wetlands is an important factor influencing biodiversity. Studies on biodiversity have greatly emphasized the species-area relationships as species diversity significantly increases with geographical area up to certain extent. Large wetlands normally have greater species diversity than small wetlands. The size is also related to habitat diversity that in turn depends on geomorphological, hydrological, hydrochemical, biological, and anthropogenic factors and the level of natural disturbance.

In central Japan, most of the mires are distributed in the highlands (700 m and 2000 m above sea level) (Omote 1998). These geogenous and topogenous mires represent bog and intermediate fen types.

Materials and methods

Two mires are investigated in this paper: Minamidobu (36°49'47.9''N, 138°29'57.9''E) covering an area of about 1 ha and Kitadobu (36°50'23.1''N , 138°30'22.9''E) covering an area of about 7 ha. Both are located on the northern foot of Mt.Daikura (altitude 1852 m) in the northeastern part of Nagano prefecture in Central Japan Fig. 1). Minamidobu mire lies at the altitude of about 1420 m and Kitadobu at about 1500 m (Table1). Minamidobu consists of a sloping rich fen with a high inclination, and thus the water moves obliquely downwards. Kitadobu is a flat bog. After the Damman (1979) classification of peatlands, Minamidobu and Kitadobu are categorized by geogenous and topogeneous peatlands. Minamidobu consists of rich and intermediate fen types, whereas Kitadobu has intermediate fen and bog types. These mires were designated as special natural monuments in Kizimadairamura in 1985. These mires are surrounded by a wide natural *Fagus crenata* forest.

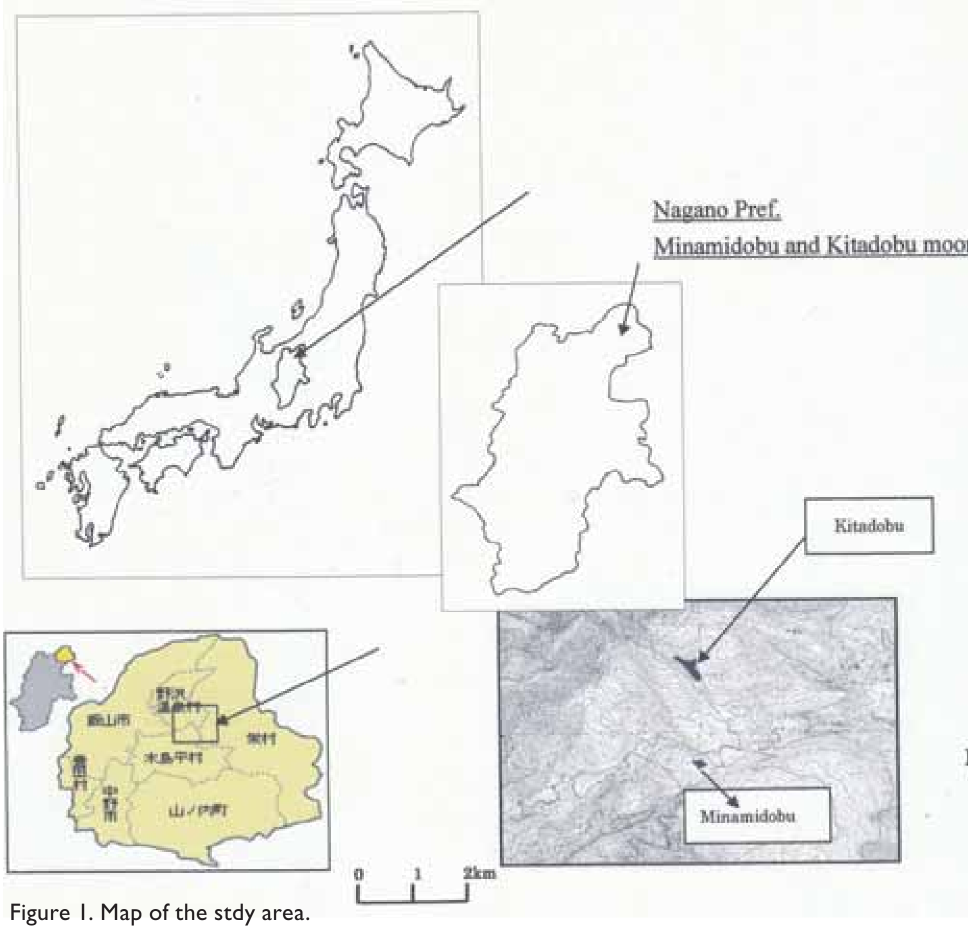


Figure 1. Map of the stdy area.

Table 1. General meteorological conditions on the study sites.

	Latitude	Longitude	mean temperature °C	precipitation mm
Kitadobu mire	36.50N	138.25E	11.30	1662
Minamidobu mire	36.49N	138.29E	11.48	1657

This report is the result of a hydrogeochemical investigation in the mires and their surrounding areas. This investigation had been carried out over 3 years, from 1999 to 2001.

Five samples were collected from each kind of plant communities. Water, soil and soil water samples from each plant community were taken every month from June to November during a three year period. The pH was measured using the pH meter and electric conductivity was measured using the conductivity meter.

Concentrations of Ca^{2+}, Na^+, K^+ and PO_4^{3-} phosphorus in water samples were determined by spectrophotometry, and concentrations of NO^{3-} nitrogen and Cl^- were determined by a flow injection analyzer. The amount of P, K, Ca, Mg, Na, Cl and Mn in soil samples was determined by the X-ray fluorescence method. Carbon and nitrogen content in plant and soil samples were analysed by using the CHN analyser. The determination of the groundwater table level was based on groundwater level measurement at several points in the area. The vegetation types of these mires were studied by the phytosociological method.

The objectives of this study were to investigate:
1. The mire vegetation classification and diversity
2. Under which ecological conditions do the mire vegetation communities occur in relation to various water- and soil chemistry parameters ?
3. The influence of substrate characteristics in soil on plant communities .
4. The influence of different hydrogical regimes on the various peatland plant species.

Results

Vegetation

Altogether 52 vascular plant species and 9 moss species in Kitadobu mire and 65 vascular plant species and 6 moss species in Minamidobu mire have been found (Appendix 1). There is a clear difference in the species composition between Minamidobu and Kitadobu mires (Table 2). *Lysichiton camtschatcense, Menyanthes trifoliata*, *Sphagnum cuspidatum*, *Sphagnum fimbriatum* and *Sphagnum teres* could only be found in the area of Minamidobu mire, while *Tofieldia japonica, Vaccinium oxycoccos, Sphagnum papillosum* and *Sphagnum magellanicum* grew in the area of Kitadobu mire.

Table 2. Characteristic of plant species for Minamidobu and Kitadobu mires.

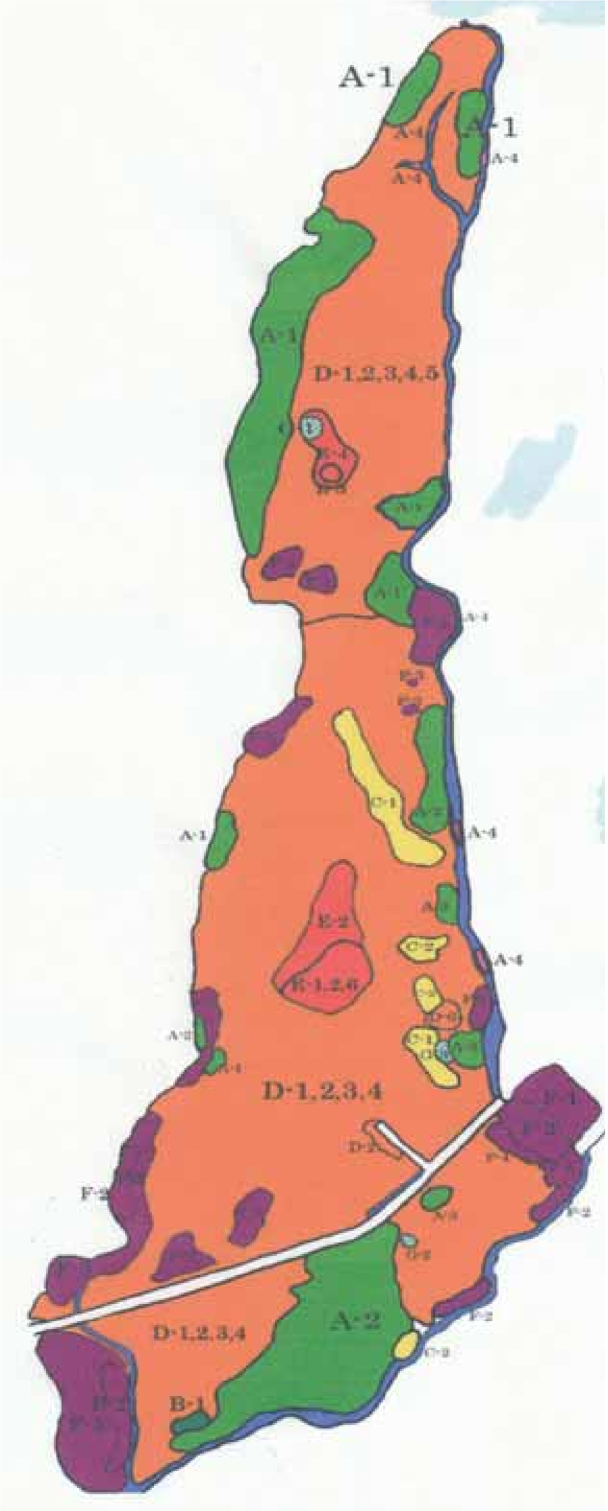
Minamidobu mire	Kitadobu mire
Juncus effusus var. decipiens	*Tofieldia japonica*
Fauria crista-galli	*Pleurospermum camtschaticum*
Epigaea asiatica	*Polygonatum macranthum*
Gentiana triflora var. japonica	*Angelica genuflexa*
Carex stipata	*Ligularia fischerii*
Galium kamtschaticum var.acutifolium	*Vaccinium oxycoccus*
Artemisia montana	*Lycopus maackianus*
Potamogeton natans	*Scheuchzeria palustris*
Typha latifolia	*Conioselium filicinum*
Narthecium asiaticum	*Chamaenerion angustifolium*
Carex stipata	*Sphagnum papillosum*
Hypericum pseudopetiolatum	*Sphagnum angustiforium*
Sparganium glomeratum	*Sphagnum fallax*
Potamogeton distinctus	*Sphagnum flexuosum*
Equisetum fluviatile	*Sphagnum magellanicum*
Lysichiton camtschatcense	*Sphagnum tenellum*
Persicaria thunbergii	
Menyanthes trifoliata	
Ligularia stenocephala	
Lycopodium inundatum	
Lysimachia thysiflora	
Hydrangea serrata	
Sphagnum cuspidatum	
Sphagnum fimbriatum	
Sphagnum teres	

Figures 2 and 3 show the vegetation maps of both study areas. Minamidobu is characterized as having rich and intermediate mire types, whereas Kitadobu is characterized as having intermediate and poor mire types. These mires can be classified into five types: 1. Rich fen, 2. Transition between rich and intermediate fens 3. Intermediate fen, 4. Transitional type between intermediate fens and bogs, 5. Bogs.

🟩	**A Rich fen**
A-1	***Carex rhynchophysa*** **community**
A-2	***Phagmites australis*** **community**
A-3	***Scirpus wichurae*** **community**
A-4	***Typha latifolia-Carex sadoensis*** **community**
A-5	***Ilex crenata*** **var.** ***paludosa*** **community**
A-6	***Iris setosa*** **community**
🟩	**B Transition between rich and intermediate fen**
B-1	***Thelypteris palustris*** **community**
B-2	***Lysichiton camtschatcence Caltha palustris*** **var.** ***nipponica***
🟨	**C Intermediate fen**
C-1	***Sphagnum recurvum*** **var.** ***amblyphyllum*** **community**
C-2	***Sanguisorba tenuifolia*** **var.** ***purpurea*** **community**
🟧	**D Transition between intermediate fen and bog**
D-1	***Inula ciliaris-Rhynchospora yasudana*** **community**
D-2	***Dorosera rotundifolia*** **community**
D-3	***Parnassia palustris*** **var.** ***multiseta*** **community**
D-4	***Rhynchospora alba - Rhynchospora yasudana***
D-5	***Rhynchospora yasudanae - Sphagnetum tenelli*** **community**
🟥	**E Emerged plant community and Floating-leaved plant community**
E-1	***Menyanthes trifoliata-Potamogeton natans*** **community**
E-2	***Menyanthes trifoliata-Sphagnum flexuosum*** **community**
E-3	***Menyanthes trifoliata*** **community**
E-4	***Potamogeton natans*** **community**
🟪	**F Mire surrounding areas**
F-1	***Osmunda cinnamomea*** **var.*****fokiense*** **community**
F-2	***Filipendula kamtschatica*** **community**
F-3	***Sasa kurilensis*** **community**
F-4	***Serratula coronata*** **var.*****insularis*** **community**
F-5	***Veratrum stamineum*** **community**
F-6	***Rhododendron japonicum*** **community**
🟦	**G others**
G-1	***Salix gilgiana*** **community**
G-2	***Betula platyphylla*** **var.*****japonica*** **community**
G-3	***Cladonia spec.***
🟩	**H Sphagnum groups**
H-1	***Sphagnum fimbriatum*** **community**
H-2	***Sphagnum squarrosum*** **community**
H-3	***Sphagnum teres*** **community**

Figure 2. Vegetation map of Minamidobu with phytosociological classifications

These mires are regarded as a complex habitat. They cover a wide range of environmental conditions and dynamics systems, which form part of the hydroseral succession from open water to dry land. Therefore, they sustain a rich variety of plant species. As a result, 38 vegetation series, identified at the association level (subassociations and communities) were recognized (Omote et al. 2004).



🟩	**A Rich fen**
A-1	***Phagmites australis* community**
A-2	***Carex rhynchophysa* community**
A-3	***Iris setosa* community**
A-4	***Cardamine yezoensis* var.*torrentis* community**
🟩	**B Transition between rich and intermediate fen**
B-1	***Sphagnum recurvum* var. *amblyphyllum* community**
🟨	**C intermediate fen**
C-1	***Hemerocallis dumortieri* var.*esculenta* community**
C-2	***Sanguisorba tenuifolia* var. *purpurea* community**
🟧	**D Transition between intermediate fen and bog**
D-1	***Rhynchospora yasudana*** **- *Hemerocallis dumortieri* var. *esculenta* community**
D-2	***Dorosera rotundifolia* community**
D-3	***Tofieldia japonica***
D-4	***Inula ciliaris-Solidago virgaurea* ssp. *asiatica* community**
D-5	***Sphagnum recurvum* var. *amblyphyllum* community**
🟥	**E Bog**
E-1	***Vaccinium oxycocus* community**
E-2	***Rhynchospora alba - Rhynchospora yasudana***
E-3	***Oxycocco-Sphagnetea***
E-4	***Sphagnum papillosum* community**
E-5	***Sphagnum magellanicum* community**
E-6	***Rhynchospora yasudanae*** **- *Sphagnetum tenelli* community**
🟪	**F Mire surrounding areas**
F-1	***Sasa kurilensis***
	- *Allium victorialis* ssp. *platyphyllum* community
F-2	***Osmunda cinnamomea* var.*fokiense* community**
	Rhododendron japonicum* var. *montanum
F-3	***Aconitum japonicum* var. *montanum***
F-4	***Aconitum senanense* community**
F-5	***Serratula coronata* var.*insularis* community**
🟦	**G Shagnum groups**
G-1	***Sphagnum fallax* community**
	- *Sphagnum angustifolium* community
G-2	***Sphagnum flexuosum* community**
G-3	***Sphagnum palustre community***

Figure 3. Vegetation map of Kitadobu with phytosociological classifications.

Hydrology

Groundwater level

Four groundwater level patterns were found during the three years measurements: 1. Non-seasonal variation, 2. Natural variation, 3. Seasonal variation, and 4. Circulatory variation (Omote et al. 2004).

Non-seasonal variation shows that the cyclic variation in groundwater table levels over three years of vegetation periods were unstable (Fig. 4). The groundwater levels decrease rapidly with seasonal development during the growing season. On sites of the this unstable ground water table level the moisture conditions may change from aquatic to seasonal drought. *Allium victorialis* ssp. *platyphyllum* and *Veratrum stamineum* were typical species for this type. This type indicates degeneration process of peatland.

In *natural variation* type, the groundwater level is rather stable during the growing season, and not influenced by the development of vegetation height (Fig. 5). It is a favourite habitat for many mire plants species such as *Lysichiton camtschtcense,* and the *Sphagnum* species.

Seasonal variation shows that cyclic variation in groundwater levels depends upon the seasonal weather and the development of plant growth so that the groundwater table level decreases when the maximum height of plants increases (Fig. 6). During the rainy (June and July) and typhoon (from September to October) seasons groundwater levels rise, and decrease during the high temperature season. On the sites of this heavily unstable groundwater table level, the moisture conditions may be changeable from wetness to dryness and from dryness to wetness. This cyclic variation (repeating

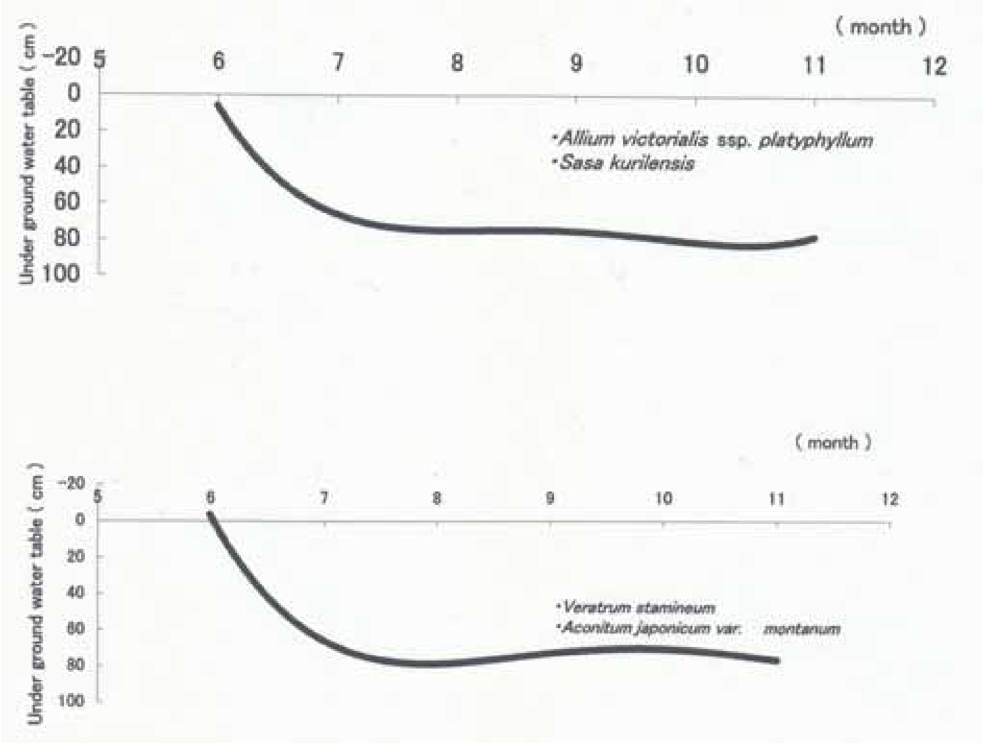


Figure 4. Non-seasonal variation of groundwater table.

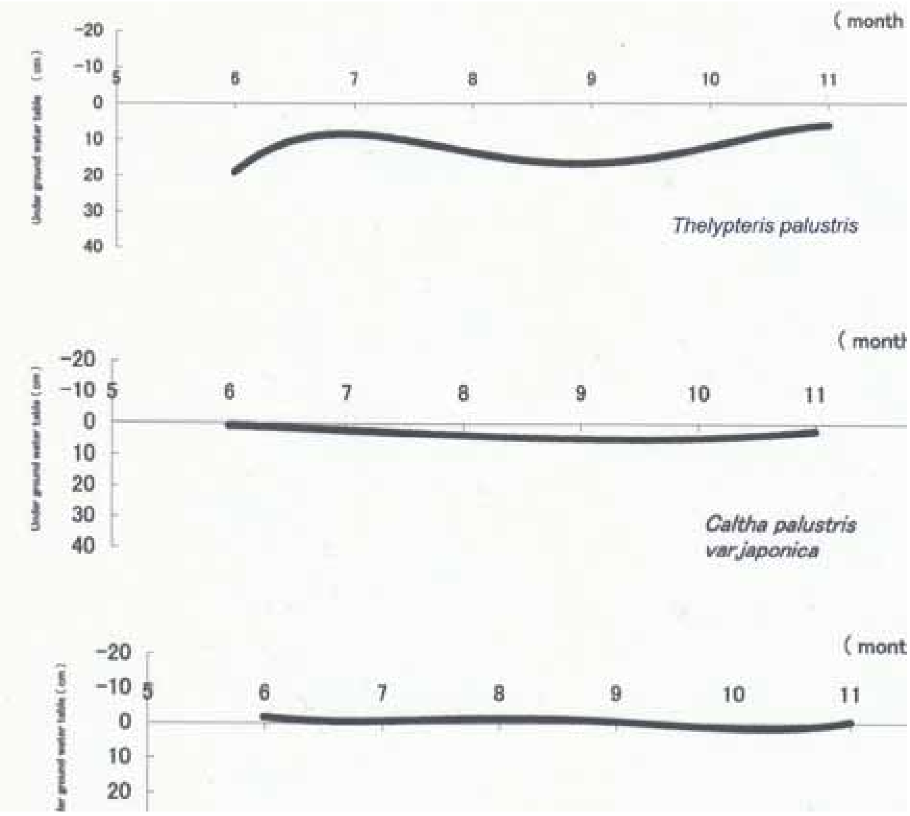


Figure 5. Natural variation of groundwater table.

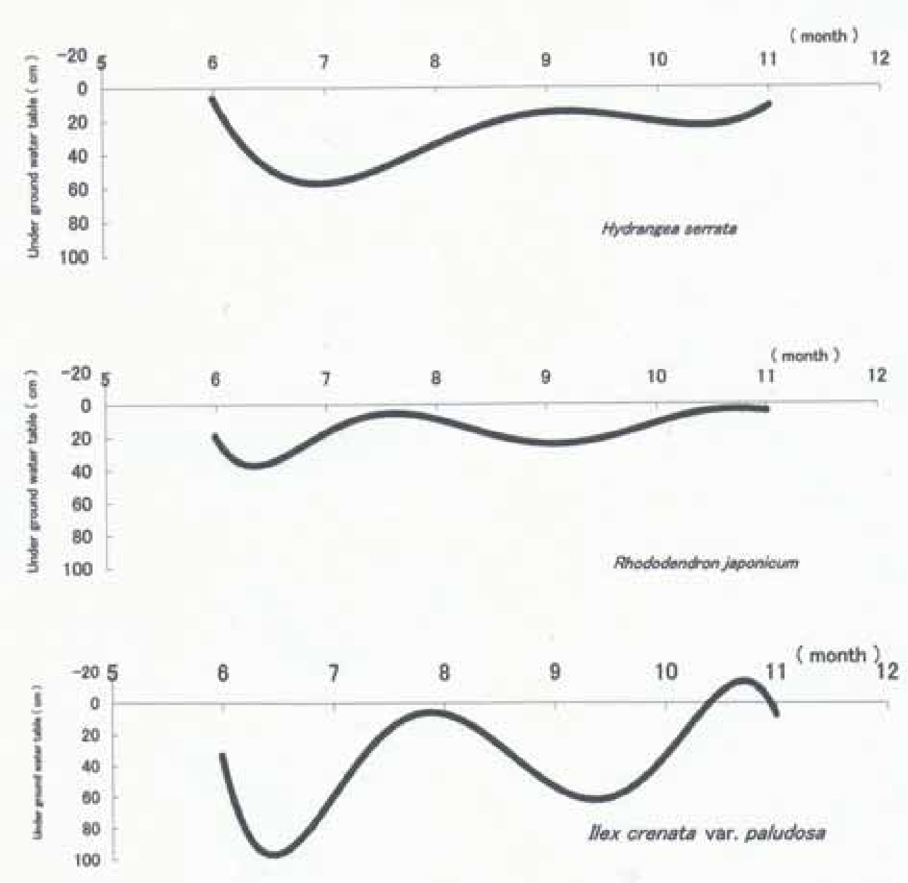


Figure 6. Seasonal variation of groundwater table.

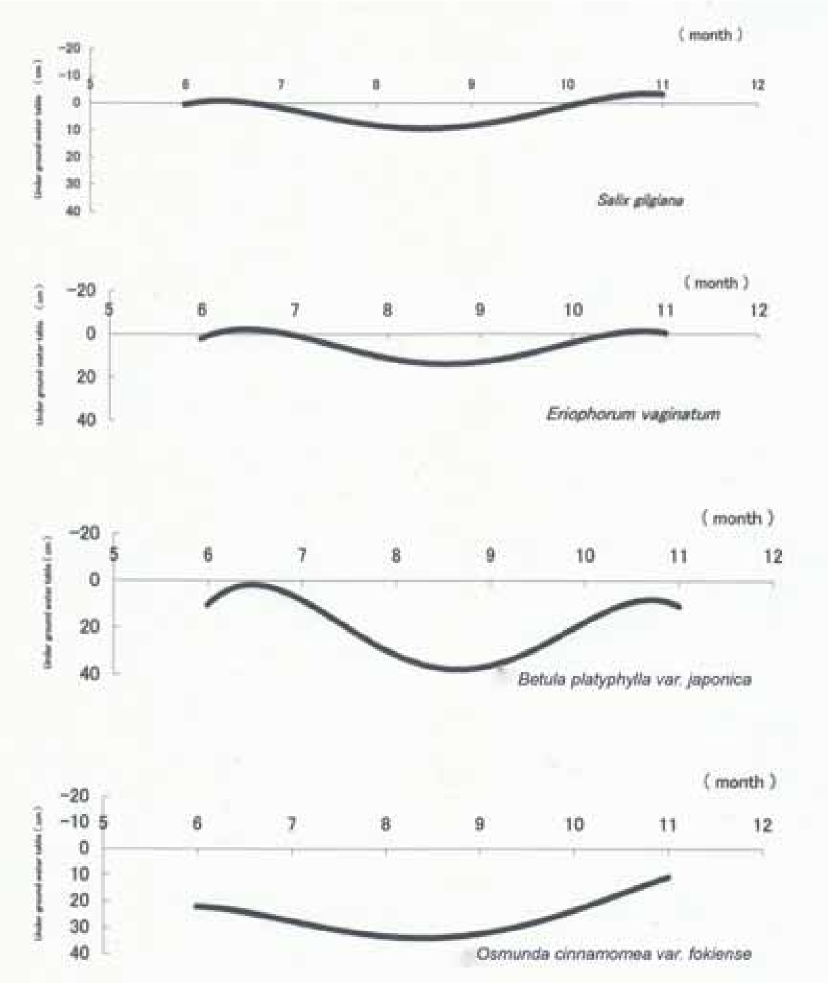


Figure 7. Circulatory variation of groundwater table.

cycles of change in water levels) over medium periods such as months occurs on well-drained soil on sandy substratum or on peat soils with high pore structure. Some mire species can tolerate heavy water fluctuations and the peat accumulation is prevented as dry seasons accelerate the rate of decomposition (Huttunen and Tolonen 2006).

In circulatory variation type, the groundwater level rises in spring and autumn, and is lowest in summer (Fig. 7).These types depend not only on the morphology of the peatland surface body, but also on well-drained soil types. Some plant species indicate dryness in the peatland (*Osmunda cinnamomea* var.*fokiense*, S*alix gilgiana*, *Betula platyphylla* var*. japonica* etc.).

Surface water and soil water quality

Hydrological conditions are important factors influencing the contribution of plant biodiversity in peatlands and are linked to the soil water and soil chemistry. The rise, fall and flow of the water influences the chemical reactions, and flow of nutrients within the soil, which in turn influences the species composition of the habitat.

There is not a clear difference in surface water chemistry between Minamidobu and Kitadobu (Table 3). Waters in the rich fen sites (Minamidobu) had a higher pH, Electric conductivity (EC), total carbon (TC), inorganic carbon (IC), total organic carbon (TOC), Ca, Na and PO_4^{3}-P than those in the intermediate fens and bogs in Kitadobu.

Base saturation and pH were the main factors which varied along the poor-rich vegetation gradient between mire types. pH is in general the factor that best explains the grouping of rich fens, intermediate fens and bogs. However, major nutrients in soil water and soil do not always reflect the poor-rich gradient, but influence species composition on study areas. There are clear differences in soil water chemistry and the distribution of plant species between the studied mires (Table 4).

There seemed to be some kind of a relationship between some plant species and NO_3-N (Fig. 8 and Fig. 9), calcium, organic carbon (TOC) and PO_4^{3-}P concentration in the soil water.

Table 3. Mean values of surface water quality in Minamidobu and Kitadobu (1999~2000)

		pH	EC	TC	IC	TOC	Ca^{2+}	Na^+	K^+	Cl^-	NO_3 -N	PO_4^3 -P
			(μs/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Minami-dobu	Mean value	6.71	26.1	7.04	3.09	3.96	2.99	3.13	1.56	2.26	0.62	0.04
Kita-dobu	Mean value	6.31	11.6	4.81	1.56	3.23	0.82	2.67	1.5	2.9	0.77	0.024

Table 4. Soil water chemistry in Minamidobu and Kitadobu

Vegetation	pH	Electric conductivity	TOC	NO_3 -N	PO_4^3—P	Cl^-	SO_4^{2}-	Ca
		μs/cm/20°C	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
[Minamidobu]								
Sphagnum recurvum var.amblyphyllum	5.9	23	14.55	0.554	0.445	0.309	0.786	1.27
Lysichitum camtschatcense	5.9	39	3.26	0.421	0.453	0.275	0.224	3.04
Iris setosa	6.2	29	4.16	0.336	0.459	0.21	0.342	4.73
Carex rhynchophysa	6.2	37	6.21	0.481	0.455	0.163	0.327	4.95
Sanguisorba tenuifolia var. purpurea	6.5	65	8.05	0.54	0.471	0.278	0.334	4.37
Filipendula kamtschatica	5.8	12	4.38	0.3	0.481	0.359	0.548	3.75
Scirpus wichurae	6.3	44	3.6	0.982	0.479	0.377	0.696	4.75
Osmundastrum cinnamomeum var. fokiense	6	15	6.91	0.543	0.469	0.314	0.332	4.31
Rhododendron japonicum	6.2	17	9.57	0.287	0.549	0.396	0.221	3.27
Ilex crenata var. paludosa	6.3	30	4.81	0.246	0.495	0.266	0.237	3.64
Prunus grayana	5.8	14	1.99	0.372	0.443	0.521	0.148	3.02
Salix gracilistyla	6.2	29	3.83	0.462	0.457	0.201	0.318	4.71
Sasa kurilensis	5.8	7	8.88	0.276	0.464	0.191	0.333	4,54
Betula tauschii	5.8	14	1.91	0.721	0.445	0.488	0.437	3.39
[Kitadobu]								
Sphagnum recurvum var. amblyphyllum	6.2	10	13.72	0.022	0.394	0.076	0.165	0.56
Sphagnum papillosum	6	18	20.08	0.02	0.388	0.286	0.122	0.51
Carex rhynchophysa	6.1	15	10	0.815	0.456	0.333	0.325	2.96
Iris setosa	5.9	45	5.22	0.731	0.473	0.144	0.342	3.05
Hemerocallis dumortieri var. esculenta	6.2	16	8.2	0.044	0.446	0.084	0.432	2.76
Aconitum senanense	5.4	16	3.61	0.409	0.483	1.543	0.449	3.91
Gentiana thunbergii var. minor	5.9	11	19.5	0.182	0.459	0.078	0.361	3.38
Viola langsdorffii ssp.sachalinensis	6.5	19	18.59	0.204	0.423	0.021	0.448	2.11
Rhododendron japonicum	6.1	12	19.67	0.403	0.455	0.241	0.541	2.25

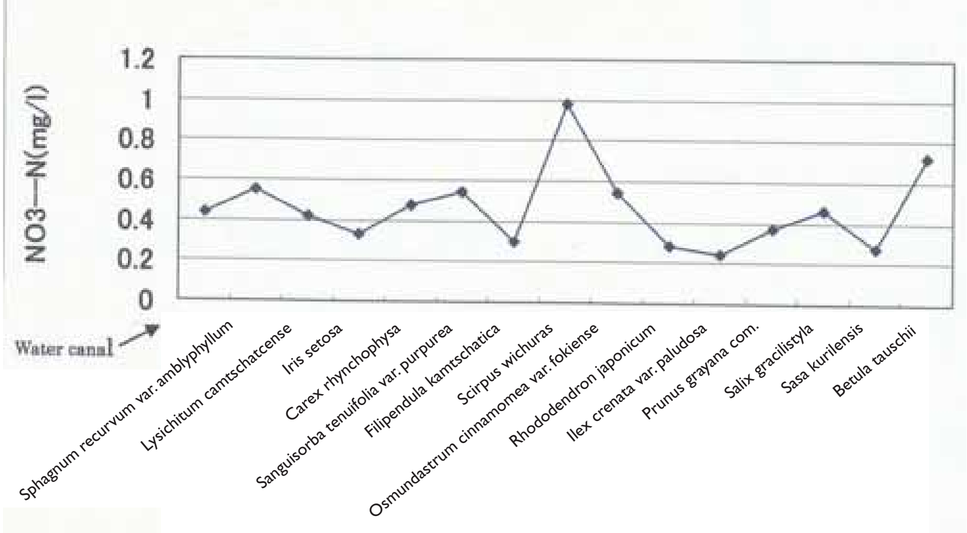


Figure 8. The relation between plant species and soil water chemistry (NO_3-N) in Minamidobu.

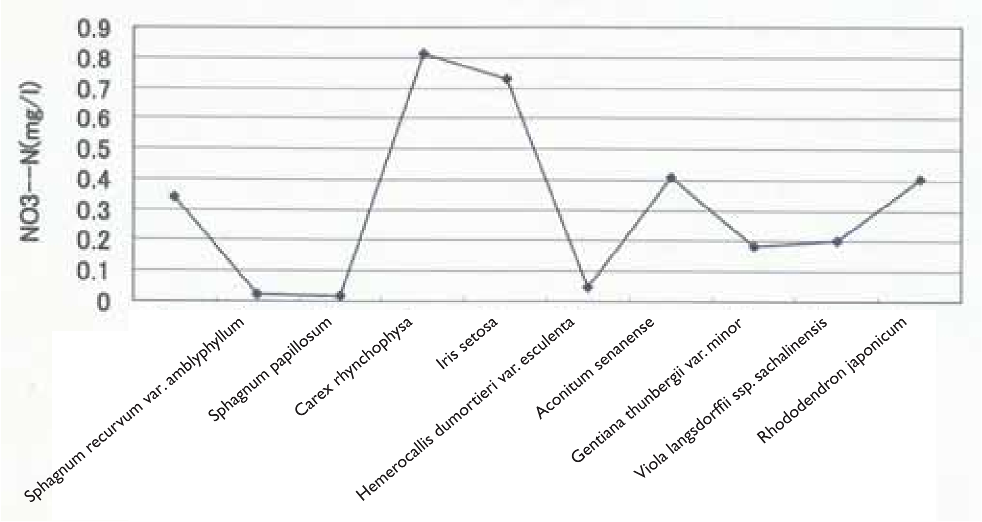


Figure 9. The relation between plant species and soil water chemistry (NO_3-N) in Kitadobu.

Soil chemistry: inorganic and organic components

Analysis of the peat soil included the main macronutrients, especially the main nutrients C, N, P, K, Ca, Mg, Na, Cl, and Mn. The poor–rich gradient in peatlands is controlled mainly by the properties of the peat soils, namely pH and concentrations of C, N, P, K, Ca, and Mg. We can see clear differences of nutrients composition among pond, rich fen, intermediate fen, bog and mire margin peat soil types (Table 5).

The nutrient accumulation of peat soil for the intermediate moor was estimated to be about 0.41 (w %) for P and 2.02 (w %) for N, which indicates a high nutrient level. On the other hand, K, and Mg accumulation was highest in ponds. C and N content was highest in mire margin soil. The availability of nutrients for plants is lowered compared to the mineral soils in these two mires, because the acidity in all five mire types is below pH 6.

Table 5. Relation between peat soil types and main macronutrients

	pH	C (w%)	N (w%)	P (w%)	K (w%)	Ca (w%)	Mg (w%)	Na (w%)	Cl (ppm)	Mn (ppm)	C/N (ratio)
Pond	5.45	17.18	1.068	0.07	0.56	0.41	0.21	0.10	167.15	180.15	16.25
Rich fen	5.86	27.52	1.82	0.07	0.30	0.28	0.21	0.13	79.69	198.0	13.84
Intermediate fen	5.55	32.06	2.02	0.41	0.27	0.11	0.14	0.11	81.1	258.6	16.08
Bog	5.26	18.43	1.62	0.06	0.41	0.56	0.11	0.08	222.6	253.2	9.49
Mire margin	5.71	35.17	2.13	0.08	0.245	0.040	0.184	0.138	78.085	97.75	16.58

Appendix 2 shows the plant species and the corresponding peat chemistry in rich fens, intermediate fens and bogs. The ratio between soil chemical featuresr(C/N), was used to help to interpret aspects of fertility. Peat C/N ratios differ between peat soil types and plant species. A high ratio of C/N can be interpreted as a high production of plant biomass. C content in peat soils is positively correlated with the N content (Fig. 10). This implies that plant species are important sinks for nutrients, especially for N. Other chemical components were not well correlated with each other.

Peat is composed of an enormously complex mixture of organic compounds, derived mainly from plant remains. The degree of decomposition and accumulation of organic matter and its components in wetlands depends on soil moisture and water table conditions. Plant species can influence soil organic matter. The rates of decomposition processes of organic matter are again determined by the nature of the components of plants species. This indicates a very close relationship between plant species distribution and organic matter. Therefore, the relationship between the peatland plant species and organic matter were investigated. The ratio and concentrations of organic matter with various levels of humic and fulvic acids and humine and bitumen were compared with the inorganic components in the peat soil under each plant species (Appendix 3).

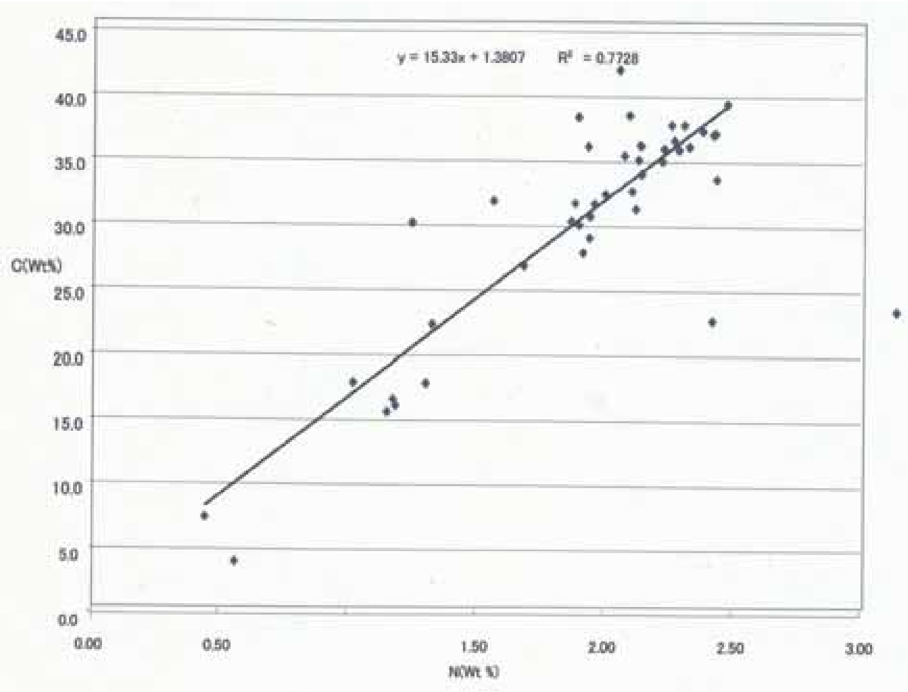


Figure 10. Relation between carbon and nitrogen in peat soils

The results show that there is a clear difference in soil organic matter among rich fen, intermediate fen, bog and mire margin. The rate of inorganic to organic matter (humic acids, fulvic acids, humin and bitumen) is 2 to 3 in the rich fen , 3 to 7 in the intermediate fen and 1 to 4 in the bog. This difference may be attributed to the influence of the source of nutrients for plant growth. The amount of organic matter is also important to know when calculated fluxes of carbon and macronutrients such as nitrogen and phosphorus (Mattsson et al. 2005). Furthermore, organic matter is a source of energy and nutrients for micro-organisms (Scully et al. 2003). The mean of organic compounds decreases in the order humic acid, fulvic acid, humine and then bitumen in all mire types.

Figures 11 and 12 show a relationship between plant species, humic acid, and fulvic acid. *Osmundastrum cinnamomeum, Rhododendron japonicum, and Scirpus wichurae*, which are rich fen plant indicators, have high contents of humic acid, whereas a high content of fulvic acid is only found in *Sanguisorba officinalis*.

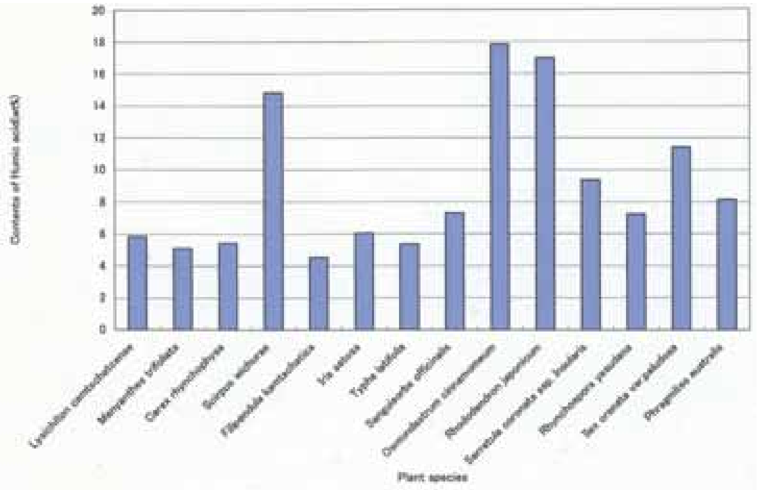


Figure 11. Relation between humic acid and plant species.

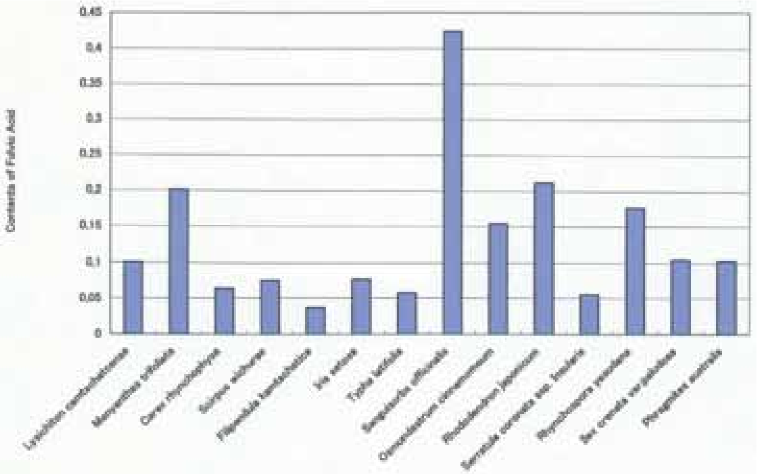


Figure 12. Relation between fulvic acid and plant species.

Discussion and conclusions

Mire vegetation types were compared with respect to the main habitat factors. The vegetation in geogenous and topogeneous or minerotrophic peatlands in submontane and rainy regions depend on hydrogeomorphologic situations. Soil water chemistry as well as soil chemistry and organic soil component showed a strong correlation with the main vegetation gradient (poor –rich gradient). Soil water PO_4^{3}-P had a high correlation with NO_3-N, Ca with SO_4, and K with C, and pH with conductivity. The distribution and plant richness were controlled mainly by the dynamic of groundwater table during the growing season and nutrient gradients of surface and soil water, namely pH, conductivity and concentration of Ca and Mg. However pH was not correlated with Ca concentration.

1. The diversity of plant communities and plant species are primarily not dependent on surface water chemistry, but soil water chemistry.
2. The diversity of plant communities is attributed to a mosaic of patches of various sizes and the length and width of peatland environmental heterogeneity.
3. The distribution of plant species in peatlands is primarily dependent on the hydrogeomorphologic dynamics (groundwater table fluctuation, permeability of peat soils, depth of surface water, annual total precipitation, balance of the inflow and outflow of surface and ground water, soil water chemistry, and soil chemistry.

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Appendix 1. Plant species found in Kitadobu and Minamidobu Mires.

Kitadobu mire		Minamidobu mire	
Vascular plants	51	Vascular plants	61
Forest plant	1	Forest plants	4
Mosses	9	Mosses	6
Total amount	61	Total amount	71
Vascular plants		Vascular plants	
	Epilobium pyrricholophum		*Epilobium pyrricholophum*
	Solidago virgaurea ssp. Asiatica		*Solidago virgaurea ssp. asiatica*
	Scirpus wichurae		*Scirpus wichurae*
	Tofieldia japonica		*Juncus effusus var.decipiens*
	Parnassia palustris var. multiseta		*Fauria crista-galli*
	Carex rhynchophysa		*Epigaea asiatica*
	Pleurospermum camtschaticum		*Parnassia palustris var. multiseta*
	Polygonatum macranthum		*Gentiana triflora var.japonica*
	Angelica genuflexa		*Carex rhynchophysa*
	Viola langsdorffii ssp.sachalinensis		*Carex stipata*
	Cardamine yezoensis var.torrentis		*Viola langsdorffii ssp.sachalinensis*
	Ligularia hodgsonii		*Galium kamtschaticum var.acutifolium*
	Filipendula kamtschatica		*Artemisia montana*
	Allium victorialis ssp. platyphyllum		*Cardamine yezoensis var.torrentis*
	Lilium lancifolium		*Filipendula kamtschatica*
	Trientalis europaea		*Potamogeton natans*
	Veratrum stamineum		*Typha latifolia*
	Hosta albo-marginata		*Allium victorialis ssp. platyphyllum*
	Platanthera ophrydioides var.monophylla		*Narthecium asiaticum*
	Cimicifuga simplex		*Lilium lancifolium*
	Eleorchis japonica		*Trientalis europaea*
	Gentiana thunbergii var.minor		*Veratrum stamineum*
	Serratula coronata ssp.insularis		*Hosta albo-marginata*
	Viola blandaeformis var.pilosa		*Platanthera ophrydioides var.monophylla*
	Vaccinium oxycoccos		*Carex sadoensis*
	Pogonia japonica		*Cimicifuga simplex*
	Sanguisorba tenuifolia var. purpurea		*Hypericum pseudopetiolatum*
	Hemerocallis dumortieri var. esculenta		*Gentiana thunbergii var.minor*
	Moliniopsis japonica		*Sparganium glomeratum*
	Orchis aristata		*Serratula coronata ssp.insularis*
	Iris setosa		*Sanguisorba tenuifolia var. purpurea*
	Thelypteris palustris		*Hemerocallis dumortieri var. esculenta*
	Lycopus maackianus		*Moliniopsis japonica*
	Aconitum senanense		*Plantago hakusanensis*
	Galium trifidum var.brevipedunculatum		*Orchis aristata*
	Scheuchzeria palustris		*Iris setosa*
	Rhynchospora alba		*Thelypteris palustris*
	Inula ciliaris		*Lycopus maackianus*
	Carex michauxiana var.asiatica		*Potamogeton distinctus*
	Rhynchospora yasudana		*Aconitum senanense*
	Conioselium filicinum		*Galium trifidum var.brevipedunculatum*
	Drosera rotundifolia		*Scheuchzeria palustris*
	Carex omiana		*Rhynchospora alba*
	Lycopodium inundatum		*Inula ciliaris*
	Chamaenerion angustifolium		*Equisetum fluviatile*
	Aconitum japonicum var. montanum		*Lysichiton camtschatcense*
	Osmunda cinnamomea var.fokiense		*Persicaria thunbergii*
	Phagmites australis		*Carex michauxiana var.asiatica*
	Caltha palustris var. nipponica		*Menyanthes trifoliata*
	Rhododendron japonicum		*Rhynchospora yasudana*
	Eriophorum vaginatum		*Ligularia stenocephala*
			Drosera rotundifolia

Forest tree			*Carex omiana*
	Sasa kurilensis		*Lycopodium inundatum*
			Lysimachia thysiflora
Mosses			*Chamaenerion angustifolium*
	Sphagnum recurvum var. amblyphyllum		*Aconitum japonicum var. montanum*
	Sphagnum papillosum		*Osmunda cinnamomea var.fokiense*
	Sphagnum squarrosum		*Phagmites australis*
	Sphagnum palustre		*Caltha palustris var.nipponica*
	Sphagnum angustiforium		*Eriophorum vaginatum*
	Sphagnum fallax	Forest trees	
	Sphagnum flexuosum		*Sasa kurilensis*
	Sphagnum magellanicum		*Ilex crenata var. paludosa*
	Sphagnum tenellum		*Hydrangea serrata*
			Rhododendron japonicum
		Mosses	
			Sphagnum recurvum var. amblyphyllum
			Sphagnum squarrosum
			Sphagnum palustre
			Sphagnum cuspidatum
			Sphagnum fimbriatum
			Sphagnum teres

Appendix 2. Relation between Vegetation and Inorganic Components of Peat Soil

	pH	C	N	P	K	Ca	Mg	Na	Cl	Mn	C/N
		(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(ppm)	(ppm)	ratio
Pond											
Potamogeton distinctus	5.89	7.442	0.45	0.04	0.6	0.085	0.25	0.11	120.6	145.2	16.53
Menyanthes trifoliata	5.24	26.92	1.686	0.1	0.52	0.74	0.16	0.09	213.7	215.1	15.97
Rich fen											
Caltha palustris var. nipponica	5.95	22.71	2.421	0.023	0.169	0.037	0.409	0.16	67.1	264.4	9.38
Carex sadoensis	6.29	42.06	2.055	0.07	0.43	0.85	0.13	0.15	95.7	250.2	13.83
Typha latifolia	6.0	17.86	1.307	0.03	0.23	0.02	0.37	0.14	53.2	215.5	13.55
Phragmites australis	5.81	39.46	2.45	0.1	0.19	0.1	0.09	0.09	84.3	108.5	13.52
Cardamine yezoensis var. torrentis	6.04	22.4	1.33	0.08	0.64	0.69	0.190	0.120	130	382.0	16.84
Ilex crenata var.paludosa	5.34	32.5	2.0	0.06	0.109	0.02	0.037	0.07	70	30	16.25
Carex rhynchophysa	6.26	15.63	1.156	0.1	0.32	0.27	0.27	0.15	57.5	135.3	13.52
Intermediate fen											
Lysichiton camtschatcense	6.11	33.69	2.435	0.03	0.27	0.03	0.35	0.15	62.9	219.8	13.84
Sanguisorba tenuifolia var. purpurea	5.73	16.13	1.19	0.06	0.16	0.3	0.2	0.11	82.1	648.2	13.66
Viola langsdorffii ssp. sachalinensis	5.57	37.8	2.31	0.082	0.199	0.108	0.074	0.078	80	80	16.36
Hemerocallis dumortierri var. esculenta	5.03	31.74	1.96	0.06	0.21	0.03	0.08	0.12	95.6	69.9	15.94
Iris setosa	5.7	30.19	1.25	0.08	0.26	0.16	0.12	0.1	81.1	198.4	24.15
Serratula coronata var.insularis	5.45	35.17	2.13	0.086	0.218	0.107	0.281	0.151	93.7	110.3	16.19
Hosta albo-marginata	5.69	36.17	2.328	0.072	0.299	0.021	0.115	0.094	72.6	270	15.54
Parnassia palustris var. multiseta	5.61	36.18	2.328	0.091	0.46	0.083	0.098	0.108	70.9	561	15.54
Filipendula kamtschatica	6.02	29.1	1.94	0.072	0.294	0.458	0.102	0.076	77.9	1041	15.29
Scirpus wichurae	5.46	36.23	2.141	0.09	0.46	0.01	0.08	0.08	81.1	227.4	16.92
Carex michauxiana var. asiatica	5.34	27.96	1.916	0.102	0.27	0.524	0.094	0.1	95.6	72.9	14.59
Inula ciliaris	5.43	37.2	2.43	0.082	0.309	0.027	0.079	0.126	100	80	15.31
Solidago virgaurea ssp.asiatica	5.55	30.8	1.94	0.052	0.172	0.001	0.115	0.094	80	120	15.88
Lilium lancifolium	5.71	31.7	1.96	0.199	0.205	0.004	0.246	0.152	70	120	16.17
Chamaenerion angustifolium	5.95	31.0	2.3	0.195	0.222	0.005	0.275	0.176	76	135	13.48
Tofieldia japonica	5.61	32.7	2.11	0.075	0.114	0.021	0.073	0.078	80	80	15.50
Epilobium pyrricholophum	5.76	31.4	2.12	0.09	0.46	0.08	0.100	0.110	70	560	14.81
Thelypteris palustris	5.52	31.9	1.57	0.061	0.280	0.044	0.075	0.145	90	60	20.32
Bog											
Sphagnum fallax	5.38	4.16	1.33	0.050	0.490	0.270	0.080	0.080	150	460	3.13
Sphagnum tenellum	5.45	3.93	1.10	0.040	0.220	0.130	0.070	0.050	150	80	3.57
Sphagnum recurvum var. amblyphyllum	5.25	4.156	1.33	0.05	0.49	0.27	0.08	0.08	153	460.6	3.12
Rhynchospora alba	5.07	35.99	2.23	0.089	0.505	0.052	0.086	0.173	108.1	83.3	15.71
Sphagnum papillosum	5.18	4.048	0.566	0.02	0.41	0.59	0.07	0.05	150	100	7.15
Drosera rotundifolia	5.36	35.93	2.287	0.116	0.117	0.083	0.075	0.054	145.2	60.6	15.59
Sphagnum fimbriatum	5.12	36.2	1.94	0.06	0.45	1.790	0.19	0.06	630	170	18.66
Rhynchospora yasudana	5.39	37.38	2.38	0.06	0.26	0.56	0.17	0.1	117.4	184.5	15.71
Sphagnum teres	5.33	4.05	1.46	0.09	0.75	1.300	0.130	0.07	400	680	2.77
Mire margin											
Cimcifuga simplex	5.91	35.5	2.08	0.084	0.216	0.036	0.280	0.157	80	130	17.07
Aconitum japonicum var. montanum	5.74	36.3	2.14	0.084	0.216	0.036	0.280	0.157	80	130	16.96

	pH	C	N	P	K	Ca	Mg	Na	Cl	Mn	C/N
		(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(ppm)	(ppm)	ratio
Hydrangea serrata	6.15	34.0	2.14	0.078	0.259	0.015	0.136	0.131	70	90	15.89
Sasa kurilensis	6.21	38.6	2.09	0.065	0.200	0.012	0.246	0.161	70	141	18.47
Angelica dahurica	5.89	30.4	1.87	0.074	0.215	0.048	0.126	0.125	80	100	16.26
Sphagnum squarrosum	5.53	35.1	2.22	0.080	0.750	0.066	0.080	0.060	250	120	15.81
Allium victorialis ssp. platyphyllum	5.24	37.84	2.258	0.099	0.23	0.015	0.312	0.158	62.9	153.2	16.92
Veratrum stamineum	5.83	36.64	2.27	0.086	0.218	0.107	0.281	0.151	93.7	110.3	16.14
Aconitum japonica var. montanum	5.96	36.26	2.136	0.084	0.216	0.036	0.28	0.157	77	132.9	16.98
Rhododendron japonicum	5.73	31.77	1.884	0.089	0.373	0.031	0.086	0.135	82.6	81.4	16.86
Ilex crenata var.paludosa	5.88	32.49	2.002	0.061	0.109	0.02	0.037	0.07	66.1	34.1	16.23
Osmunda cinnamomea	5.52	37.12	2.422	0.062	0.323	0.029	0.111	0.16	86.2	74.6	15.33

Appendix 3. Composition of organic- and inorganic components of Peat soil (%)

Mire type	Plant species	Inorganic	Humic acid	Fulvic acid	Humine	Bitumen
Pond	*Potamogeton distinctus*	32.4	16	37.2	10.8	3.68
	Menyanthes trifoliata	27.5	41.3	22	9.17	0.02
	Mean value	**(30.0)**	**(28.7)**	**(29.6)**	**(10.0)**	**(1.9)**
Rich fen	*Carex rhynchophysa*	44.6	23.5	15	14.9	1.93
	Pragmites australis	25.5	48.8	14.2	8.5	3
	Caltha palustris var. nipponica	53	19.2	8.8	17.7	1.34
	Mean value	**(41.0)**	**(30.5)**	**(12.7)**	**(13.7)**	**(2.1)**
Intermediate fen	*Sanguisorba tenuifolia var. purpurea*	48.7	13.9	20.2	16.2	1.02
	Lysichiton camtschatcense	39.6	16.3	28.1	13.2	2.94
	Hemerocallis dumortieri var. esculenta	24.4	47.9	14.8	8.13	4.7
	Sphagnum recurvum var. amblyphyllum	-	36.5	15.7	46.4	1.48
	Mean value	**(28.2)**	**(28.7)**	**(19.7)**	**(21.0)**	**(2.5)**
Bog	*Rhynchospora alba*	19.1	37.7	35.6	6.37	1.28
	Sphagnum papillosum	-	17.4	28.4	49.2	4.97
	Racomitrium lanuginosum	-	47.3	6.6	40	5.98
	Mean value	**(6.4)**	**(34.1)**	**(23.5)**	**(31.9)**	**(4.1)**
Mire margin	*Aconitum japonicum var. montanum*	27.8	41.2	20.8	9.28	0.93
	Allium victorialis ssp. platyphyllum	25.9	40.4	22.8	8.64	2.25
	Veratrum stamineum	40.7	13.9	28.6	13.6	3.21
	Mean value	**(31.5)**	**(31.8)**	**(24.1)**	**(10.5)**	**(2.13)**
	Total mean value	**27.4**	**30.8**	**21.3**	**17.4**	**2.5**

The invasive alien plant species of Kolkheti lowland, Georgia

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Introduction

Georgia is situated in an interesting geobotanical position as part of Caucasus – the region which links Europe with Asia (Nakhutsrishvili 1999). The landscape of the country includes different types of desert and semi-desert vegetation mainly in the eastern parts of Georgia, luxurious Kolkheti Sphagnum percolation bogs (Joosten et al. 2003) and Kolkheti relict forest of moist, almost subtropical climate in the west, and high-mountain plant communities in the north and in the south. The lowlands of Kolkheti (Colchis in English and Kolhida in Russian) are situated in the triangle between the Black Sea and the Likhi/Surami Range and the Greater and Lesser Caucasus Ranges (Fig.1). Its largest width reaches from North to South (Sukhumi to Batumi). Climatic and geographical situation of the Kolkheti region represents a centre of biodiversity and human activity on the transition of Europe and Asia. It constitutes a region of global importance for biodiversity conservation, especially its valuable and unique mires and relict forests (Table 1).

Figure 1. Map of Georgia. Kolkheti lowland is shown as green.

The Kolkheti area in Western Georgia (Caucasus) at the coast of the Black Sea is known for its extensive and special mires that - situated between citrus groves and tea plantations - form a structural and functional transition between the mires of the boreal and those of the tropical zones (Joosten et al. 2003). The special character of the area and its mires brought Botch & Masing (1983) and Succow & Joosten (2001) to the distinction of a specific Kolkheti mire region within Eurasia.

The characteristic mire type of this region is the percolation bog, a dome-shaped *Sphagnum* mire only fed by precipitation, which in contrast to bogs in other parts of the world has slightly humified and highly permeable peat over its total depth (Haberl & al 2006). The extremely poor percolation bogs are not the most sensitive for adventives plants but the other mire habitats are (Fig. 2). The Kolkheti lowlands have furthermore a high diversity in other hydrogenetic mires including lithogenous water rise mires and flood mires. The Kolkheti mires display a diverse vegetation with many endemic species and relicts from the glacial period, consisting of Tertiary, (sub) Mediterranean and boreal species. The climate of Kolkheti lowlands is very specific and there are several criteria to determine it from subtropical to temperate. The climate is characterised by a high mean annual temperature of 14.1 ºC with warm winters and hot summers (Joosten et al. 2003). Mean January temperature in the major part of Kolkheti does not fall below 0 ºC and frost in winter is rare. The precipitation is high and nearly evenly distributed over the year. The highest precipitation occurs in the Batumi – Kobuleti area, being more than 4000 mm/yr.

History of adventives plants in Kolkheti

Invasion of alien species and their spreading among the local flora is caused by inexpedient activities of man (დავითაძე, 1981; Гроссгейм 1915, 1916). Spreading of plants means the widening of the geographical distribution of species (გაგნიძე 1996).

Figure 2. Central Kolkheti - Churia mire. Professor Hans Joosten is giving field lesson about the growth system of *Molinia litoralis*, which is the structural plant in percolating bogs. The loose *Spagnum* carpet practically climbs up using *Molinia litoralis* as a frame of the community (All photos Tapio Lindholm).

დავითაძე (1983, 1981), Davitadze (1983), მაჭუტაძე (2003) has repeatedly mentioned about the invasion of alien species and their mildening in wetlands coenosis, many of which create an independent plant cover. East Asian adventive species are recorded in the northwestern part of Adjarian percolation bog Ispani II, (Joosten & al 2003) e.g. *Paspallum thunbergii, Paspallum dilatatum, Hydrocotyle vulgaris* and *Hydrocotyle ramoflora*.

There are also adventive East Asian species *Spiranthes sinensis* in Ispani II, which was recorded in Batumi Botanical Gardens in the plant community of *Miscanthus sinensis.* The appearance of adventive plants in SW Georgia in Adjara (Fig 1.) is associated with the introduction of foreign cultivated plants (Дмитриева 1948, 1990). Already long ago the first adventive plants appeared along with rice cultivation: *Oplismenus undulatifolius*, *Eleusine indica*, *Arthraxon hispidus*, *Cyperus difformis*, *Acorus calamus* etc.

In 1870`s South Kolkheti became a centre of world trade in Transcaucasia, from were lot of different goods were imported, generally wood and fruit (სიჭინავა 1956). In 1882, lots of German, English, French and Belgian ships entered the Batumi sea port. At the end of 19th and in the beginning of 20th century, lots of adventive plant species were introduced through railway and marine transport, which belong to "neophytes" according to the migration time (დავითაძე, 1974, 1981), the first appearance of which is more or less precise. After 1900 *Ambrosia artemisiifolia* was introduced from Crimea to Kobuleti, and it became so wild, that it required a strict quarantine as a weed (Fig. 3). We may suppose that in the same period, with the railway or marine transport, dry grass, ship wool or another product, also *Calluna vulgaris* was introduced (Kaffke & al 2002).

One of the reasons for the extinction of the floral species and further invasion is the destruction of the habitat due to the anthropogenic factor. For instance, the uncontrolled and irregular cutting down of original forest ecosystems caused the colonization and

Figure 3. *Ambrosia artemisiifolia*.

growth of the *Pawlovnia fortunei* tree, which was introduced to be cultivated on the secondary meadows as the *Pawlovnia* forest plantation. Due to the absence of the law on invasive species and habitats in the legislation on the environmental protection, the tree has colonized spontaneously wide areas. In the same way, *Spiraea japonica, Polygonum perfoliatum* and *Crassocephalum crepidioides* became wild and dominant in the degenerated tea plantations.

The pretentious socialist agricultural development in Kolkheti was accompanied by a massive deforestation of the unique relict forest (dominated by *Pterocarya pterocarpa, Quercus hartwissiana* and *Buxus colchica*). The virgin forests were replaced by plantations of tea (*Camellia sinensis*), citrus (*Citrus* spp.), and tung tree (*Aleurites cordata*). The beautiful plant community that had established during the ages was badly disturbed.

Deforestation was accompanied by drainage of the mires. Canals were dug to drain the wetlands. In total, 140 000 ha were drained. In the large percolating bogs of Imnati and Ispani I (Joosten & al 2003), the uppermost 2m of peat was extracted to be used as soil improver in the plantations. The Maltakva, Shavtskala and Grigoleti mires completely lost their original structure and function as a result of peat extraction. These peatlands were mostly not used for agriculture, but became covered by secondary coenoses. Adventives became the permanent components of these wetland cenoses and gradually replaced the Kolkheti relict and endemic plant species. The list of Red Date Book species was growing (Matchutadze et al. 2005).

Particularly abundant are the invasive species in Southern Colchis – Adjara where tea, citrus and tung were planted in place of cut-down forests, i.e. after planting the subtropical cultures that changed the unique habitats of Colchis. The lowland forest is completely destroyed here. Only Ispani II is preserved in ultimate south-east and Tikeri forest section to the north of Ispani. As we go further northwards the number of invasive species decreases. Thus, in Anaklia only *Hydrocotyle vulgaris* is met in peatland and *Duchesnea indica, Polygonum thunbergii* and *Phytolaca americana* in the forests (Fig. 4).

Figure 4. *Polygonum thunbergii.*

Results

There are about 2000 vascular plant species found in Kolkheti Lowland. Of them, 423 are invasive. From the 423 invasive 308 occurs in Kolkheti wetlands (Дмитриева А, 1990, მაჭუტაძე, 2008). Most of them are vascular plants, 310 species, of which two species are ferns (Table 2). Most of the invasive plant species are growing in drained areas, secondary meadows, where the anthropogenic impact is highest. Most of the adventive species are from *Poacea, Asteraceae, Fabaceae, Brassicaceaea* and *Apiaceae* (დავითაძე 2001).

Polygonum thunbergii created a kind of "monopoly" on high-humidity meadows and owing to its particularly aggressive morphogenesis you never meet any other species with it, except for *Cuscuta* sp. and *Ambrosia artemisiifolia*. It is mostly met in ruderal habitats as well as former maize fields and agricultural grasslands. It should be noted that the natural habitat of *Urtica dioica* is reducing due to the de-cultivation of *Ambrosia artemisiifolia.* Together with *Duchesnea indica* and *Polygonum thunbergii* it is vastly spreading northwards and is the creator of grassland of the relict Kolkheti forests.

The most important species accompanying the rice field cultivation are: *Schoenoplectus juncoides, Eleusine indica* and *Oplismenus undulatifolius* (დავითაძე. 2001). Despite the wide net of quarantine inspection and agrotechnical improvement, the adventitious flora of Adjara is growing more and more in number.

The plants are inadvertently brought to Adjara by the following methods and ways (დავითაძე, 2001):
1. With inoculums and planting materials of cultivated plants;
2. By transport of water and ground;
3. By way of natural agents. That means: sea streams, winds and animals, especially birds. (Дмитриева А., 1990, დავითაძე 2001).

Most adventitious plants were brought to South Kolkheti with seeds and planting materials. This becomes apparent from the fact that the number of adventitious species increased simultaneously with the import of inoculums and planting materials of tea and other subtropical crops. Several adventitious species are only found in tea plantations, indicating that they were introduced with the planting material. Also the Botanic Garden of Batumi and other collection points were hotspots of the deliberate and accidental introduction of many foreign plants.

One way in which foreign species become a part of the local flora is by cultivated plants spreading into the wild. Such wilding plants spread into secondary habitats, but also into indigenous cenoses, sometimes becoming the weeds of cultivated plants.

Already Краснов (1913) pointed out at the rapid distribution of alien crops in South Kolkheti in Adjara. Introduced plants occupied new places so rapidly that the local vegetation changed in a short time. On many slopes and gorges they replaced native plants and created their own communities. The changed flora of the modern seaside of Adjara is mainly represented by communities of the following species: *Anthoxanthum odoratum, Paspalum dilatatum, P. digitaria, Miscanthus sinensis, Pueraria dirsuta, Spiraea japonica* etc., i.e. species that were introduced as fodder, decoration, or for slope fixation. Before long, birds had spread *Spiraea japonica* all over seaside gorges of Adjara.

The most numerous invasions of foreign species are connected to the destruction of the primary (forest and peatland) plants in Southern Kolkheti and the creation of agro-cenoses in their place. The process of the plant invasion comprises three independent and successive stages:

1. Transference-dissemination of the species Diaspora;
2. A complete-cyclical sustainability in a new environment;
3. Establishment in the local cenoses as a component.

The anthropogenic factor is not restricted by the transference of the diaspores. A great significance is rendered to the destruction of the primary plant cover and the formation of the new living environment in its place. The changed location creates favourable conditions for the invasive plants to be established.

The classification of the advent flora in Adjara is based on three criteria:

1. Time of migration;
2. Ways and means of invasion;
3. De-cultivation.

According to the migration ways, the invasive species are divided into archaeophytes, coenophytes, neophytes and euneophytes.

According to the invasion-naturalization level they are divided into:

1. Ephemerophytes are lightly naturalized species not showing the ability of distribution. From time to time they appear in small quantities, but they do not renew themselves, some of them even completely disappear. They include*: Oplismenus burmanii, Kyllinga metzii, Commelina bengalensis* and *Gymnaster savatieri*.
2. Proneophytes are not inclined to wide distribution, but in the places of their initial appearance they normally grow and develop with a full life cycle. They include: *Saxifraga sarmentosa, Lespedeza cuneata, Centella asiatics* and *Ixeridium dentatum*.
3. Epecophytes permanently renew on secondary habitats. In the vegetation period they may be found in various phases of development – beginning with shoots and finishing with ripe seeds. Some of them are typical weeds: *Microstegium imberbis, Commelina communis, Polygonum perfoliatum* and *Crassocephalum crepidioides* (Fig. 5).
4. Neoindigenophytes have expanded beyond the secondary habitats. They normally grow and develop in local coenoses for many years. They create independent plant communities, which include for example: *Microstegium japonicum, Paspalum digitaria, Anthoxanthum odoratum, Kyllinga gracillima, Pueraria hirsuta, Hydrocotyle ramiflora* and *Lonicera japonica*.

More than 60 invasive plant species in Adjara stem from the East Asian floristic region (floristic regions according to Takhtajan 1986) for example*: Mischantus sinensis, Microstegium cordata, Polygonum thunbergii, Lespedeza yuncea, Centella asiatica* and *Lysimachia japonica*.

From the (mainly South- and West-) Mediterranean floristic region come *Digitaria pectiniformis, Briza maxima, Arisarum vulgare, Ulex europaeus*, and *Erigeron crispus.*

From the Atlantic - North American region come more than 20 species, including *Panicum lanuginosum, Phytolacca americana, Amaranthus albus, Euphorbia maculata, Hypericum mutilum, Ambrosia artemisiifolia, Bidens bipinnata*, and *Erigeron canadensis.*

From the Central Brazilian region are, for example, *Paspalum dilatatum, Tradescantia fluminensis, Amaranthus deflexus, Chenopidium ambrosioides, Physalis periviana* and *Solanum pseudocapsicum*.

Figure 5. *Commelina communis*.

In artificial channels, dominant species are: *Scirpus juncoides, Cyperus difformis, Kyllinga gracillima, K. metzii, Acorus calamus, Juncus tenuis, Hydrocotyle ramiflora, H. vulgaris, Polygonum thunbergii, P. posumbu, P.minus, Lindernia procumbens, Egeria denca, Elodea canadensis, Althe officinalis, Sagittaria plaithylla* and *Ranunculus sceleranthus.* In case of destruction or the change of habitat all the local relicts are destroyed and the invasive species take their places in the created ecological emptiness.

Kolkheti lowlands comprise over 85% of the advent species, the reason of which is the cut-down of forests, irrigated and drained ecosystems and dried-out peatlands.

Conclusions

1. The appearance of adventitious plants in the flora of Adjara is associated with the introduction of the first subtropical cultivated plants. 14 adventitious plant species belong to the group of archeophytes.
2. We can divide the process of formation of the adventitious flora in Adjara into the following periods:
3. I: The period before the beginning of the 20th century;
4. II: The first two decades of the 20th century, when active introduction of plants out of the Batumi Botanical Garden started;
5. III: The period from the 1920s to the 1940s, covering the establishment of socialist agriculture and the destruction of the Kolkheti pristine forests;
6. IV: The period from the 1940s to the present.
7. Most adventitious plants (95 species) penetrated into the flora of Adjara with inoculums and planting materials of cultivated plants. Natural agents (sea streams, wind, animals etc.) played a minimal role in the enrichment of the adventitious flora with new species.
8. A major part of the adventitious plants (70 species) belongs, with respect to their naturalization, to the neoindigophytes and played a main role in the formation of the secondary herb vegetation of the seaside of Adjara.

9. A leading role in the formation of the adventitious flora of Adjara has been played by plants from subtropical Eastern Asia, which is caused by the analogue climatic conditions and the wide introduction of important subtropical crops from that region.

Most invasive plant species grow in drained, secondary meadows with much anthropogenic impact and belong to the families *Poaceae, Asteraceae, Fabaceae, Brassicaceae* and *Apiaceae.* The reason for the abundance of invasive plant species are (მაჭუტაძე 2008) the lack of a law about flora and habitats; incorrect forest management, improper development of infrastructure; very low environmental awareness; high demand of population in timber firewood and absence of alternative heating means, and shortcoming of legislative basis.

What are the ways to solving the problems, what is to be done immediately (მაჭუტაძე 2008)?

There is a need to accept a law and to make management plan for the protection of the local flora; to make strict control on invasive species. There is a need to make rules and guidelines how to establish and grow artificial forest of exotic trees on past meadows, so that they would help on timber needs local population and would not escape from plantations to natural habitats. The country needs assistance in the improvement of scientific/financial/technical mechanisms for habitat rehabilitation, biodiversity monitoring and sustainable resource use. The country also needs assistance in the formulation, review and endorsement process of a biodiversity strategic/action plan for Kolkheti. There is a need to enhance communication among stakeholders and to encourage public awareness and involvement in addressing the problems of the unique biodiversity. It is also necessary to make a selection of territories and allotment, for a pasture of cattle.

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Table 1. Main Habitats of Kolkheti lowland

No.	Habitat	Definition/ Description	Example
1	**Sea littoral**	Littoral/benthos with Zostera marina	Grigoleti, Tskaltsminda
2	**Coastal zone**		
2.1	Coastal dunes	Significant areas in Chorokhi delta and Ananklia- Churia coastline are still unpolluted. Dominated by: Pancratium maritimum, Convolvulus persicus, Cakile euxina, Asparagus litoralis, Tamarix tetrandra, Paliurus spina christi	Kobuleti, Chaqvi, Piti, Grigoleti
2.2	River mouth		Riv. Chorokhi, Rioni, Khobi
2.3	Brackish/saline waters	Small ponds with brakish waters along the coast, dominating with Bolboschoenus maritimus	Chorokhi
3.	**Wet grassland (Without peat)**	wet and often inundated areas, which are usually developed and maintained under pastoral influence.Used as low quality grassland,	Surroundings of the peatlands of Imnati, Grigoleti, Maltakva, Ispani
3.1	Juncetum	Areas dominated by Juncus sp. (but without peat) often inundated	North of Ispani II mires, South of the mires Imnati, North of Supsa
3.2	Typhetum+Iris+ Polygonum Mixed grassland	Vegetation of channels dominated Typha angustifolia, Iris pseudocorus, Sparganium neglectum, Polygonum thunbergia, Butomus umbellatus, Equisetum palustris	Guria, Piti-Maltakva, Samurzakano
4	**Open water**	Includes lakes, ponds, and channels	
4.1	Channels, little lakes, mirror like surface	Lakes and channels with with submerged plants such as: Potamogeton sp. Ceratophyllum demersum, Egeria denca (as invasive species) dominated by Nymphaea alba, Nymphaea colchica and Nuphar lutea	Palistomi, Imnati
4.2	Permanent freshwater lakes, ponds	Dominant species is Trapa colchica, Trapa maleevi, Trapa hyrcana, Artificial (former fish ponds)	Chorokhi delta, Grigoleti, Tskaltsminda, Narionali. Narionali, Grogoleti, Anaklia, Imnati, Chorokhi
5.	Peatland	A Peatland is an area with or without vegetation with a naturally accumulated peat layer at the surface	

5.1.	Sphagnum bog in particular Percolation bog	bog which is fed by rain water or precipitation (ombrogenous) Raised above surrounding landscape. Percolation bogs are found in landscapes where water supply is large end evenly distributed all over the year. With regard to the bog the water supply only arises from the precipitation. The water table in the mire is almost constant. Species like Sphagnum imbricatum, Sphagnum papillosum, Molinia litoralis are dominating. Peat is presented with under moss layer from overheated plants remnants, alive roots.	Ispani II, Imnati, Grigoleti
5.2	Fen	Fens (geogenous), are fed by groundwater water from the surroundings. Situated in depressions. After peat extraction which was carried out by dredging open water remained.	Anaklia-Churia
5.3.	Juncetum-Caricetum	Dominated by Juncus effusus, J. articulatus, Carex vesicaria	Nabada, Narionali
5.4	Typhetum+Phragmitetum	Typhetum is more frequent, and is widely distributed in low-lying areas. Contributes swamping and peat-formation processes.	Maltakva
5.5	Degraded peatlands	Peatlands, that have been drained, or peat was extracted, mainly for agricultural purposes. At huge areas the vegetation comprises recently by Pteridium aquilinum, Rubus spec., Polygonum perfoliatum	Onaria, Shavtskala, Ispani I
6	Secondary Meadow	After wood cutting and deforestation	
6.1	Secondary cenosis	Covering big vast areas and represented with the secondary cenosis after the former agricultural use dominant species is: Cynodon dactilon, Sisyrinchium angustifolium Used for hay-meadow Pastureland dominated by: Paspallum thunbergii, Polygonum thunbergii.	Grigoleti, Anaklia-churia, chorokhi Narionali, Samurzakano, Guria lowland
6.2	Agrocenosis	Used for growing of monoculture(Zea mays)	Guria, Kobuleti, Anaklia-chiria, Kakhabaeri
7	Forest and shrubs	Dominant species all kind of trees and shrubs	
7.1	Relict Kolkheti forest	mires of Kolkheti are unique for the fact that they are naturally transformed into the fragmentally presented Kolkheti forests characteristic warm-humid broad-leaved deciduous forests with evergreen understory, rich in endemic and relict tertiary species: Pterocaria pterocarpa, Quercus hartwissiana, Buxus colchica, Carpinus betulus , Morus nigra, Crataegus macrophylla , Humulus lupulus, Salix caprea	Churia, Imnati, Ispani I and Ispani II
7.2	Degraded forest	Degraded forest now secondary meadows	surroundings of Ispani II and Imnati
7.3	Alder (Alnus barbata) +Salicata (Salix caprea) shrubs	Water-logged soil with a summer ground water level close to the surface, but seldom above it. Are often invaded by trees and shrub including willows and alder with lianas (Lonicera caprifolia, Smilax excelsa)	Chorokhi delta, margins of the bogs and parts of the Kolkheti National Park

Table 2. Invasive plant species of Kolkheti wetland habitats (also Дмитриева, 1990, 1967, დავითაძე, 2001., მაჭუტაძე, 2003). EA = East Asia, Med = Mediterranean, NA = North America, SA = South America, Br = Brazil, AE = Atlantic Europe

Coenophytes				**Neophytes**				**Euneophytes**				**Archaeophytes**			
	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status
Annual															
Achilea biebersteinii	EA	2.1,6.1,6.3	Ep	*Ageratum houstonianum*	NA	5.5,6	Ep	*Althea officinalis*	AE	6	Ef	*Acorus calamus*	EA	3.1,6	Pr
Achillea nobilis	Med	2.1,6	Pr	*Anthoxanthum odoratum*	Med	5.5,6	Neo	*Arctium lappa*	AE	6	Ef	*Arthraxon hispidum*	EA	6	Neo
Botriochloa ischaemom	Med	2.1,6	Ef	*Artemisia vulgaris*	Med	5,5.6	Neo	*Cymbalaria muralis*	AE	6	Ef	*Cyperus esculentus*	Med	3.1,6	Pr
Bromus inermis	AE	2.1,6	Rr	*Aster novae-angliae*	NA	6	Ef	*Dianthus barbatus*	Med	6	Neo	*Hydrocotyle ramiflora*	EA		Neo
Bromus orientalis	AE	6	Pr	*Aster novi-belgii*	NA	6	Ef	*Egeria denca*	NA	4.1,4.2	Neo	*Oplismenus undulatifolius*	EA		Neo
Cardaria draba	Med	6	Pr	*Centaurea stenolepis*	Med	6	Ef	*Elodea canadensis*	Na	4.1,4.2	Neo				
Agropiron juncoides	AE	6	Pr	*Erinathus ravennae*	EA	2.1,6	Ef	*Festuca heterophylla*	AE	6	Pr				
Cerastium caespitosum	AE	6	Ep	*Gymnaster savatieri*	EA	6	Ep	*Galium ruthenicum*	EA	6	Pr				
Centaurea oxylepis	Med	2.1,5.5,6	Ep	*Houttuynia cordata*	EA	6	Ef	*Geranium sibiricum*	AE	6	Pr				
Cerastium glomeratum	Med	2.1,6	Pr	*Hydrocotyle vulgaris*	EA	3.1,5.5,6	Neo	*Helianthus tuberosus*	NA	6	Pr				
Chenopodium ambrosoides	SA	2.1,6	Ep	*Hydrocotyle maritima*	SA	3.1,5.5,6	Neo	*Hemerocalis falva*	EA	6	Ef				
Chenopodium anthelminticum	BR	6	Ep	*Hydrocotyle ranunculoides*	EA	3	Pr	*Juncus tenius*	NA	3.6	Pr				
Cirsium arvense	AE	6	Ep	*Miscanthus sinensis*	EA	3.1,5.5,6	Neo	*Ixeridium dentatum*	EA	6	Ef				
Cirsium incanum	AE	6	Pr	*Muhlenbergia schreberi*	EA	6	Ef	*Marrubium vulgare*	Med	6	Ef				
Duchesnea indica	EA	7.1,73,7.4	Neo	*Oplysmenus burmannii*	EA	6	Ef	*Narcissus poeticus*	Med	6	Ef				
Conyza graminifolia	NA	6	Pr	*Ornithogalum kochii*	Med	6	Ef	*Narcissus tezzeta*	Med	6	Ef				
Fallopia convolvulus	AE	6	Pr	*Oxalis violacea*	Med	6	Ep	*Ophiopogon japonicum*	EA	6	Ef				
Convolvulus arvensis	AE	6,7.3	Pr	*Paspalum dilatatum*	Sa	3	Neo	*Psoralea bituminosa*	Med	2.1,6	Ef				
Cyperus badius	Med	3,5.5	Pr	*Paspalum scrobiculatum*	Br	3.1,5.5,6	Ef	*Reynoutria japonica*	Ea	6	Pr				
Galium humifusum	Med	3	Pr	*Santolina chemaecyperissus*	Med	6	Ef	*Rudbeckia hirta*	NA	6	Pr				
Hemarthia altissima	Med	3	Ep	*Sisyrichium angustifolium*	AE	6	Neo	*Saxifraga sarmentosa*	EA	6	Ef				
Holcus lanatus	AE	3,5.5	Pr	*Trifolium alpestre*	AE	6	Ep	*Solanum carolinense*	SA	6	pron				
Kyllinga gracillima	EA	3,5.5	Neo					*Sonalum persicum*	Med	6	Ep				
Lamium maculatum	AE	3	Pr					*Tetragoneteca helianthoides*	NA	6	Ep				
Lamium purpureum	AE	3,6,5.5	Pr					*Tradescantia fluminensis*	SA	6	Ep				
Leonorus quinquelobatus	AE	3,5.5	Pr					*Tradescantia virginiana*	NA	6	Ep				
Leucanthemum vulgare	AE	6	Pr					*Tritonia crocosmaeflora*	Med	6	Ef				

Coenophytes				**Neophytes**				**Euneophytes**				**Archaeophytes**			
	Origin	Habitat	Status	Species	Origin	Habitat	Status	*Species*	Origin	Habitat	Status	Species	Origin	Habitat	Status
Lysimachia japonica	EA	3	Pr					*Vicia minor*	AE	6	Ef				
Malva ambiqua	AE	6	Pr					*Viola mandshurica*	EA	6	Ef				
Malva neglecta	AE	6	Pr												
Microstegium japonicum	AE	3	Neo												
Nasturtium officinale	Med	3	Pr												
Othanthus maritimus	Med	5.5,6	Pr												
Paspalum paspaloides	EA	3	Neo												
Paspalum thunbergii	EAS	3	Neo												
Phytolaca americana	NA	3,5,5	Neo												
Pycreus korschinskyi	EA	3,5.5	Pr												
Ranunculus sceleratus	AE	3,5.5	Neo												
Rorripa sylvestris	AE	3	Pr												
Scrophularia nodosa		3	Neo												
Sieglingia decumbens	AE	3	Pr												
Sorghum halepense	Med	3	Neo												
Sporoborus fertilis	EA	3	Neo												
Stellaria graminea	AE	3,5.5	Neo												
Viola prionanatha	EA	3,5.5	Neo												
Perennial															
Acalypha australis	EA	6	Neo	*Abutilon theoprasti*	Med	6	Ef	*Ageratum conyzoides*	Br	6	Ef	*Cyperus difformis*	EA	3.1,6	Pr
Adonis aestivalis	Med	6	Pr	*Althea hirsuta*	Med	6	Ef	*Ammania verticillata*	EA	5.5,6.3	Ef	*Dichrocephala bicolor*	EA	3	Pr
Aira elegans	Med	6	Pr	*Ammania auriculata*	EA	3	Ef	*Avena ludoviciana*	Med	5.5,6	Ep	*Eleusine indica*	EA	3	Pr
Amaranthus albus	NA	2.1,5.5	Pr	*Avena fatua*	Med	6	Ef	*Brassica nigea*	Med	2.1,5.5,6	Ef	*Schoenoplectus juncoides*	EA		Neo
Amaranthus blitoides	Med	6	Pr	*Avena sativa*	Med	6	Ef	*Coix lacrima-jobi*	EA	3.1,5.5,6	Ef				
Amaranthus cruentus	Br	6	Pr	*Brassica juncea*	Med	3	Ef	*Cyperus glomeratus*	EA	3.1,5.5,6	pron				
Amaranthus deflexus	Br		Pr	*Bromus squarrosus*	Med	3	Ef	*Echinochloa phyllopogon*	Med	3.1,5.5,6	Ef				
Amaranthus lividis	NA	6	Pr	*Commelina bengalensis*	EA	3.1,5.5,6	Ef	*Eleusine tristachia*	NA	2.1,5.5,6	Ef				
Amaranthus retroflexus	NA	6	Pr	*Conringia orientalis*	Med	3.1,5.5,6	Ef	*Euphorbia nutans*	NA	6	Pr				
Ambrosia artemisiifolia	NA	5.5,6	Neo	*Croton oblongifolia*	NA	3	Ef	*Galega officinalis*	Med	2.1,5.5,6	Ep				
Anagalis arvensis	AE	5.5,6	Pr	*Cyperus glaber*	Med	3	Ef	*Galinsoga parviflora*	NA	3.1,5.5,6	Ef				

Coenophytes				**Neophytes**				**Euneophytes**				**Archaeophytes**			
	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status
Anthemis cotua	AE	5.5,6	Pr	*Descurania sophia*	AE	5.5,6	Ef	*Hordeum distichium*	Med	3.1,5.5,6	Ef				
Arenaria serpilliifolia	AE	5.5,6	Pr	*Eragrostis pilosa*	Med	6	Ef	*Jpomea purpurea*	NA	3.1,5.5,6	Ep				
Atriplex patula	Med	Mead	Pr	*Eragrostis megastachya*	Med	2.1,6	Ep	*Lupinus albus*	Med	3.1,5.5,6	Ep				
Atriplex tatarica	Med	Mead	Pr	*Faba bona*	Med	6	Ef	*Mercurialis annia*	Med	3.1,5.5,6	Ep				
Brassica campestre	EA	6	Ef	*Fillago gallica*	AE	2.1,5.5	Ef	*Bidens bipinnata*	AE	3.1,5.5,6	Pr				
Briza maxima	Med	5.5,6	Pr	*Fumaria capreolata*	Med	6	Ef	*Phalaris minor*	Med	3.1,5.5,6	Ep				
Cardamine hirsuta	AE	3	Pr	*Fumaria officinalis*	AE	6	Ef	*Physalis peruviana*	SA	3.1,5.5,6	Ep				
Cerastium holosteoides	AE	5.5,6	Pr	*Galium tricornutum*	AE	2.1,5.5	Ef	*Sisymbrium altissimum*	EA	3.1,5.5,6	Ep				
Chenopodium album	SA	5.5,6	Ef	*Geranium pusillum*	Med	6	Ef	*Solanum luteum*	Br	3.1,5.5,6	Ef				
Chenopodium polyspermum	AE	5.5,6	Ef	*Hordeum geniculata*	Med	2.1,	Ef	*Solanum sisymbrifolium*	SA	3.1,5.5,6	Ef				
Chenopodium urbicum	AE	5.5,6	Ef	*Hypericum mutilum*	NA	5.5,6	Pr	*Trifolium incarnatum*	AE	3.1,5.5,6	Pr				
Commelina communis	EA	3	Pr	*Kummerovia striata*	EA	6	Pr								
Coronopus didymus	SA	3.1,6	Pr	*Lepidium campestre*	Med	3.6	Ef								
Crasspcephalum crepidioides	SA	6	Neo	*Lepidium sativum*	AE	6	Ef								
Crepis setosa	Med	6	Pr	*Lolium temulentum*	Med	6	Ef								
Datura stramonium	AE	2.1,6	Pr	*Lunaria annua*	AE	6	Ef								
Digitaria ciliaris	Med	6	Neo	*Lysimachia fortunei*	EA	3.6	Pr								
Digitaria ischaemum	EA	3.6	Pr	*Omphalodes linifolia*	Med	6	Ep								
Digitaria sanguinalis	Med	3.6	Pr	*Papaver macrostomum*	Med	5.5,6	Ep								
Digitaria violascens	EA	2.1,3.1,6	Neo	*Papaver rhoes*	AE	5.5,6	Ep								
Echinochloa crusgalli	Cosm	3.6	Pr	*Papaver somniferum*	Med	6	Pr								
Elscholzia ciliata	EA	3.6	Pr	*Perilla nankinensis*	EA	6	Pr								
Erigeron annus	NA	3.6	Neo	*Perilla ocymoides*	Ea	6	Pt								
Erigeron canadensis	NA	6	Neo	*Physalis ixocarpa*	NA	6	Pr								
Erigeron crispus	Med	6	Pr	*Ranunculus arvensis*	AE	6	Ef								
Euphorbia humifusa	Med	6	Pr	*Raphanis raphanistrum*	Ae	6	Ef								
Euphorbia maculata	NA	6	Pr	*Sinapis alba*	Med	6	Ef								
Euphorbia paralias	Med	2.1,3.1,6	Pr	*Strigosella africana*	Med	6	Ef								
Euphorbia peplis	Med	2.1,3,6	Pr	*Trifolium diffusum*	Med	6	Ef								

Coenophytes				Neophytes				Euneophytes				Archaeophytes			
	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status
Fimbristylis dichotoma	EA	3	Neo	*Trigonella coerulae*	Med	6	Pr								
Galinsoga ciliata	NA	6	Ep	*Vicia grandiflora*	Med	6	Pr								
Galium spurium	AE	3	Pr	*Vicia lutea*	Med	6	Ef								
Geranium columbium	Med	6	Pr	*Vicia nabronensis*	Med	6	Ef								
Geranium dissectum	Med	6	Pr	*Vicia panonica*	Med	6	Ef								
Geranium molle	Med	6	Ef	*Vicia villosa*	Med	6	Pr								
Heliotropium ellipticum	Med	6	Ef	*Vulpia bromoides*	Med	6	Ef								
Lathyrus aphaca	AE	6	Ef												
Lathyrus nissolia	Med	6	Ef												
Lindernia procumbens	Med	3	Pr												
Lolium rigidum	Med	3	Pr												
Ludwigia palustris	NA	3	Pr												
Microstegium imberbe	EA	3	Neo												
Oxalis corniculata	NA	6	Pr												
Poa annua	AE	3	Neo												
Polycarrpon tetraphyllum	Med	2.1,3,6	Pr												
Polygonum alatum	EA	3.6	Pr												
Polygonum aviculare	EA	3.6	Pr												
Polygonum perfoliatum	EA	3,5.5	Neo												
Polygonum posumbu	EA	3	Neo												
Polygonum thunbergii	EA	3	Neo												
Portulaca orelaceae	AE	3.6	Pr												
Ranunculus chius	Med	3.6	Pr												
Ranunculus muricatus	Med	6	Pr												
Ranunculus trachicarpus	Med	3	Pr												
Rapistrum rugosum	Med	5.5,6	Ef												
Scrophularia annua	AE	2.1,3,6	Ef												
Senecio sylvaticus	AE	2.1,3,6	Ef												
Senecio vernalis	Med	6	Pr												
Senecio vulgaris	AE	6	Pr												

Coenophytes				**Neophytes**				**Euneophytes**				**Archaeophytes**			
	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status
Setaria faberi	Med	6	Pr												
Setaria glauca	Med	6	Pr												
Setaria viridis	Med	6	Pr												
Sherardia arvensis	AE	2.1,3,6	Neo												
Siegesbekia orientalis	EA	2.1,3,6	Ed												
Sinapis arvensis	Med	6	Ef												
Sisymbrium loeselii	Med	6	Pr												
Sisymbrium officinale	Med	6	Pr												
Solanum decipiens	AE	3.2,6	Pr												
Solanum nigrum	AE	2.1,6	Pr												
Sonchus asper	Ae	6	Pr												
Sonchus oleraceus	Ae	5.5,6	Pr												
Tagetes minuta	SA	5.5,6	Pr												
Torilis heterophylla	Med	6	Ef												
Trifolium echinatum	Med	5.5,6	Ef												
Trifolium micranthum	Med	2.1,6	Ef												
Valerianella dentata	Med	5.5,6	Pr												
Veronica persica	Med	5..5,6	Ef												
Veronica polita	Med	5.5,6	Ef												
Vicia angustifolia	EA	6	Ef												
Vicia lathyroides	Med	5.5,6	Ef												
Vicia tetrasperma	Med	5.5,6	Ef												
Xantium californicum	MA	2.1,3	Pr												
Xantium occidentale	NA	2.1,5.5,6	Ef												
Xantium spinosum	SA	2.1,5.5,6	Ef												
Xantium strumarium	NA	2.1,5.5,6	Pr												
Biennial															
Capsella bursa-pastoris	Csm	6	Pr	*Berteroa incana*	Ae	5.5,6	Ef	*Ammi visnaga*	Med	5.5,6	Ep				
Cirsium vulgare	Med	5.5,6	Ep	*Lolium multiflorum*	Med	5.5,6	Pr	*Digitalis purpurea*	AE	5.5,6	Ep				
Crepis foetida	AE	5.5,6	Ep	*Oenanthe biennis*	NA	2.1,5.5,6	Pr	*Ericastrum armoracioides*	AE	5.5,6	Ef				

Coenophytes				**Neophytes**				**Euneophytes**				**Archaeophytes**			
	Origin	Habitat	Status	*Species*	Origin	Habitat	Status	*Species*	Origin	Habitat	Status	Species	Origin	Habitat	Status
Cynoglossum creticum	Med	5.5,6	?	*Silybum marianum*	Med	2.1,5.5,6	Pr	*Falcaria vulgaris*	AE	3,5.5,6	Ef				
Echium biebersteinii	Med	2.1,5.5,6	Ef	*Vicia dasycarpa*	Med	5.5,6	Ef	*Melilotus albus*	AE	3,5.5,6	Ep				
Echium plantagineum	AE	5.5,6	Ep					*Onopordum acanthium*	AE	3,5.5,6	Ep				
Eophorbia stricta	Med	5.5,6	Ep												
Erigeron bonariensis	Br	5.5,6	Ep												
Gnaphalium affine	EA	3	Ef												
Gnaphalium luteo-album	EA	5.5,6	?												
Hyosciamus niger	AE	5.5,6	pro												
Lepidium texanum	NA	5.5,6	Ef												
Linaria vulgaris	AE	5.5,6	Ef												
Reseda lutea	Med	6	Ep												
Silene gallica	Med	6	Pr												
Stelaria media	AE	6	Neo												
Torilis japonica	EA	6	Ep												
Verbena officinalis	AE	6	Pr												
Liana															
				Lonicera japonica	East Asia	Forest	Neo	*Vitex rotundifolia*	EA	5.5,6,7	Pr				
Vitis labrusca	NA	6	Neo	*Polygonum multiflorum*	East Asia	sec	Pr								
				Pueraria hirsuta	East Asia	Forest	Neo								
Scrubs															
				Baccharis halimifolia	NA.	wet	Ef								
				Clerodendron foetidum	EA.		Neo								
				Gomphocarpus fruticosus	Africa		Neo	*Lespedeza bicolor*	EA	6	Ep				
				Hibiscus siriacus	EA	sec	Pr	*Lespedeza cuneata*		5.5,6	Ep				
				Lespedeza juncea	E.A.	sec	Pr	*Solanum pseudocaspicum*	Br	5.5,6	Ep				
				Ulex europaeus	Med		Neo	*Spiraea japonica*	EA	5.5,6,7	Neo				

Coenophytes				**Neophytes**				**Euneophytes**				**Archaeophytes**			
	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status	Species	Origin	Habitat	Status
Trees															
								Acer palmatum	EA		?				
								Ailanthus altissima	EA		?				
								Catalpa speciosa	NA		?				
								Cinnamomum glanduliferum	EA						
								Cryptomeria japonica	EA						
								Cupressus lusitanica	NA						
								Gleditchia triacanthus	NA						
								Pavlovnia tomrtosa	EA						
								Mallotus japonicus	EA						
								Quercus acutissima	EA						
								Quercus mirsinaefolia	EA						
								Quercus palustris	NA						
								Rhus javanica	EA						
								Robinia pseodoacacia	NA						
Palms															
								Trachycarpus fortunei	EA						
Bamboos															
								Pleioblastus distichus	EA						
								Pleioblastus humilis	EA						
								Pleioblastus pumilis	EA						
Ferns															
								Onoclea sensibilis	EA						
								Pteris vitata	Med						

Spatial analysis and description of eastern peatlands of Tierra del Fuego, Argentina

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Introduction

The eastern part of Tierra del Fuego, where the main concentration of Argentinian mires is located, is a unique type of environment in the Southern Hemisphere. Mire and forest combinations form a special landscape with exceptional ecosystems that provide valuable environmental services, such as hydrological self-regulation (Joosten & Clarke, 2002, Baumann, 2006) and carbon retention capability. The information related to this area and its mires is truly scarce and considerably less than that available for the farther Antarctic Islands. Although historically Tierra del Fuego has been attractive for scientific expeditions, explorations were usually limited to shorelands and accessible areas. However, even now, the poor accessibility of inland sites across extensive bogs is a constraint for research.

In southern South America, the fates of peatlands and forests are linked because of their intricate connection at the ecosystem level (Arroyo & al, 2005). With the aim of conserving the special characteristics of this zone, local and international organisations are campaigning for the Península Mitre to be declared a protected area. Despite the important natural value and special features of the region, it remains without protected area status because of the lack of specific studies and peatland inventories. Thus, the purpose of this survey is to determine the full extent of peatlands in eastern Tierra del Fuego, their spatial distribution, and their relationship with climate and relief, as well as to describe their main characteristics. This way, we hope to contribute to improving the knowledge base of this wild part of Tierra del Fuego and supply information and a basis for appropriate conservation policies.

The study area (5286 km^2), which includes the Península Mitre region, is located in southern Argentina, on the eastern part of the "Isla Grande de Tierra del Fuego". It is delimited by the western water divides of the Moat and Láinez river basins (Fig. 1). The mountain range on the southern side decreases in altitude from west to east and presents discontinuities, which materialise as wide valleys whose rivers discharge in well-defined bays. In contrast, the northern shoreline has no significant that character.

According to Olivero & al (2001), on the southern side of Peninsula Mitre, the basement is composed of metamorphic rocks of the Jurassic-Cretaceous Lemaire and Yahgan formations. The Lemaire formation is an association of acidic volcanic and volcaniclastic marine rocks composed of quartz, alkaline feldspar and rhyolitic fragments. Three main facies within the Yahgan formation are a) black mudstone, fine-

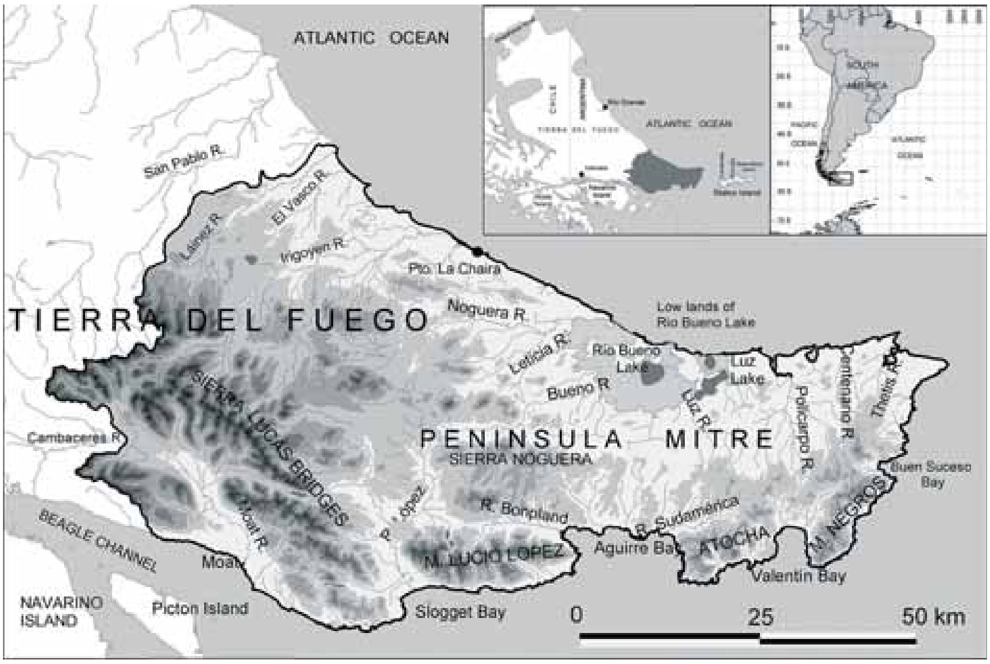

Figure 1. Location of the study area

grained turbidites and tuff, rich also in quartz and feldspar; b) classical turbidites; c) sandstones dominated by lithic andesitic fragments and plagioclase. The northern coastal area shows outcrops of Late Cretaceous-Paleogene strata of sedimentary rocks. (Olivero & al., 2002).

During the last glaciation the glacier lobe of the Beagle channel reached its eastern limit at Punta Moat (Coronato & al., 1999, Rabassa & al., 2000). The Fagnano lobe did not reach the western boundary of the study area, but part of the ice flow drained to the Atlantic coast along the valleys of the Irigoyen and Láinez Rivers. Although that region was not influenced by the main glacier lobes, it could have been affected by local glaciation.

According to Tuhkanen (1992), the main systems affecting the region are the belt of prevailing westerlies, the frequent eastward passage of extra tropical cyclones, and the occasional cold air intrusions from Antarctica, which presents marked oceanic features. The influence of the South Pacific anticyclone, the cold marine currents, and the mountain range, complete the list of factors that drive this complex climate model and determines favourable conditions for mire development

There is a lack of direct observations of the climate of the area, but insight can be gained from extrapolations that are supported by topography and biological indicators.

Mean annual temperature is 5.5 ºC in both Río Grande and Ushuaia localities with monthly January and June averages of 10.8ºC / -0.4ºC and 9.1ºC / +1.2 ºC respectively. This range can be applied to the coastal land in the study area as well. There is no permafrost but it is normal for peatlands to experience surface frosts in winter.

Precipitation is strongly affected by wind and relief. The coastal zone of the Beagle Channel is less oceanic than Península Mitre because the incoming humid south-west winds are intercepted by the Hoste and Navarino islands, which is not the case further east. In Ushuaia, yearly precipitation at 20 m a.s.l. amounts to 530 mm, but reaches 1000 mm at a nearby location 300 m a.s.l.

Precipitation data of the States and Observatorio islands, eastward of the Península Mitre, also present marked differences because of the influence of relief. Parry Station (States Island) is located at sea level but because of the nearby mountains, annual precipitation amounts to 2000 mm (data collected by the authors). Mean annual precipitation observed during the period 1900-1920 in the flat Observatorio Island, 10 km east of Parry, is 650 mm (SHN, 1997). A similar average precipitation of 612 mm was observed in the Staten Island in Crossley Bay, also near to Parry but with no influence from relief.

Comparable regional conditions suggest analogous effects over the eastern part of the study area, where the mountains are exposed to the southwestern oceanic winds. Observations over a 10 month period in 1985-86 at Moat, close to the Beagle channel, at 10 m a.s.l, indicate precipitation is 1.45 times higher than in Ushuaia, which suggests total annual precipitation of 750 mm. This increases eastward because of the influence of the Lucio Lopez, Montes Negros and Atocha mountains. It is likely that, apart from the northwestern coastal zone, precipitation in the study area is in the range of 700-1000 mm, which Auer (1965) considered appropriate for development of mires.

Distinctive species appear as biological indicators of wetter climatic conditions; the abundance of Astelia pumila, typical of rainy and windy climates (Auer, 1965, Moore, 1983, Heusser, 1995) characterises cushion mires very different from Sphagnum bogs. Wind protected sites provide more suitable conditions for mosses (Dierßen, 1996). Raised Sphagnum bogs are typical in the wind protected western valleys but are not representative of eastern Tierra del Fuego. The native evergreen Nothofagus betuloides forest, well adapted to waterlogged and poor soils (Romanya, 2005), appears in higher proportion than in other parts of Tierra del Fuego. Drimys winteri, common on the humid coastal environment, is also more frequent in the mixed forests of southern Peninsula Mitre. Deciduous forests of Nothofagus pumilio and N. antarctica on the northern side also suggest a decreasing gradient of humidity northward.

There is more available information about floristic composition and units of vegetation in the Moat zone, located in the western sector of the study area (Roig & Collado, 2004).

Beaver (*Castor canadensis*) were introduced to Tierra del Fuego in 1946. The species expanded rapidly and their activities changed the regional ecology and biotic composition, and physical structure of forests and bogs (Lizarralde & al., 2004).

In the absence of roads and ports, human presence is currently very scarce, but had more importance a century ago when sheep farming and logging were significant activities in the coastal areas. The construction of a road connecting Ushuaia with the north reduced human presence in the isolated eastern area in the second half of the 20th century.

Apart from Peninsula Mitre, the central and southern parts of Navarino Island (Chile) also contains many peatlands. To a smaller extent, peatlands are found on States Island and throughout the rest of the archipelago.

Materials and methods

Remote sensing offers efficient tools for detecting and mapping regional landscape patterns and processes in wetland environments (Roughgarden et al. 1991, Poulin et. al. 2002). Previous work applying satellite imagery in Tierra del Fuego was addressed to produce a mire inventory for an area of 377 km^2 located in the central part of Tierra del Fuego (Roig, et al, 2001). Other results used in this survey as basic information at macroscale are the Forest Inventory of Tierra del Fuego (Collado et al, 2001) and the Map of drainage and water basins produced by the Water Agency of Tierra del Fuego.

Land cover identification and mapping was performed by visual analysis and on-screen digitising in vector format using ArcView tools.

The automatic classification technique offered faster results and facilities to classify different kinds of vegetation, but the visualisation method was efficient for the single analysis of the peatland coverage and their spatial distribution. Under a GIS framework, visualisation procedures offer a means to combine and view several channels of data concurrently (Gahegan, 1996). Grasslands and vegetationless areas were identified, in addition to peatlands. The grassland category includes all non-forest, herbaceous vegetation growing on mineral soil. Forest and hydrology data were available layers.

These land cover types contrast well in satellite images, except in some places, mainly along the northern shore, where wet grasslands and dry fens show similar reflectance. After completing a preliminary map, the uncertain sites along the coastal area from Irigoyen to Policarpo were checked. In addition, field observations were performed in the area from the year 1988 at the following places: Moat shore, Moat Valley, inland hills of Moat, inland areas close to Río Bueno and Luz Lakes, Slogget Bay shore, Aguirre Bay and Buen Suceso Bay. Field activities included identification of dominant species, peat coring, water quality observations and river flow measurements.

The scale of the general analysis was 1:50000. In several areas the resolution was improved by using aerial photographs from 1970, scale 1:40000 and 1:20000.

Peatland development under well-developed forest canopy was sometimes undetected, resulting in an underestimation of peatland cover. The error in total peatland cover was estimated at +1% to -3%.

The digital elevation model of South America generated by the 2000 Shuttle Radar Topography Mission (SRTM) was used to evaluate relationships between peatland distribution and altitude and slope. The altitude of peatlands was determined by querying both peatlands and land elevation model grids using a 30m grid size. Similarly, the grid data for peatland slope was made, after generation of a land slope grid data from SRTM by using Arc View 3.2 software.

The identification of peatlands and their relationship with relief was complemented by the description of mire formation in the area.

Typologies and terms related to large and meso-scale mire entities are not internationally homogenised. In the USA, a mire complex is mostly considered to be an area consisting of several hydrologically connected but often very different mire types (Glaser, 1992, Rydin & Jeglum, 2006). On the other hand, the European classification considers at less two hierarchical levels for mire unit associations: mire systems and mire complexes – or mire massifs - (Masing, 1984, 1998, Laitinen, 2006, 2007) where mire systems are the largest scale units including several mire complexes. Mire complexes are units at lower macroscale, which are normally composed of mires belonging to the same type, such as raised bog complex, cushion mire complex, etc. We used the latter terminology to describe mire organisation based on field observations, aerial photographs, satellite images and oblique aerial photographs.

Results and discussion

Mire coverage and distribution

Peatlands are the dominant type of ecosystem covering a surface area of 2394 km^2 (45.3 %). This differs from other zones of Tierra del Fuego. For example, the result of a peatland inventory for a nearby sector of central Tierra del Fuego indicates a forest cover 3.6 times greater than peatland cover (Roig, & al, 2001). Although there is insufficient information relating to peatland thickness, it is possible to estimate 3m as the approximate average value for the whole area. On this basis, the total approximated peat volume in the study area is close to 7200 millions m^3.

Altitude and slope are significant factors driving mire distribution. Figure 2 shows the distribution of peatlands with respect to altitude. About 45% of the mires are below 100 m a.s.l. and 98.5 % below 400 m a.s.l. (Table 1). Peatlands are most common on relatively flat areas with slopes < 6% and less frequent on slopes > 15% (Fig. 3). More than 80% of flat areas (typically valley bottoms; slope <3%) are covered by peatlands.

In comparison to other types of cover (Table 2, Fig. 4), peatlands are the dominant type of cover on slopes < 10%. Forests dominate on steeper sites. Very steep slopes (> 60%) are mostly devoid of vegetation. Grassland patches occur with increased frequency on slopes > 15% but are never the dominant type of cover.

Hydrological conditions change substantially along a short slope range, affecting peatland development (cf. Germann, 1990, Olden, 2006). Whereas mires are less likely to be able to maintain a regular water level in steep areas, *Nothofagus* forest can colonise these with its surface roots adaptable to thin soil layers. Still, sloping mires with *Sphagnum magellanicum* and *Marsippospermum grandiflorum* occur with relative frequency on slopes of 50% (Fig. 3).

Although landslides are rare at large scale, they are recurrent, especially after exceptional rain events. Based on analysis of several peat slides in Buen Suceso Bay (easternmost Tierra del Fuego, Fig. 1) Gallart & al.(1994) concluded that peat soils become unstable when thickness exceeds a critical value, which depends on slope.

The upper limit of the forest decreases considerably to the east along the southern coastal area. Hillslope orientation also affects the vegetation limit (Puigdefabregas & al., 1988). In Martial Mountains, close to Ushuaia City, the timberline reaches 550 and 600 m a.s.l. respectively on hillsides exposed to the South and the North. In Sierra Lucio Lopez it reaches 500 and 550 m and decreases in the eastern mountains to 350 and 450 m a.s.l. Whereas in the West the upper vegetation is forest, towards the east it becomes peatland, particularly in the case of rounded summits below 400m a.s.l.

The alpine vegetation above the tree line also diminishes and often disappears. At the Martial Mountains, the upper limit for vascular-plant communities is 850m (Branca

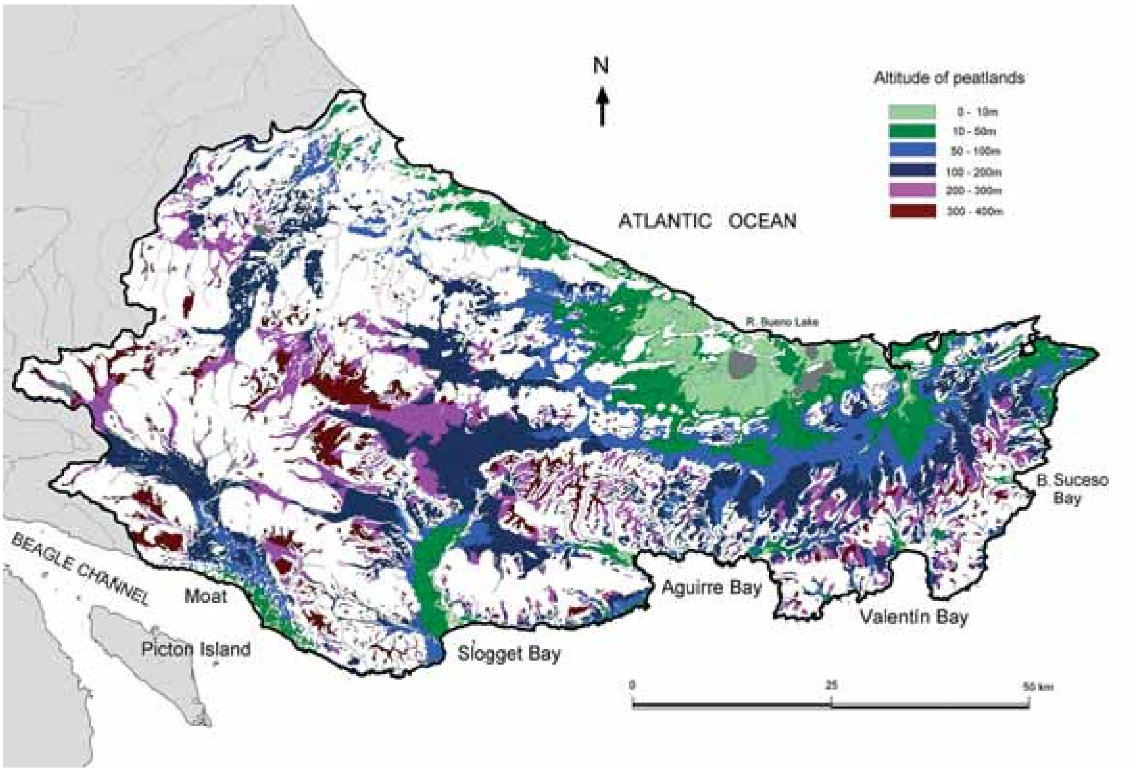

Figure 2. Peatland distribution by altitudinal ranges

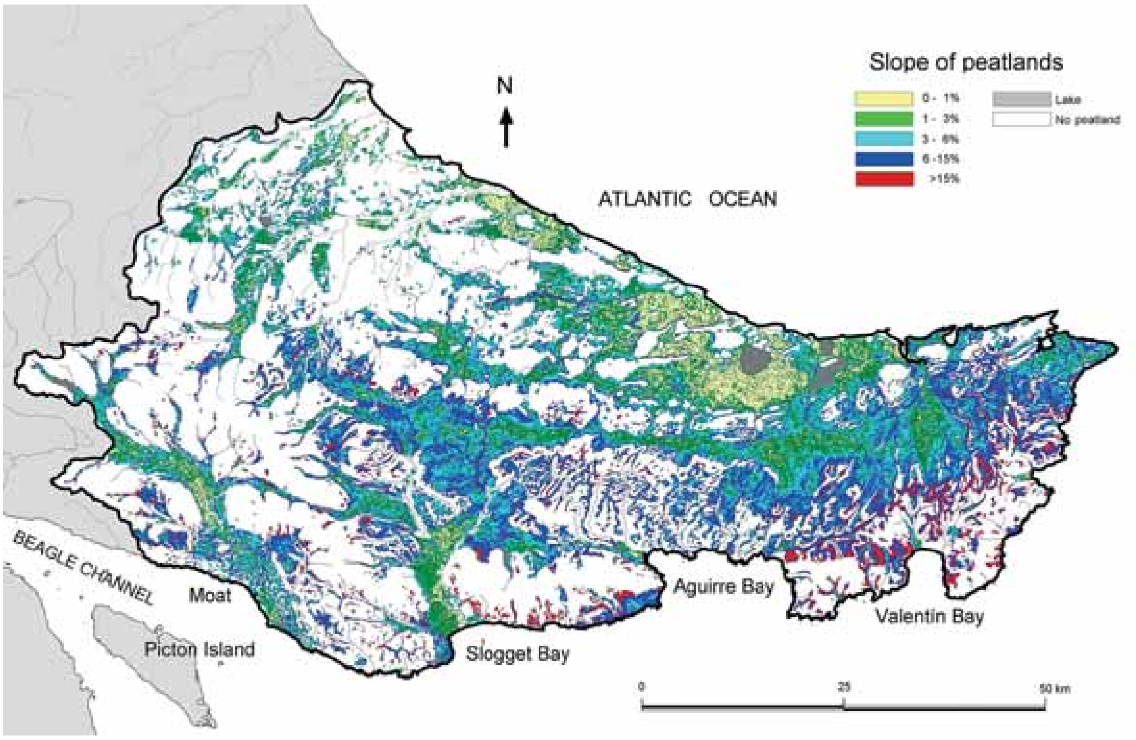

Figure 3. Peatland distribution by slope categories

Table 1. Area of peatlands by altitude.

Altitude (m)	Area (km2)	Area %	Accumulate Area %
0-10	171.2	7.2	7.2
10-50	465.3	19.4	26.6
50-100	435.2	18.2	44.8
100-200	765.6	32.0	76.7
200-300	351.0	14.7	91.4
300-400	170.2	7.1	98.5
400-500	34.1	1.4	99.9
500-530	1.5	0.1	100.0
Total	2394	100	

Table 2. Frequency of land cover categories by slope range

Surface area (km2)						
Slope range %	Total area	Peatlands	Forest	Grassland	Bare soil	Lakes (1)
0-1	306.3	260.0	7.1	11.0	0.2	28.0
1-3	671.4	569.8	55.7	42.0	0.9	
3-6	819.4	621.4	152.7	40.3	3.0	
6-10	832.1	487.1	302.4	30.2	7.4	
10-15	754.2	288.4	413.9	38.2	13.7	
15-21	629.3	126.7	414.8	62.5	25.2	
21-35	769.4	37.5	537.9	116.4	77.6	
35-60	454.6	3.0	270.5	70.6	110.5	
>60	49.0	0.0	13.9	7.4	27.6	
Total	5285.6	2394.0	2168.9	418.5	266.2	28
Total %	100.0	45.3	41.0	7.9	5.0	0.5
(1) Endotelmic pools are not included.						

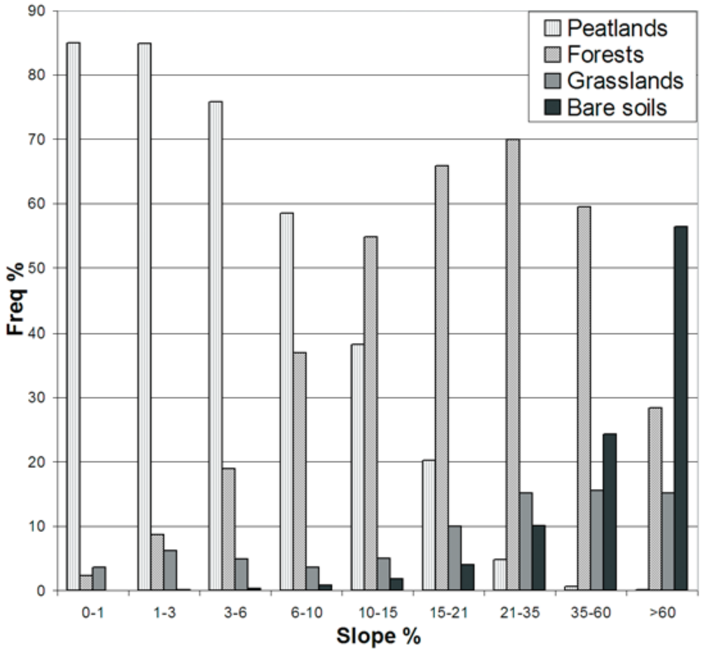

Figure 4. Land cover composition for different slope categories.

Figure 5. Astelia mire in Moat (Photos Rodolfo Iturraspe).

leoni & al., 2003) and 1250m for scattered vascular-plants in favorable micro-habitats (Mark & al., 2001). In the study area, alpine vegetation has small significance, mainly because of the lower relief, and also because mires occupy most of the potential habitat of these communities.

Description of mire systems and mire complexes

Mire complexes present well marked zonal particularities responding to differences in hydrology, local climate, relief, chemical properties of water and soils and geomorphology

Mires of the northwestern zone are located in the Láinez and El Vasco basins as well as in part of the Irigoyen basin. Peatland distribution is mainly associated with glacial and pro-glacial landforms. Mires are present as isolated units or linked in elongated systems of *Sphagnum-Empetrum-Marsippospermum* bogs and *Carex* fens surrounded by *Nothofagus pumilio* forest. This is a unique zone in the study area where forest coverage is greater than that of peatlands. Only the northwestern sector and the Moat coastal area are accessible by road. A new road across the Láinez and upper Irigoyen basins was recently opened for forestry activities. Such new roads invariably lead to additional impact on natural systems, including peat-mining activities, which have a high incremental rate in Tierra del Fuego (Iturraspe & al., 2004).

Mires of the large southern valleys occupy the wide valleys of Moat and López Rivers. They are mire systems composed of several kinds of mire complexes: sloping mires, blanket bogs, fens and cushion bogs in the coastal areas. Because of differences in hydrological conditions, mosaics with different mire types occur in the intermediate Moat valley: *Sphagnum* bogs, *Carex* fens as well as spots of *Astelia*. Mires occupying the bottom valley are characterised by elongated endotelmic pools, oriented transversally to the slope. Gallery forests typically occur along the rivers, also across peatlands. They are strongly affected by the activities of beavers (*Castor canadensis*).

Figure 6. Pool system in the López River valley. Oblique aerial view towards east of the lower valley. Astelia communities and small Nothofagus betuloides trees cover the peatland. Red dish-brown spots are Sphagnum - Tetroncium communities. Three tributaries flanked by incipient gallery forests can be seen meandering between the pools. The forest along the main river (lower edge) is better developed. The steep riverbank on the left shows the glacial deposits that underlie the wetland.

The lower Moat Valley is geologically a continuation of the Cambaceres Valley. The latter is located outside the study area, but has also significant peatlands. The Cambaceres and Moat valleys constitute a transitional zone from *Sphagnum* bog communities to *Astelia* mires. *Astelia* mires are dominant in the coastal areas of Moat. These flat and compact cushion-bogs (Fig. 5) are normally deeper, composed by *Astelia pumila*, *Donatia fascicularis*, *Caltha dioenifolia*, dwarf forms of *Nothofagus betuloides*, *Empetrum rubrum*, *Drossera uniflora* and *Oreobulu*s *obtusangulus*. *Sphagnum magellanicum* and *Tetroncium magellanicum* occur on the pool margins. EC values between 300-400 µS denote that these sites are rich in nutrients. Corings indicate that the cushion bog species have overgrown former *Sphagnum* mires. Heusser (1995) determined 2600 years B.P. as the start of development of cushion bogs in Moat. *Juncaceae* mires dominate above 300 m a.s.l, with mainly *Marsippospermum grandiflorum*, *Rostkovia magellanica*, *Empetrum rubrum*, *Chiliotrichum diffussum* and *Pernettya pumila. Marsippospermum grandiflorum* also grows in areas inundated by old beaver dams. Roig & al. (2004) determined the following percentages of mire types for Moat zone: *Astelia* 24 %, *Juncaceae* 14%, *Sphagnum* 20.3%, transitional mires (from forests to mires) 41.7 %.

East of Moat, the López Valley, which ends in Slogget Bay, presents a particular mire complex that completely covers the 4 km wide valley and shows a strongly patterned system with hundreds of small pools (Fig. 6). Several tributary parallel streams runs from the western hillside towards the main course in the eastern border of the valley. The *mires at the top of Sierra Noguera*, east of Slogget Bay, cover rounded hill summits. They are characterised by patterned pools situated on the top. Forest development occurs in the well drained and wind protected hillsides of the narrow and deep fluvial valleys. This particular morphology has led to the formation of ”incomplete” blanket mires at 300-400 m a.s.l. (Fig. 7). Their location on water divides proves that despite the high wind exposure, periods of water deficit are infrequent. *Marsippospermum*

Figure 7. Typical landscape of Sierra Noguera near Slogget Bay with mires located on the top and Nothofagus betuloides forests on the well drained hillsides.

grandiflorum, *Rostkovia magellanica* and *Empetrum rubrum* are dominant species. Coring indicates that the peat layer is about 2 m deeper in this kind of mire.

The *mires of the eastern part of the peninsula* experience the most oceanic conditions, comparable with those on the States Island. The leeward northern slopes of Montes Negros represent the main part of peatland cover, with the Policarpo, Luz and Thetys basins covered by blanket bogs (Fig. 8). Peatlands cover more than 80 % of these catchments. *Astelia* mires are the dominant type but mixed mires become more important further inland. The coastal forests are mainly composed by *Nothofagus betuloides* and *Drimys winteri*. Matteri & al. (1991) described typical moss communities of this environment based on studies in Buen Suceso Bay.

The *mires of the northern shore,* from Irigoyen River to Leticia River, show floristic gradients and signs of degradation, with decreasing *Sphagnum* cover to the East and increasing cover of small bushes such as *Empetrum rubrum*, *Chiliotrichum diffussum* and dwarf *Nothofagus antarctica*. A large *Sphagnum* mire complex extends from Puesto La Chaira to the South, on low and flat lands surrounded by low hills. Eastward of Puesto la Chaira *Sphagnum* occurrence decreases. Another big mire system occupies the Leticia Valley. Both areas show a variety of mire components with groundwater providing significant water input. Corings in a patterned bog near the right margin of the Leticia River (S 54° 39′, W 65°51′) indicate thickness of 3.70 to 5.00 m.

Forest, grassland and marginal peatlands in the entire coastal area are affected by the excessive presence of wild cows, horses and guanacos (*Lama guanacoe*). This, in addition to the negative effects of beaver activity, causes degradation of the natural environment: overgrazing on grasslands, lack of regeneration in forests, and destruction of marginal areas of peatlands.

The *Río Bueno Lake* is surrounded by an extensive mire system that has a particular floristic composition, morphology and hydrologic features. A thin layer of vegetation is composed of *Caltha dionaeifolia*, *Empetrum rubrum*, *M. grandiflorum* and *Rostkovia*

Figure 8. Patterned blanket bogs in eastern Península Mitre.

magellanica. This vegetation grows over a highly degraded dark *Sphagnum* peat matrix. Although corings indicate that *Sphagnum* dominated in the past, it is rare at present, occupying only small marginal areas. *Astelia* is rare but becomes more frequent eastward.

The entire coast of Río Bueno Lake is constituted of peat. In the western coastal zone of the lake, significant peat mass movements were observed. Corings in the area indicate a mean peat layer of 3.10 m. Similar values were observed in the mire located between the lake and the shore.

Between the *Policarpo River and the Luz Lake*, mosaics were found of well-developed *Astelia* mires and mires similar to those observed near Rio Bueno Lake. Peat accumulation in this zone (S 54° 40′ W 65° 35′) varies from 4.0 m to 5.5 m.

The whole area below 10 m a.s.l. that surrounds both the Rio Bueno and Luz Lakes and includes part of the Leticia basin, is a wetland of 160 km^2 with lakes, pools and mires, fed by surface water and seepage from the mountains (Fig. 9). On these flat slopes, these endotelmic lakes do not display elongated forms. Water bodies cover 22% of the area. The area located to the South of Río Bueno Lake has higher pool concentration (7.5 pools × km^{-2}). A stream network drains excess surface water but does not connect most of pools. However, pools may drain by breach of the downslope margin or by subsurface piping (Mark & al., 1995). Beaver activity heavily affects the gallery forest along these streams. Beaver dams flood extended flat areas and create surface links between pools, resulting in important changes to the local hydrology.

The general mire morphology, the presence of a basal clay layer, and the low and uniform altitude, suggest that this peatland originated after water level fell in a big lake that covered the entire area. Old beach levels near the outlet of Bueno River indicate that changes in the relative sea level would have formed the basis for this development.

Figure 9. The lowlands of Península Mitre. Pools, streams and the Río Bueno Lake in the background.

Peatlands and basin hydrology

Mires have high significance for the hydrological regime, drainage network patterns and water quality in the landscape (Ivanov, 1981, Ingram, 1983, Boelther & al., 1977, Gilman, 1994, Glaser, 1997, Price & al., 2005). The relevance of peatlands as drivers of the runoff at the water basin scale depends on the mire cover ratio. In the study area it increases from 21% in the Láinez Basin, located in the northwestern side, to 83 % in the Luz Basin, in the eastern zone. Peatlands are the main water storage and regulation systems in the basins of the study area and determine special hydrological properties. Iturraspe & al. (2000) proposed an eco-hydrological classification for the water basins of Tierra del Fuego, based on water storage and recharge available systems, with “peatland basins” as a special category.

The high concentration of humic acids affects the water quality of the main rivers. The water shows a typical brownish dark color, pH values close to 5, and very low salt concentrations but high Fe values (Iturraspe & al., 1989). Blanket bogs and sloping mires protect the hillsides and control the transport of sediment to the rivers, lowering rates of solid discharge. The peatlands of Peninsula Mitre have high capacity to regulate excess water; however flood events in these peatland catchments can be extreme when intense rainfall occurs during conditions of saturated peat soil, for example after an intense snowmelt process.

Several authors completed studies related to mire hydrology in Tierra del Fuego at micro or meso-scale (Iturraspe et al, 2000b, Köpke, 2005, Baumann, 2006), However, there are no studies in the region related to the significance of mires on hydrological processes at water basin scale. The high rate of peatland coverage and the variety of mire types in the water basins of Península Mitre motivate special interest for research on that matter.

Conclusions

Most Argentinean peatlands are found in Tierra del Fuego, and most Fuegian peatlands in the eastern region of Peninsula Mitre. The total area of peatlands in the Argentinean part of Tierra del Fuego is estimated to be 2700 km^2, 2400 km^2 of which is in Peninsula Mitre.

Peatlands are the dominant vegetation type in Península Mitre, followed by forest. This is in contrast to the north of Tierra del Fuego where grassland dominates, and the central and southwestern regions where forest is dominant. The climatic gradient in the region, characterised by increasing humidity and oceanic influence from West to East, induces a positive gradient of peatland coverage ratio as well as changes to the dominant species on mires from *Sphagnum* to *Caltha dioeniaefolia* to *Astelia*. Forest species also change along the Northern shore from *Nothofagus pumilio* to *N. betuloides* and, as part of the mires' floristic composition, from dwarf *N. antartica to* dwarf *N. betuloides*.

Local slope and altitude have a strong influence on forest and peatland distribution. Although both ecosystems are able to survive under a range of conditions, bottom valleys and gentle slopes (close to 10%) are normally covered by mires, with steeper slopes (>15%) dominated by forests.

Both, peatlands and forests are similarly restricted by high elevation, but the oceanic influence allows peatland development on lower rounded summits. The upper limit found for mire development in the study area at the level of small patches on favourable settings is 530m a.s.l.

In addition, wind exposure, water supply from upper lands, drainage patterns, basal soil composition and geomorphologic features are significant factors that contribute to define mire or forest dominance.

Many mires of the region have never been visited by humans, but there are signs of degradation in mires and forests, caused by over-population of introduced fauna that affects their natural condition.

The significance of peatlands in this region is not restricted to their extent. While they do not have high species diversity, they support highly specialised species typical of the austral region. Biodiversity is most evident in the large variety of mire types, each with typical surface patterns and biological communities. In addition, mires are dominant highlights of this landscape, which is characterised by a large uninterrupted wilderness whose integrity is necessary to preserve.

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Mires Down Under – the Peatlands of Australasia

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Introduction

The Australasian region extends from 54ºS to the equator and includes temperate, tropical and arid landscapes. The region comprises the continental block of Australia with the island of New Guinea, and the oceanic islands of the south west Pacific, notably New Zealand, the subantarctic islands, New Caledonia, Fiji and the Solomon Islands (Fig. 1). It is defined by common elements in the floras that reflect ancient connections or migration paths. A wide variety of peatlands occur where moisture is abundant but extensive peatlands are rare.

Although some of the peatland types that occur in the region have northern hemisphere counterparts (e.g. *Sphagnum* bogs, sedge fens, *Phragmites-Typha* riparian fens, mangroves), peatlands are not generally dominated by species of *Sphagnum* moss. Some structural forms are peculiar to the region - for example the buttongrass moorlands of Tasmania, the Restionaceous-sedge peatlands of New Zealand, *Melaleuca* swamp forests in northern Australia and New Guinea, Podocarpaceae-dominated swamp forests in New Zealand, New Caledonia and New Guinea, and hard cushion bogs in western New Guinea. Whinam & Hope (2005) provide the first regional accounts of peatlands and this paper is based on that review. It summarises the range of peatland types and reviews their conservation status. There are few national or provincial studies of mires, other than mire vegetation descriptions. The tropical peatlands, in particular, are poorly known.

Peatland classification

Unlike the northern hemisphere, there is no accepted scheme of peatland nomenclature for Australasia. Many of the definitions applied to northern hemisphere peatlands are not appropriate for the region. We use the term ‘peatlands’ to indicate terrestrial sediments in which organic matter exceeds 20% dry weight and with a depth generally greater than 30cm. However some mires, such as Tasmanian buttongrass moorland, are usually only 15-20cm deep, but must be included as they form extensive organic terrains (c 1 million ha).

The nutritional status of most peatlands is not known, nor can the supposed origin of the peat be used in classification. The practical distinction between ombrotrophic and minerotrophic is blurred, as dramatically infertile sites (e.g. on Precambrian quartzite

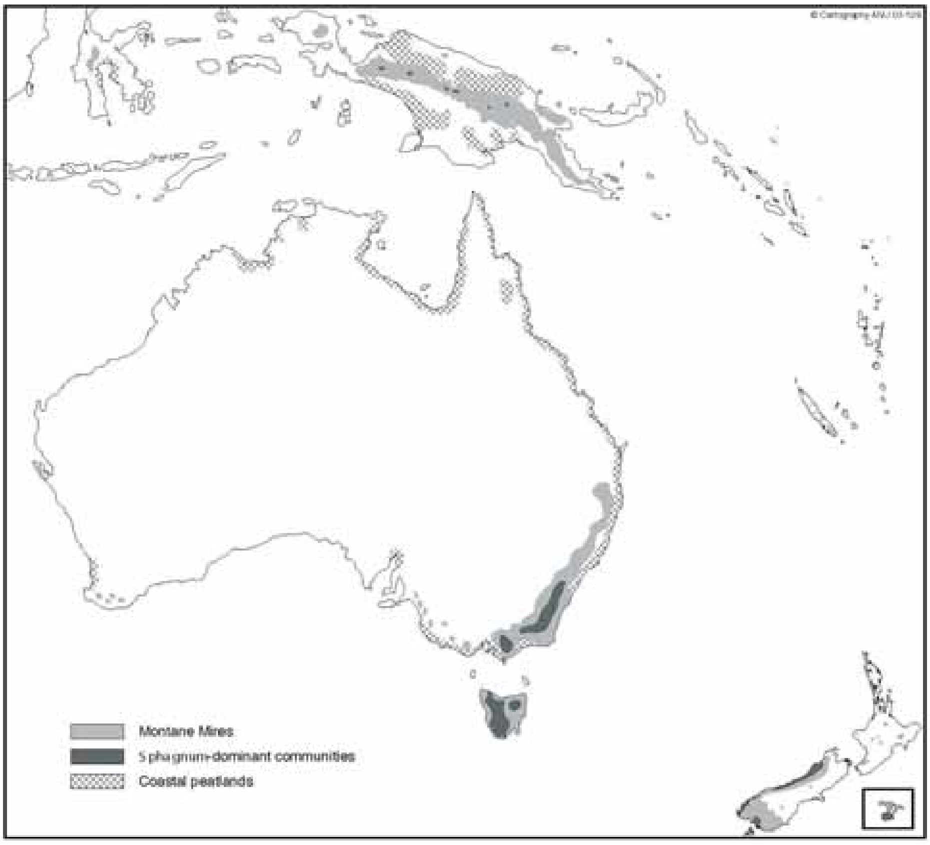

Figure 1. The Australasian region showing major peatland areas.

in Tasmania) may have lower levels of fertility than some purely ombrotrophic sites, given relatively high salt and dust accession levels in the region. Thus in Australasia, peatland classification is primarily concerned with the structure and life forms of the peat-forming vegetation (Table 1). This approach has the considerable merit of not attempting to pre-judge trophic or causative factors that cannot be readily measured. A classification system for New Zealand wetlands (Johnson & Gerbeaux 2004) is based on distinctive combinations of substrate, water regime, nutrient status and pH, where vegetation reflects these controls. The New Zealand wetland classes having peat substrates include bogs, fens, swamps, seepages, and pakihi/gumland.

The terms bog and fen are used here as a simple division based on vegetational structure. This expands the restricted trophic definition of bog as purely ombrotrophic, to include a range of peat-forming vegetation with a complex structure which raises large parts of the surface above the average water table. Shrubs (typically Ericaceae), cushion plants (including Caryophyllaceae, lilies such as *Astelia*, mosses and ferns) and some graminoids (such as *Empodisma minus*) may contribute. Thus 'bog' includes large areas of partially topogenic mires in addition to raised and blanket bogs. Moorland is a particular case of blanket bog, restricted to Tasmania, which can occur on slopes of over 40°.

In contrast, fen is restricted to simple stands of graminoids (Cyperaceae, Juncaceae, Juncaginaceae, Liliaceae, Poaceae, Restionaceae, Typhaceae and Xyridaceae) with few subsidiary species, where the average water table is generally at the surface. These include the tall graminoid fens (swamps in NZ) of 1.5-4m high stands of bulrush, rushes, grasses, (eg. *Phragmites communis)* and tall sedges (eg. *Scirpus, Eleocharis, Lepidosperma*)

Table 1. Structural classification of Australasian mires. r = rare, + = present, ++ = widespread, +++ = common and extensive.

Vegetation Formation	Peat	SubAnt	New Zealand	Tasmania	Southern Australia	Arid Australia	Northern Australia	Tropical Pacific	New Guinea
Sphagnum bog	montane, occ coastal	+	++	++	+			r	r
Blanket bog	subalpine	+	++	++	+				+
Wet tundra	alpine	++	++	+	r				
Cushion bog	subalpine	++	++	++	r				++
Low shrub bog	montane	+++	++	+++	+++			+	++
Moorland	Oligotrophic sites		+	+++	+				
Grass bog	montane		++	+	+				++
Tall graminoid	Coastal-floodplain		++	++	+++	+	+++	++	+++
Tall closed shrublands	Coastal, montane		++	++	++	r	++	++	+
Sedge fen	Topogenic, blanket	+++	+++	+++	+++				+
Swamp Forest	Lowland, montane		++	+			+	++	+++
Mangrove	Coastal		+		++		+++	+++	+++

which are often telmatic and which occur in all areas except the sub-antarctic. Peatlands dominated by tall shrubs or trees are generally termed closed shrublands or swamp forest. These are found throughout the region and are characterised by the presence of Myrtaceae, such as *Leptospermum, Melaleuca* and *Xanthomyrtus,* and some specialised southern conifers, eg Podocarpaceae in New Zealand and the Pacific. An additional class of swamp forests are the mangroves which extend to 39°S and achieve their highest diversity in New Guinea and north eastern Australia. In some areas these accumulate wood or detritus peats although they more commonly occur on sands and organic-rich muds.

Pollen and charcoal studies have been made on more than 800 swamps in the region (Hope & al. 1999, Pickett & al. 2004, Wilmshurst unpublished), providing an overview of the formation of the peat. The great majority of peatlands that have been investigated have proven to be no older than the late Pleistocene and many are mid-Holocene or younger. Upland and subantarctic basins respond to increasing temperature and humidity after 15 000 yr BP, with a decrease in mineral deposition and the spread of sedge and grass onto valley fills. This vegetation seals the valleys and intercepts water, allowing peat to form. However the age of initiation can be quite variable, as shown for southeastern Australian swamps by Kershaw & Strickland (1989). The site and its substrate appeared to be a major control, there being little correlation of age with altitude. In New Zealand and New Guinea longer sequences are much more common, often sealed by tephra layers, reflecting the maintenance of moist conditions through the glacial peak.

The Subantarctic islands

The subantarctic islands of the Australasian region include Macquarie, Heard and McDonald Islands belonging to Australia and Auckland, Campbell, Snares, Bounty and Antipodes Islands belonging to New Zealand (Fig. 2). Due to the cool and wet climate on these rugged islands, blanket and mire peat deposits are extensive. Eight endemic species of macrophyllous forbs occur in the coastal zone, on fens and in the upland tundra where they can cover extensive areas (Meurk & al. 1994b). There are also considerable areas of cushion herbs, sedges, rushes, and bryophyte species, especially on oligotrophic, poorly drained peats and in the upland tundra zone (Meurk & al. 1994b), but *Sphagnum* is uncommon, and does not play a significant role in peat formation (Whinam & Copson 2006).

Most of the ground surfaces of the islands are covered by peat, and can occur as blanket peat, raised bogs and quaking mires (Taylor 1955, Campbell 1981, Rich 1996, McGlone 2002, Fig. 3). Upper peat layers tend to be more fibrous and less humified. Nutrient status of the peats is generally low, but coastal exposure to wind-blown spray considerably changes the nutrient input, often incorporating large percentages of mineral material (Selkirk-Bell & McGlone 2005).

Tasmanian blanket bogs – geo- and biodiversity of these unique mires

Tasmanian blanket bogs or buttongrass moorlands consist of highly distinct communities of plants and are unique to Tasmania. Buttongrass moorlands cover about 1,000,000 ha of undulating terrain in western Tasmania (Pemberton & al. 2005). They provide examples of long-ongoing ecological processes initiated in late Pleistocene to early Holocene times. They occur in regions which experience more than 1600 mm of rainfall per annum, have high humidity (typically greater than 80%) and low evaporation (Pemberton 1989). From a world perspective they appear to be very marginal

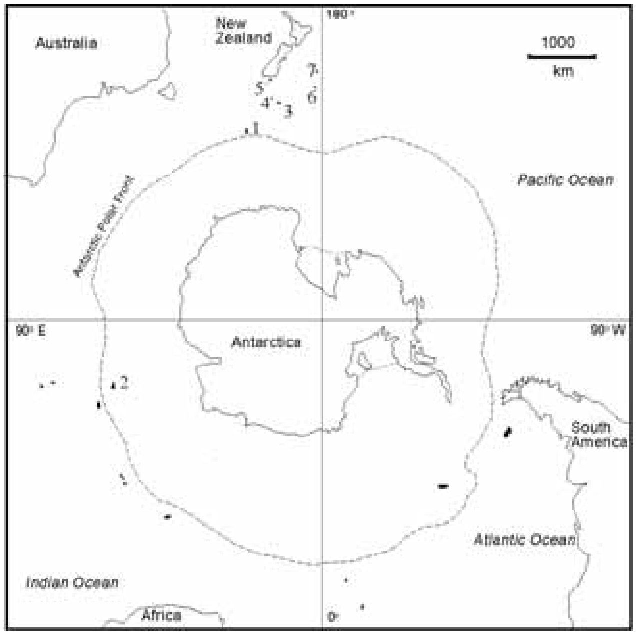

Figure 2. The subantarctic islands with peatlands: 1. Macquarie Is., 2. Heard and McDonald Is., 3. Campbell Is., 4. Auckland Is., 5. The Snares, 6. Antipodes Is., 7. Bounty Is.

Figure 3. Homestead Ridge Bog at 50m on Campbell Island is an *Oreobolus* cushion bog with stunted shrubs of *Dracophyllum*. The animal is Hookers Sealion (Photo Janet Wilmshurst).

mire systems, primarily due to relatively dry and mild summers, and could therefore be impacted by climate change. Buttongrass moorlands occur on a range of geological types, but appear best developed on inert siliceous substrates where mineral soil development is minimal (Pemberton & al. 2005). They extend from almost sea level to altitudes of over 700 m and from relatively flat ground to slopes of over 40° (Fig. 4). The deepest peats occur in lowland depressions and can be up to 4 m deep whilst they are less than 0.3 m on slopes. In these locations it is arguable whether they qualify as organosols (Isbell 1996), but with virtually no other soil development it is impossible to classify them as any other soil type (Pemberton & al. 2005).

Tasmanian blanket bogs are formed under a heathy-sedgeland or sedgeland-heath vegetation typically referred to as 'buttongrass moorland'. The moorland is unique globally, being the only extensive vegetation type dominated by a hummock forming, tussock Cyperaceous sedge, *Gymnoschoenus sphaerocephalus* (Jarman & al. 1988). The buttongrass flora is comprised of 272 vascular species, of which 30% are endemic to Tasmania (Jarman & al. 1988, Pemberton & al. 2005).

Figure 4. Towterer Beach in south-west Tasmania with buttongrass moorland extending over the mountain ranges; Melaleuca scrub in foreground (Photo Jon Marsden-Smedley).

The most conspicuous invertebrates in Tasmanian buttongrass moorlands are the burrowing crayfish in the endemic genera *Ombrastacoides* and *Spinastacoides* (Hansen & Richardson 2006). Their burrows are significant landscape features, and the presence of crayfish in such acid peats is globally unusual. Another conspicuous invertebrate feature of buttongrass moorlands are the large (up to 0.5 m tall) nesting mounds created by jack jumper ants (*Myrmecia pilosula* group).

Sphagnum peatlands

In comparison with peatlands in the northern hemisphere, Australasian peatlands dominated by *Sphagnum* (typically *S. cristatum*) are generally small in area, restricted in distribution, and have low species richness (Whinam & al. 2003b). Peatlands are generally dominated by Restionaceae, Cyperaceae, and Ericaceae species, with *Sphagnum* often an important component. Throughout Australasia, 25 species of *Sphagnum* have been recorded (Whinam & al. 2003b).

The importance of *Sphagnum* peatlands in the landscape generally increases from north to south and with increasing altitude - in Australia between 600 to 1000 m altitude, while in New Zealand they range from sea level to 1500 m. One of the major factors limiting the development of *Sphagnum* peatlands in Australia and New Zealand is moisture availability, in particular evapotranspiration in the driest month. *Sphagnum* occurs mainly on humic acid peats and deep accumulations of *Sphagnum* peat are unknown, suggesting that it is always a subsidiary taxon in Holocene mire communities. They tend to be partly minerotrophic in Australia but fully ombrotrophic in New Zealand.

The major geomorphic types of *Sphagnum* peatlands in Australasia include: kettle holes and moraine-dammed valleys of the depositional zone; glaciofluvial outwash or colluvial valley fill deposits; riparian or lacustrine environments; horizontally-bedded sandstone shelves; karst sinkholes (Whinam & Buxton 1997). The major structural types include: snowpatch, subalpine coniferous; sedgelands; shrublands (including New Zealand pakihi wet heath, Mew 1983); rainforest; grassy tussock and aquatic. Descriptions of *Sphagnum* communities in New Zealand are included in Wardle (1991), for Tasmania in Whinam & al. (1989, 2001) and for mainland Australia in Whinam & al. (2003a,b).

Peatlands of New Zealand

New Zealand peatlands may be classified as bogs, fens, swamps, seepages, or pakihi/gumland based on distinctive combinations of substrate, water regime, nutrient levels, and pH (Johnson & Gerbeaux 2004). They cover c. 400,000 ha (Rydin & Jeglum 2005), though widespread drainage and use have resulted in only 67,000 ha retaining native vegetation (P. Gerbeaux, Department of Conservation, and A-G. Ausseil, Landcare Research pers. comm.). Finer divisions recognise wetland form (e.g., dome, blanket, cushion, string) as well as vegetation structure and composition.

Bogs are the most common peatland class in New Zealand and are widespread throughout the country. They are rain-fed, nutrient-poor, and acidic (pH 3–4.8), and many have accumulated substantial quantities of peat. Bogs are characterised by a range of vegetation types dominated variously by restiads (family Restionaceae), mosses (mainly *Sphagnum* spp.), sedges, ferns, cushion plants, shrubs and trees.

Figure 5. Recently burnt blanket bog on Chatham Island with charred stems of *Dracophyllum* among clumps of Gleichenia dicarpa (Photo Bev Clarkson).

Restiad bogs occur on mainland New Zealand and Chatham Island, with strongholds in the cooler lowland areas of southern and western South Island. The most abundant restiad is *Empodisma minus*, being relatively common throughout New Zealand between latitudes 35° and 47° S. (It also occurs in eastern Australia and Tasmania). There are two additional bog restiads: *Sporadanthus ferrugineus*, north of 38° S, and *Sporadanthus traversii*, endemic to Chatham Island (Clarkson & al. 2004a, b). The northern North Island bogs, co-dominated by *S. ferrugineus* and *E. minus*, form extensive lowland domes, once covering several thousand hectares with peat up to 13 m deep (Campbell 1983). *E. minus* is the main peat-former and produces at the bog surface a dense mass of cluster roots that have similar water-holding properties to *Sphagnum* moss. *Sphagnum* mosses are present, but do not thrive in the shade of the much taller restiads or dry conditions. Short-stature heath shrubs are also typical in these systems, e.g., *Leptospermum scoparium*, *Epacris pauciflora* and *Dracophyllum* spp. on mainland New Zealand, and *Dracophyllum scoparium* on Chatham Island.

Blanket bogs are extensive in the very south of the South Island, Stewart Island, Chatham Island and the subantarctic islands (Fig. 5). These are characterised by low relief, cool temperatures, frequent cloud cover, high humidity and exposure to strong oceanic winds. *Sphagnum* mosses (mainly *S. cristatum, S. australe*, and *S. novo-zelandicum*) are common in wetter areas, along with *E. minus* (mainland New Zealand), *Sporadanthus traversii* (Chatham Island), heath shrubs, sedges, and small trees (e.g., *Dracophyllum arboreum* on Chatham Island).

Cushion bogs are locally present in the North Island but are best represented on the mountain plateaus in the South Island, descending to sea level in the far south as well as in the subantarctic islands. They are also important in Tasmania, with common species and genera being *Donatia novae-zelandiae, Phyllachne colensoi, Oreobolus, Gaimardia*, and *Centrolepis.*

String bog dam and pool systems are most extensively developed under cool, moist conditions in valley heads and on glacial benches in southern South Island (Mark & al. 1995). Important species include *Oreobolus pectinatus, Sphagnum* spp., *Carex gaudichaudiana, C. echinata, Baumea tenax, Empodisma minus, Dracophyllum* spp., and *Leptospermum scoparium*.

Fens are characterised by having a mainly peat substrate, although are usually shallower and with higher decomposition status than in bogs. They are both rain- and groundwater-fed, have a low to moderate nutrient status, and a pH of about 4 to 6. Fens can occur on slightly sloping land, around margins of bogs, on terraces or in basins. Dominant species include sedges (*Baumea teretifolia, B. rubiginosa, B. arthrophylla, Schoenus pauciflorus, Carpha alpina),* ferns (*Gleichenia dicarpa*), tussock grasses (*Chionochloa rubra* – common in southern peatlands and at higher altitudes), and heath shrubs (*Leptospermum scoparium*).

Swamps are usually more recent formations or have had a long history of disturbance, e.g. intermittent river flooding. They have surface water and groundwater inputs, with peat and/or mineral substrate, moderate to high nutrients and a pH range of 4.8–6.3. Swamps develop on valley floors, plains, terraces and deltas throughout New Zealand and have a mixture of species including sedges (*Carex*), reeds (*Typha orientalis*), megaherbs (*Phormium tenax*), shrubs (*Coprosma*), and trees (*Dacrycarpus dacrydioides*, *Syzygium maire*, *Cordyline australis*).

Seepages typically occupy small areas on slopes, having flowing water with enhanced aeration and water supply. They are more frequently features within larger wetlands in the bog and fen classes but can occur as localised stand-alone wetlands. The vegetation usually reflects these enhanced environmental conditions, with important species being sedges (*Carex* spp., *Schoenus pauciflorus* and *Carpha alpina*), as well as mosses, cushion plants and occasional shrubs or trees (Dobson 1979).

Pakihi and gumlands are characterised by extremely infertile, acidic soils (pH 4.1–5) of poor drainage because of an impervious lower horizon, being mainly rain-fed and prone to temporary drought. The soils may be mineral, peat or mixtures of both; those with peat can be classified as bog or fen (Johnson & Gerbeaux 2004). Extensive areas of peat-producing pakihi occur on fluvio-glacial terraces on the west coast of the South Island where annual rainfall is usually >2200 mm. Gumland is confined to the warmer and drier northern North Island on land formerly occupied by forests of kauri (*Agathis australis*), and was widely exploited for subfossil kauri gum. Typical vegetation in the pakihi and gumlands (Burrows & al. 1979) includes sedges (*Baumea*, *Schoenus*, *Gahnia*, *Tetraria*, *Lepidosperma*), ferns (*Gleichenia dicarpa*), restiads (*Empodisma minus*), and varying amounts of heath shrubs (*Leptospermum scoparium*, *Dracophyllum*, *Epacris, Pomaderris*).

Montane Swamps of eastern Australia

Topogenic fens and swamp shrublands are widespread in montane eastern Australia (Kershaw & al. 1993, Hope 2003). Fens dominated by *Carex gaudichaudiana* and other sedge and restionaceous species such as *Lepyrodia anarthria* and *Baloskian australe* form large peatlands up to 300 ha in extent (e.g. Wingecarribee Swamp, southern New South Wales). Peat growth varies in montane peatlands from slow to rapid (e.g. 6m over 3000 years at Wingecarribee), often with periods of oxidation and erosion. The oldest bogs, such as Bega Swamp, southern New South Wales, are about 12,500 years old and on the wettest sites at mid-altitude. Fires, during drought periods, are very common, as evidenced by the presence of fine charcoal in peat profiles. Regular or occasional catastrophic fires favour sedgeland species over shrubs (Hope and Kershaw 2005).

Peatlands dominated by Myrtaceous and/or Ericaceous shrubs are widespread in the mountains, although with small amounts of peat accumulation. Alpine peatlands (above 1800m on mainland Australia and less in Tasmania) can be dominated by *Empodisma minus* (Restionaceae) with *Astelia alpina*, various sedges such as *Oreobolus pumilio* and *Carex* spp, and forbs such as *Chionogentias*, *Celmisia* and *Brachycome* present. In Tasmania, montane peatlands can be dominated by the fern *Gleichenia alpina*, although they are generally shallow, low organic-content peats.

Temperate coastal peatlands in Australia

There is marked variation in climatic conditions around the coastline and coastal lowlands of temperate Australia: summer rainfall dominance, but with appreciable rain throughout the year, in southern Queensland and northern New South Wales; winter maxima in southern New South Wales, Victoria and Tasmania; and a very strongly winter rain dominated Mediterranean climatic regime in south west Western Australia. An extensive stretch of the southern coastline and hinterland in South Australia and Western Australia is arid and lacks peatlands.

Much of the coast is fringed by sand dunes, which support a diversity of wetlands. Interdune swales may contain extensive wet heaths and woodlands, sedge swamps and lakes. Lakes may be window lakes, exposing the freshwater lens found in most dune systems, or perched lakes, where water is held up above the regional water table by an impervious organic layer. Some of the best examples of perched dune lakes in the world occur on Fraser Island (where the main peat former is the restiad *Empodisma minus*) and the Cooloola sand mass in southern Queensland (Sinclair 1997).

The coastal plains in Western Australia have much more subdued relief than the east coast dune systems. Although the rainfall is strongly seasonal, there are large numbers of permanent wetlands, mostly with shallow organic profiles. Some of the better developed are on the Swan Coastal Plain where unconfined aquifers in the deep sandy soils keep depressions regularly, if not permanently, saturated (Adam & Horwitz 2005). The organic profiles are derived from sedgeland/restiad species.
Peatlands under *Melaleuca* and/or sedge/grass on the coastal plains were up to 6 metres deep and covered more than 1 million ha at the time of European settlement (Williams 1974). Spectacular examples of these peatlands included Coorong (Taffs 2001) and Kooweereup swamps (Roberts 1985) but they have now been destroyed for agriculture. Peat deposits have also formed on areas of impeded drainage on and above seacliffs. Similar coastal springs and seepages can result in build-up of organic rich soils in far south-western Australia, particularly where contact zones between impervious gneiss or granites and more porous limestones are exposed by coastal erosion (Adam & Horwitz 2005).

Figure 6. Flying Fox Springs in the Northern Territory has built up over 3m of fibrous peat (Photo Bev Johnson).

Inland spring mounds

The Great Artesian Basin is the world's largest artesian basin, with water outflow at mound springs formed by the build-up of precipitates and aeolian sediments (Boyd 1990). Evaporation in this arid environment is great, but occasionally, there is sufficient water to form permanent swamps, some with peat (Boyd & Luly 2005). The timing of peat formation in tropical mound springs differs widely, occurring in response to the dynamics of groundwater systems rather than the more immediate effects of climate. Spectacular examples are the active swamps at Dalhousie Springs, *c*. 50 km west of the Simpson Desert, in a region of 100 mm annual rainfall. The springs are surrounded by stone-covered clay plains with sparse low chenopod saltbush. Survival of the springs is threatened by decreased groundwater pressures in the Great Artesian Basin (Boyd & Luly 2005).Mound springs are also part of the tropical landscape, forming in localities fed by artesian waters or where overflow of aquifer intake areas occurs, such as Flying Fox Springs in the Northern Territory (Fig. 6).

Tropical Peatlands

Areas north of the Tropic of Capricorn have a seasonal climate, dominated by summer rain that increases northwards, with inland Australia being semi-arid with an unreliable 1-3 month summer wet season. However areas of north east Queensland and the western Pacific islands can have very high rainfall throughout the year, where the southeast Trade winds meet mountains. Equatorial regions, such as New Guinea north of 8°S, are amongst the wettest places on earth, due to the warm seas and the deep ITCZ in the western Pacific. Peat forming mires are common in the tropics wherever drainage is impeded and fall into four main groups: coastal infill swamps; topogenic mires such as valley fill deposits; successional mires in closed basins formed by tectonic, volcanic or glacial processes, and high altitude blanket bog formed by sedges, grasses and cushion plants.

Table 2. Estimates of the extent of organic soils (including peat) in Papua New Guinea based on broad scale soil survey. Mean depths are based on type sections from palaeoecological sites but have not been verified by extensive stratigraphies. Except for the subalpine mires these formations also occur in northern Australia and the high Pacific Islands.

Dominant vegetation	Peat types	Average thickness m	altitude range	Area in PNG Mha
Mangrove and Nipa palm saline forests	Organic muds, wood peat	0.8	0-15	3.60
Sago swamp woodland	Muck peat, organic clays	1.0	5-250	2.28
Swamp woodland (incl. Melaleuca swamp forest)	Humic peat and clay	0.4	5-60	2.18
Tall grass fen on floodplains	Organic muds, fibrous peat	2.0	2-2000	0.73
Mixed swamp forest	Fibrous peat	4.0	5-500	0.48
Montane swamp forest	Fibrous wood peat	2.5	500-3000	0.14
Tall sedge-grass swamp	Fibrous peat, humic clays	4.0	500-3000	0.08
Subalpine Astelia-Gleichenia blanket bog, Hard cushion bog or sedge-grass fens	Humic peat, Fibrous peat	1.5	2500-4500	1.69
Palaeo-peats	Humic and fibrous peats	5	1500-2500	<0.02

New Guinea has the largest extent of peatland in the region, perhaps totalling about 8 Mha, or ca 12% of the land area. The range for Papua New Guinea is given as 0.5-2.9 Mha (Maltby and Immirzi 1993) and figures at least double this seem likely in the Indonesian province of Papua (formerly Irian Jaya) where estimates of the extent of swamp forest peatland alone range from 3.6-8.9 Mha (Radjagukguk 1997). Vegetation surveys (eg Paijmans 1976) for Papua New Guinea define nine classes of mires associated with altitudinal variations (Table 2). These divisions also apply to Papua Province (the western half of the island) (Paijmans 1990).

The first four categories in Table 2 include both peat-forming and mineral-soil supported vegetation, and the proportions that grow on peat are not accurately known. These peatlands are topogenous because they receive surface water and nutrients from catchments.

Coastal swamps in the tropics

Coastal peatlands occupy a variety of settings in which impeded drainage and high rainfall allow preservation of organic materials. Coastal settings most conducive to peat accumulation include mangrove swamps, inter-dune swales, perched dune lakes and the broad floodplains of major wet tropical rivers. In New Guinea extensive forested swamplands may form ombrotrophic peatlands.

True mangrove peat - material in which loss on ignition values exceed 35% (Wüst & al. 2003) - is uncommon in northern Australia and the tropical Pacific. It is found in sheltered locations where restricted water circulation prevents flushing of accumulating organic matter into the open ocean and where persistent anoxia inhibits bioturbation and consumption by crabs or other mangrove residents. Though mangrove peat is most often found in wet tropical settings, peat beds outcrop on eroding beaches in the dry tropics, for example on Orpheus Island north of Townsville. Similar deposits occur on many Pacific islands, where mangrove-dominated peat is covered by anthropogenic muds after 3000 yr BP (Hope & al 1999).

Mangrove and associated forests in New Guinea are extremely diverse. Because of high rainfall the mangroves are often backed by saline or freshwater swamp forest in which *Nipa* or *Metroxylon sagu* palms are a significant component. These palms usually grow in organic mucks over silts but can also occupy deeper peats, as described by Ellison (2005) for southern Papua. Other *Metroxylon* palms form extensive swamps with *Pandanus* and sedges in the Pacific. With a good water supply the sedgeland-grassland-fern component may increase (Southern 1986). Human burning and increased slope erosion has sealed many bogs with layers of clay above which sedge-grass peats occasionally build up, as on Fiji (Clark & Hope 2001). Other bogs may reach an equilibrium with the sea level and cease to accumulate peat in the last 2000 years or so.

Other peatlands occupy barrier lagoons or interdune swales. Interdune peats in Queensland (e.g. Whitsunday Island) are formed by swamp forest species such as *Melaleuca leucadendra* and *Pandanus* sp., as well as sedges such as robust-growing *Gahnia* species. Perched lakes are found on extensive coastal dune systems, principally in Cape York (Lees & Saenger 1989). Organic muds form in the lakes but around the margins, more fibrous peats are derived from swamp forests, sedges, water lilies and water ferns. Dunefields are rare in the Pacific but some impounded swamps are known (Anderson & al 2006).

Tropical Floodplains

Major river systems in the wet tropics region develop broad flood plains laced with palaeochannels and lagoons. The typical vegetation in northern Australia and southern New Guinea is a tall forest of *Melaeuca argentea*. While many of the palaeochannels are filling with terrigenous over-bank sediments, lagoons further from the main channels accumulate more organic materials derived from local gallery forests eg Jabiluka Billabong (Clark & Guppy 1988). Much larger swamps such as Babinda Swamp and Eubenangee Swamp owe their origins to ponding of water between the Malbon-Thompson Range and associated alluvial fans (Crowley & Gagan 1995).

The most striking examples are the infilled estuaries of some of the large rivers of New Guinea such as the Sepik (Chappell 2005) and lower Mamberamo Rivers. A complex of oxbow and levee dammed lakes have peat forests and sedgelands around their margins.

Swamp Forest

The most enigmatic swamp type is the lowland *mixed swamp forest* that can occupy deep peats. This type, dominated by dipterocarps, is widespread in Kalimantan (Borneo), where extremely acid raised bogs with a specialised tree flora occur (Rieley and Page 1997, Page & al 2006). In New Guinea the occurrence of domed peatlands has not been described and the extent of peat under the forests has not yet been investigated. Therefore, it is not known if analogous peat structures exist in New Guinea. However, there is about 3-5 Mha of swamp forest in Papua province in both the south and northern lowlands whose depth of substrate is unknown (Paijmans 1990). Later stage swamp forests have *Campnosperma brevipetiolata, Nauclea coadunata, Neonauclea* spp., *Syzygium* spp, and *Terminalia caniculata* in the canopy with species of *Barringtonia, Pandanu, Garcinia* and *Myristica* as an understory (Paijmans 1990). *Campnosperma* also forms open forests with *Pandanus* and tall sedge understory.

Topogenic mires

Topogenic mires occur in areas with abundant water and shallow gradients. Mire complexes dominated by grass-sedgelands are extensive in New Guinea and the Pacific. For example, Nadrau Swamp, at 700 m altitude in Fiji, has 5 m of sedge-grass peat built up in the last 2000 years (Hope & al. 1999). New Guinea swamps such as Kosipe Swamp (Fairbairn & al 2006) and Kayemanda Swamp (Walker 1972) support very tall stands of grass-sedge fens, with marginal forests of *Pandanus*, *Dacrydium* and *Castanopsis*.

Volcanic activity can block valleys which forms extensive and depp peatlands, such as Tari in Papua, New Guinea (Haberle 1998). Lake Tagamaucia, at 780 m on Taveuni Island, Fiji is a subsided volcanic caldera, and has an extensive floating sedge mat that drifts about the lake (Southern 1986). Some craters on the Atherton tableland have filled with organic sediments and their modern surfaces are maintained at a level determined by the relative height of outlet channels. Swamp forest with *Dacrydium* and *Retrophyllum* have formed peatlands in the past but these conifers are now extinct (Kershaw & al 2007).

Tectonic basins such as fault dammed valleys and subsidence basins are relatively common. The largest tectonic peatland in the region is the Lake Plain, in northern New Guinea. This 2.5 million ha basin floods to a depth of 3 m each wet season and is mostly covered with swamp forest (Lam 1945). Peat depth is unknown, but away from the main rivers it may be very considerable.

Other types of closed basins are known. Landslides can dam valleys as at Nurank Swamp in Papua New Guinea. Here *Sphagnum* and sedge peat form a 1m mat over water (Gillieson & al. 1990). Solution basins are also widespread in both limestone and ultramafic rocks, and many of these are infilled with lake sediments and peats (Stevenson & Hope 2005). Above 3600m in New Guinea glaciation has left widespread rock basins and moraine dammed valleys. These have successional mires of several types of sedgeland and shrub bog (Hope 1980).

Blanket and Cushion Bogs

The high wet mountains of New Guinea support large areas (perhaps 250,000 ha) of mosaic blanket bogs and sedge and grass fens above 3000m. At high altitudes fires initiated by humans have cleared forest and allowed peatlands to expand**.** Shrubs can contribute to peat formation, most notably *Rhododendron saxifragoides* (Fig. 7), which forms hummocks up to 2m in extent. In places a hard cushion bog exists with abundant mosses and hepatics. A cushion forming herb, *Astelia papuana*, is sometimes dominant in hard cushion bog (Gibson & Hope 1986, Hope 1980). Fern bog dominated by *Gleichenia vulcanica* is widespread on only a few mountains. More widespread is grass bog dominated by *Deschampsia klossii* and *Poa* spp., as this follows stream lines and occupies wet slopes. *Carex gaudichaudiana* and *Carpha alpina* dominate fens in the alpine on level ground or around tarns.

Figure 7. Hard cushion bog of *Oreobolus* and *Centrolepis* at 3200m near Lake Habbema, Papua, Indonesia with the cushion shrub *Rhododendron saxifragoides* and the ant-plant, *Myrmecodia emergent* (Photo G. Hope).

Threats

Peatlands in the region range from natural and undisturbed (e.g. the subantarctic peatlands, the *Sphagnum* peatlands of alpine and sub-alpine New Zealand and Tasmania, often in conservation reserves), through to disturbed sites where either historical or current land use patterns threaten the integrity of the peatlands (e.g. grazing in the montane swamps of eastern Australia, land subdivision on the temperate coastal peatlands). Other sites have been highly modified by deforestation (in tropical rainforests), peat mining (e.g. Wingecarribee Swamp), drainage, agriculture and burning (particularly tropical peatlands).

Vegetation clearance and changes in catchment land use can alter flow regimes and sediment input, both of which have significant effects on peatlands. Groundwater extraction for both domestic consumption and irrigation use has severely impacted on the coastal peatlands of Western Australia, as well as the tropical mound springs (Adam & Horwitz 2005).

Overlying these historic threats is the likely catastrophic impacts that climate change, both directly and indirectly, will have on the climatically constrained peatlands of Australasia. Increased fire intensity and frequency is likely to have a major effect on size, peat accumulation and vegetation of peatlands. Many Australasian peatlands – such as the inland spring mounds and *Sphagnum* peatlands - are located at climatic limits for peat accumulation and this predisposes them to changes in temperature, precipitation patterns, cloud cover and evapotranspiration.

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<tr><td><i>Tekijä(t)</i></td><td colspan="4">Tapio Lindholm ja Raimo Heikkilä</td></tr>
<tr><td><i>Julkaisun nimi</i></td><td colspan="4">Mires from pole to pole
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<tr><td><i>Tiivistelmä</i></td><td colspan="4">Mires from pole to pole on Kansainvälisen Soidensuojeluyhdityksen (IMCG) Suomessa 24.-27.7.2006 järjestetyn XII symposion julkaisu. Julkaisuun sisältyy seuraavia aiheita: 1. Kohti soiden monimuotoisuuden ja suojelun ymmärtämistä eri maissa, 2. Polygonisoiden rakenteet Koillis Jakutiassa. Kasvillisuuden ja veden merkitys, 3. Suot Venäjän kartalla, 4. Perämeren maankohoamisrannikon aapasoiden hydrotopografian kehitys, 5. Perämeren rannikon aapasoiden sukkessiosarjan rakenteiden kehitys, 6. Maatalouden alku Ruotsin Lapissa, 7. Sammalten monimuotoisuus Maanselän vedenjakajan soilla, 8. Juortanansalon soidensuojelualueen soiden kasvillisuus ja sen kartoitus, 9. Holoseenikauden kasvillisuusdynamiikka ja hiilikertymä kahdella suolla Ystävyyden puistossa, 10. Ileksan-Vodlajärven aapasoiden kasvillisuuden dynamiikka, 11. Keskiboreaalisten puustoisten soitten kasvillisuus Karjalassa, 12. Soiden kasvisto, kasvillisuus ja suojelu Karjalan tasavallassa, 13. Arkangelin alueen Kenozeron kansallispuiston eteläosan soiden tyypit, 14. Ruohoisten soiden ojituksen jälkeinen kasvillisuuden dynamiikka Karjalan eteläosassa, 15. Suomalainen turpeennoston paradoksi: poliittista tukea ympäristön tuhoamiselle, 16. Valtakunnallisesti ja alueellisesti uhanalaiset suosammalet Suomessa, 17. Suohabitaattien uhanalaisuuden arviointi Suomessa, 18. Ennallistettujen soiden seuranta suomalaisilla luonnonsuojelualueilla, 19. Perhosten lajimäärä ja runsaus luonnontilaisilla ja ojitetuilla soilla Suomessa, 20. Soiden ennallistamisen vaikutus ravinteiden huuhtoutumiseen Länsi- ja Etelä-Suomessa, 21. Suojelualueiden merkitys rahkasammalten monimuotoisuuden säilyttämisessä Karjalan Kannaksella ja Suomenlahden saarilla, 22. Rahkasammalpintojen vaihtelu kasvukauden aikana, 23. Luonnontilaisten ja entisten turvesoiden kasvipeite Mescheran kansallispuistossa Venäjällä, 24. Kolmen latvialaisen keidassuon ja yhden leton hoito ja seuranta, 25. Karstisoiden alkuperä, kehitys ja nykytila Tulan alueella Venäjällä, 26. Soiden pinnan painuminen. Vedenjakajien siirtyminen, virtausjuottien ja kaltevuuden muutos sekä kuivumisen ja vettymisen vaikutus, 27. Vähittäisten muutosten ja maiseman heterogeenisyyden merkitys vesien selkärangattomille ennallistamisessa, 28. Slovakian suot – nykytila ja suojelu, 29. Koillis-Kiinan Heilongjiangin maakunnan kosteikkojen tila ja suojelu, 30. Laidunnuskokeilut Ranskan Baskimaan soiden hoidossa, 31. Soiden hydrogeokemian suhde kasvillisuuteen Japanin keskiosassa, 32. Georgian Kolkhetin alangon soiden tulokaskasvit, 33. Tulimaan itäosan soiden spatiaalinen analyysi ja kuvaus, 34. Australaasian suot.</td></tr>
<tr><td><i>Asiasanat</i></td><td colspan="4">International Mire Conservation Group, soiden monimuotoisuus, soidensuojelu, soiden hoito</td></tr>
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PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral (SYKE)			*Datum* December 2012
Författare	Tapio Lindholm och Raimo Heikkilä			
Publikationens titel	**Mires from pole to pole** (Myrar från polen till polen)			
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Sammandrag	Mires from pole to pole är en publikation av det XII symposiet av International Mire Conservation Group. Symposiet hölls i Finland 24–27.7.2006. Följande frågor behandlas i publikationen: 1. Synpunkter på mångfalden av myrar och deras skydd i olika länder, 2. Strukturen hos polygonmyrar i nordöstra Yakutia, Sibirien: vegetationens och vattnets roll, 3. Myrar på Rysslands karta, 4. Utvecklingen av hydrotopografin hos aapamyrar på landhöjningskusten vid Bottenviken i Finland, 5. Utvecklingen av strukturen hos en successionsserie av aapamyrar vid Bottenviken i Finland, 6. Jordbrukets tidiga skeden i Lappland i Sverige, 7. Mossornas diversitet i myrar på Maanselkä vattendelarområde, 8. Studier och kartläggning av myrvegetationen på myrskyddsområdet Juortansalo, 9. Vegetationsdynamiken under Holocenperioden och kolackumulationen vid två myrar i Vänskapens park i östra Finland, 10. Vegetationdynamiken hos aapamyrar i Ileksa-Vodlozero-trakten, 11. Vegetationen på mellanboreala skogbevuxna myrar i Karelen, 12. Myrars flora, vegetation och skydd i Karelska republiken, 13. Typer av myrar i södra delen av Kenozero nationalpark i Arkangelskregionen i nordvästra Ryssland, 14. Vegetationsdynamiken på örtrika myrar i södra Karelen efter att de blivit dikade, 15. Paradoxen inom den finska torvutvinningen: politiskt stöd till förstöring av naturen, 16. Nationellt och regionalt hotade myrmossor i Finland, 17. Bedömning av hotade myrhabitat i Finland, 18. Uppföljning av restaurerade myrar på finska naturskyddsområden, 19. Artantal och abundans för fjärilar på myrar i naturtillstånd och dikade myrar i Finland, 20. Myrrestaureringens inverkan på utsköljningen av näringsämnen i västra och södra Finland, 21. Skyddsområdenas roll i bevarandet av vitmossornas diversitet på Karelska näset och öar i Finska viken, 22. Variationen hos vitmossytorna under vegetationsperioden, 23. Växttäcket på myrar i naturtillstånd och på tidigare torvmossar i Meschera nationalpark i Ryssland, 24. Vård och uppföljning av tre lettiska högmossar och ett rikkärr, 25. Karstmyrars ursprung, utveckling och nuvarande tillstånd i Tularegionen i Ryssland, 26. Nedsjunkning av myrens yta. Vattendelare förflyttas, strömningsrutter och sluttningsgrad förändras samt effekter av att en myr torkar och åter blir blöt, 27. Betydelsen av gradvisa förändringar och landskapets heterogenitet för akvatiska evertebrater vid restaurering, 28. Myrar i Slovakien – nuläge och skydd, 29. Våtmarkernas tillstånd och skyddet av dem i Heilongjiang i nordöstra Kina, 30. Provbetesgång vid skötseln av myrar i Baskien i Frankrike, 31. Relationen mellan hydrogeokemi och vegetation i myrar i mellersta Japan, 32. Nykomlingar inom växtarterna på myrar på Kolkheti lågland i Georgien, 33. Spatial analys och beskrivning av myrar i östra delen av Eldslandet, 34 Myrar i Australasien.			
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Mires from Pole to Pole contains papers based on the presentations and posters of the XII IMCG symposium in Eerikkilä, Tammela, 24th to 27th July, 2006. The book contains a variety of global information about mire conservation, mire ecology, biodiversity and management. Some articles are purely scientific papers and some deal with practical issues. All articles have gone through a peer review process. In this publication there are 34 articles.

The articles give valuable information on mires in a wide spectrum of expertise and interests, from research scientists to consultants, and government agency specialists to peatland site managers.

The International Mire Conservation Group (IMCG) was established in Klagenfurt, Austria in 1984. The idea had emerged during a mire ecology workshop at Oulanka Biological Station, Finland in 1983, arranged by Seppo Eurola, professor of botany at the Oulu University. The basic idea of the IMCG has been to gather together mire researchers and conservationists to promote the protection of mire biodiversity, carbon storage and other ecosystem services.

Since 1984, biennial field symposia have been arranged in different countries in Europe, Asia, America and Africa. The 12th Biennial symposium was arranged in Finland as an excursion from Lapland to the southernmost part of the country, and a symposium was held at the Eerikkilä Sports Institute in Tammela, southern Finland. The aim of the event was to raise the international awareness about mires of Finland, their conservation and the impacts of different ways of their utilization.

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