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PALLAS–SYMPOSIUM 1996

EDITED BY LASSE LOVÉN AND SINIKKA SALMELA

ROVANIEMI RESEARCH STATION

METLA

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Proceedings of the research symposium held in the Pallas-Ounastunturi National Park on 10.–11.10.1996

Edited by Lasse Lovén and Sinikka Salmela

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The Pallas-Ounastunturi National Park is a part of the Finnish nature reserve research network managed by the Finnish Forest Research Institute. Including more than 20 000 hectares of high altitude and high latitude timberline forests and about 30 000 hectares of open arctic fell tundra and mires, it possesses a wide range of nature. Pallas-Ounas lies in the cleanest corner of European atmospheric environment and provides an extensive range of background features for monitoring the global environmental change. The cultural environment in and around the national park is also unique because the park lies on the border between southern Finnish culture and the northern Sami or Lappish culture.

The National Park is opening itself up to international co-operation on research and cultural change and aims to arrange scientific or cultural symposiums highlighting major items and issues of ongoing projects. These proceedings are the end result of the first international research symposium held on 10–11.10.1996 in the Pallas-Ounastunturi National Park. The symposium was focusing mainly on the role of the national park in monitoring global environmental change.

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Dear colleagues,

On behalf of the Finnish Forest Research Institute, I have the great pleasure of welcoming you to the Pallas Symposium. Here in Lapland, the summer is a season of sun and holidays, but once the autumn colours have disappeared from the forests and the fells, it is the right time for hard work. We are now within the Pallas-Ounastunturi National Park, at a point in time when bright growing season ends and the long winter is about to begin, just the time for this kind of a meeting of cooperation, attended by researchers from different countries, different institutions, and of different disciplines, to plan joint research activities.

The Finnish Forest Research Institute, founded in 1917, is responsible for managing around 144 000 hectares of land. This is divided into experimental forests, national parks, and strict nature reserves. The oldest experimental forests were established already in 1923. The first national parks and other nature conservation areas, established by law, were transferred to the care of our institute in 1937. These include the Pallas-Ounastunturi National Park, which is the largest, contiguous area managed by our institute.

We at the Forest Research Institute, or Metla as we also like to call our institute, consider that forest research needs a wide range of forests subjected to different levels of human impact. ***Experimental forests*** are managed outside special research areas like permanent plots, according to normal forest management practices, while taking into account, of course, the needs of different research activities. ***Strict nature reserves*** are areas most strictly protected against human impact; even to walk in such a reserve requires the granting of a special permission. ***National parks*** lie between these two extremes: forestry operations are not allowed, or they are permitted only for the purpose of reindeer husbandry or the management of the park. On the other hand, national parks are completely open to the public, and only certain small areas have restrictions on passage. These regulations provide a national park like the Pallas-Ounastunturi National Park with an excellent basis for use as an area for multidisciplinary forest research and environmental research.

Nine years ago, the Finland's national parks celebrated their 50th anniversary. Before we turn to today's theme, "Research Activities in the Pallas-Ounastunturi National Park", in more detail, it is interesting to take a look at the themes that were of current interest in 1988. Eighteen presentations were divided to be delivered in four groups: The Importance, Management and Use of Nature Conservation Areas, Basic Mapping of Nature Conservation Areas, Ecosystems and Their Changes in Nature Conservation Areas, and Multiple-Use Research in Nature Conservation Areas. No anthropogenic damage issues were taken up at the time. Within the field of "Ecosystems and Their Changes", the results of research on the structure of natural forests, vole populations, windthrow areas, occurrence of insects and the effects of fire were presented.

My feeling is that today environmental issues are the main area of research, even here in the Pallas-Ounastunturi, which is one of the cleanest areas in Europe. Clean air, undisturbed nature and the fact that a research unit is managing a national park employing, professional personnel and comprehensive facilities, together provide excellent possibilities for fruitful multidisciplinary research. I hope that, during these two days, we can further deepen the cooperation between our institute and researchers both at home and abroad. I wish every success to this symposium.

Martti Varmola
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National park as research area for monitoring environmental change

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Pallas-Ounastunturi National Park

Pallas-Ounastunturi National Park was established in 1938 under the management of the Finnish Forest Research Institute (Metla) and it is one of the oldest and largest national parks in Finland. Located at 67 °55 – 68°20'N, 24°07'E, the park covers 50 000 hectares consisting of 22 000 hectares of timberline forests, 10 000 hectares of open wetlands, and 18 000 hectares of open fell tundra. The park was founded for the purpose of protecting the beautiful Pallas-Ounas chain of fells as well as the rare timberline environment and all the ecosystems included therein. The geologically unique fells, the old growth virgin forests (Fig. 1) typical of the boreal zone, and the historic sacrificial places of the sámi people add to the value of this area. The founding of the park also helps to preserve the purity of the park's many streams and lakes. Tourism is an important function of the park as it serves about 100 000 tourists a year. Inside or nearby the park there are two information centers, one located in the village of Hetta and the other at Pallas, next to the small mountain hotel.

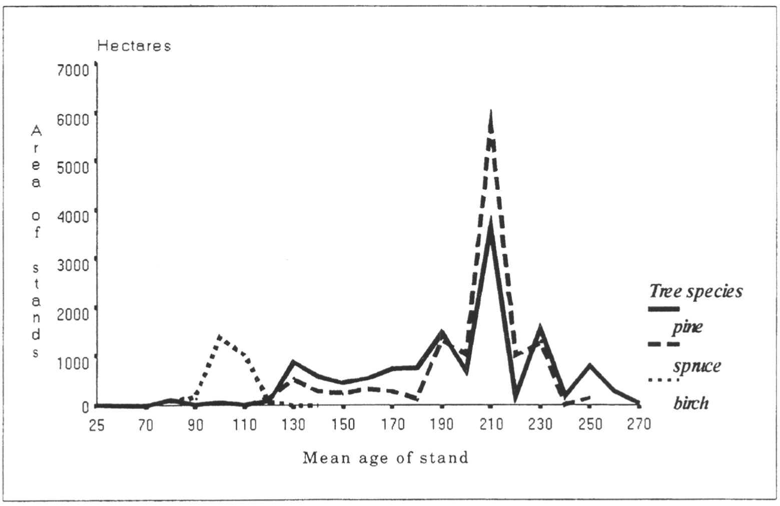

Figure. 1. Areas of virgin forest stands in various age classes in Pallas-Ounastunturi National Park (Source: Vilén 1976).

The park is located on the distribution border of many northern and southern species of flora and fauna, and this gives the park a unique mix of species. The northern high-latitude timberline of Norway spruce (*Picea abies*) runs through the middle of the park and Scots pine (*Pinus silvestris*) and birches (*Betula sp.*) have their high-altitude timberlines in Pallas-Ounas. The extensive timberline habitat is due to the great variation in elevation within the park, i.e. more than a 500 m between the highest and lowest points in the park. The park's highest point is Taivaskero fell at 807 metres above sea level.

Pallas-Ounastunturi National Park serves the needs of many different groups including reindeer herders, tourists, and researchers. Reindeer herding associations have been granted certain privileges and are allowed to have pastures inside the park. They maintain their corrals, driving fences and other structures for the management of about 10 000 head of reindeer inside the park. Tourists and nature enthusiasts have at their disposal about 200 km of hiking trails and cross-country ski trails maintained by the park staff. There are also ten cabins for resting and staying overnight plus ten shelters with fireplaces. The park has two wilderness zones where people are free to camp and make campfires. Hotel Pallas is located inside the park and maintains two skilifts.

The park supports a wide range of research activities. More than ten research institutes have on-going projects inside the park or very close to it and well over 100 scientific reports have been published about the nature, economy, and users of Pallas-Ounastunturi National Park. The main research activities today in the park involve environmental change monitoring projects (Fig. 2). There are also many more specific or smaller research projects; all in all, more than thirty projects covering a wide range of park-related topics. These can be of great use for understanding the park's nature and visitors and improving park planning and management.

2 Monitoring environmental change at Pallas

2.1 Monitoring atmospheric change

Pallas-Ounastunturi National Park contains a group of atmospheric research stations, which are part of a worldwide network of such stations. The Finnish Meteorological Institute (FMI) established a Global Atmosphere Watch (GAW) station in 1994, and it has been expanded in subsequent years (Laurila 1995). The Pallas station has a sister station in Sodankylä monitoring the upper atmosphere (stratosphere), while the Pallas station concentrates more on the lower and border zones of the atmosphere (troposphere and boundary layers). These two stations are located within what is arguably the cleanest area in Europe, and so they serve to create baseline data on atmospheric composition. More polluted areas can be compared to this relatively clean area. Special attention is paid to such hot issues as: greenhouse gases, reactive gases, and the ozone layer (both stratospheric and troposphere). Pallas has three atmosphere-watch substations.

The main GAW station is located in the southern part of the park, on the top of a fell at an elevation of 560 metres (over 300 metres above the surrounding terrain). Temperature, wind, and precipitation profiles can be gathered from the boundary layer conditions of the area. The data are used for research and for weather service purposes in northern Finland. The station has automatic analyzers measuring O_3, SO_2, NO_x and CO_2 concentrations. Canister samples are taken twice a week and sent to the FMI's Helsinki lab for analysis. The air in the canisters is used or planned to study the greenhouse gases like VOC, CO_2, CH_4, and N_2O.

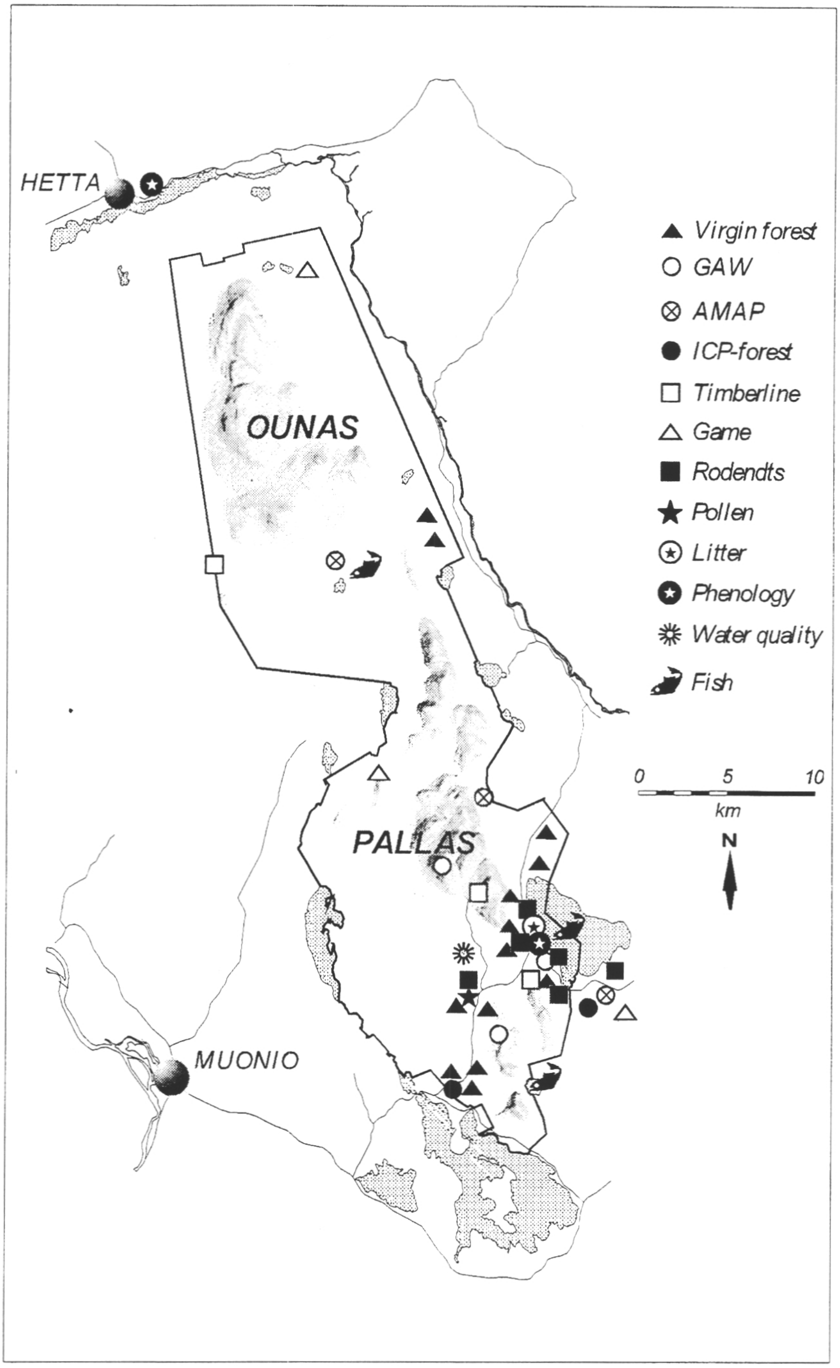

Figure 2. Permanent research sites monitoring environmental change in Pallas-Ounastunturi National Park.

2.2 Arctic Monitoring and Assessment Programme, AMAP

Pallas-Ounastunturi National Park is involved in the Arctic Monitoring and Assessment Programme (AMAP, The Monitoring ... 1993), an international body responsible for assessing the current state of the environment in the arctic and sub-arctic regions of Finland, Norway, Sweden, Iceland, Greenland, Canada, the United States, and Russia. Most AMAP studies at Pallas are carried out by the Finnish Environment Institute. The programme is also responsible for coordinating future environmental programmes in these regions. Assessment topics in AMAP include (+ if monitored in Pallas) the following:

- heavy metals (+)
- nuclides
- acidifying deposition and water/soil acidification. (+)
- fish populations (+)
- human health
- use of bioindicators (+)
- pesticides, PCB's and other persistent chemicals (POPs) (+)

Pallas is involved in many AMAP activities and most of the related monitoring takes place at the AMAP master station south of Lake Pallasjärvi and close to it. The measurement and recording equipment focus on POPs, heavy metals, mercury, pesticides, PCBs, and air particles. Filters on the equipment are changed regularly and sent to laboratories for examination. Snow and rain are collected for study and also sent to various labs. Work is also being done with bioindicators, such as insects, voles, and lichens, to determine pollution and contamination levels. In the central part of the park, sediments and fish samples are gathered from the small lakes. AMAP projects are integrated with researchers from many universities and institutions. AMAP works closely with the meteorological research carried out at Pallas and shares some of the data in examining atmospheric processes.

2.3 Timberline monitoring

Pallas contains about 22 000 hectares of virgin timberline forests, this makes it an excellent location for studying the dynamics of high-altitude, or alpine, and high-latitude timberline formations. Studies are being done to determine the production, growth rate, and fluctuation of the timberline, as well as species composition. The monitoring plots are located on four fells within the park. The first plot lies in the lower, more productive forest and the rest rise into and above the timberline, thus providing an overall picture of the area. The information gathered is used by the Finnish Forestry Research Institute (Metla) in addressing the following issues outside the park:

- land-use planning in timberline areas
- ecology of timberline regions
- multiple-use of timberline forests
- silviculture of timberline forests.

Ecological studies look at the existing flora and fauna. Tree species (regeneration, growth), movement of the timberline and explanations for it, and the influence of human activities are also examined. Multiple-use of timberline areas is studied to find the appropriate balance between practices such as reindeer husbandry, hunting, fishing, tourism, and the collecting of wild berries and mushrooms. Silvicultural studies look into issues such as natural and artificial regeneration, forest and tree breeding, methods of good silviculture, and the problems caused by exotic tree species.

Much work remains to be done in the endeavour to develop a better understanding of timberlines ecosystems and this may well be one of the fastest growing areas of research here at Pallas, especially because of the great international interest focusing on it.

2.4 Intensive Control Program (ICP) Forest

Europe-wide network of more than 400 plots is established for the purpose of studying forest health. The ICP forest at Pallas is under the control of Metla. The research programme focuses on the condition and development of the forest and the relation of these factors to environmental changes. Pallas has two plots where many aspects of forest health are being monitored. Growth, general state of health, and needles are under year-to-round observation and a ground check is performed every 10 years.

2.5 Monitoring of virgin forests

The southern part of Pallas-Ounastunturi National Park has thirteen field plots established for the purpose of monitoring the ecology of virgin forests. These forests comprise different tree species, site classes, succession classes, and their combinations. Leading subjects of interest connected to these plots are the following: monitoring the competition among trees in virgin forests, the accumulation of dead wood, and the dynamics of different insects and fungi relying on dead wood. Virgin forests also produce information on the renewing capacity of natural forests in different stages of succession.

2.6 Small mammalian population dynamics

Since 1970, Pallas has been a pilot area of continuous monitoring of microtine cycles in the context of environmental change (Henttonen et.al. 1987). The research project has established large-scale field experiments on the role of nutrition, and monitoring of predators in relation to the dynamics of rodent populations. There has been intensive research on rodent parasites, and so far the information collected in the Pallas rodent project has been used in about 110 publications, including three Ph.D. theses.

2.7 Monitoring of forest litter

Forest litter accumulation in the virgin forests of Pallas takes place in natural conditions without man-made silvicultural impacts. At Pallas, litter collecting has been carried out since the early 1960s. Litter samples are stored in a bank for later use. Examples of later use includes such things as historical analysis of chemical contamination of virgin timberline and analysis of the impact that climate change may have on epiphytes.

2.8 Monitoring of pollen

Pallas is part of a net used for monitoring of pollen depositioin in boreal forests (Hicks 1994). The vast virgin forests of the park annually produce varying amounts of pollen, depending mainly of climatic conditions. In Pallas conditions are ideal for pollen monitoring because there is a large area without silviculture present to effect the results.

3 Integrating research with other uses in a national park

Integrating research with other park uses causes managerial problems, especially if many different organisations are working concurrently on monitoring projects in the field with tourists and local people also visiting or using the park. National parks include areas, which are too valuable from the point of view of nature conservation to be allocated to research. These zero-areas are surveyed and pinpointed in specific management plan of park.

In situations where there is considerable and continuous interest in monitoring or researching sites, the most practical way to solve the multiple-use issue is to include specific *research zones* in the park's master plan. Research zones may be understood as being subareas within the park, where the primary use is nature conservation and the secondary use is research of virgin areas, especially with the aim of long-term monitoring of environmental changes.

Monitoring of environmental changes is an ongoing which is implimented for long ter use after an initial period of trial and error is worked out. When routines are developed and the methods and tools are developed monitoring becomes continuous. This standard monitoring routine can be largely automated or competent park staff, as is the case at Pallas, can be employed to support the monitoring function. If the park can use local people for the work needed in monitoring programs, the park will also be in a better position to develop understanding and cooperation with the local communities.

References

Henttonen, H., Oksanen, T., Jortikka, A. & Haukisalmi, V. 1987. How much do weasels shape microtine cycles in the northern Fennoscandian taiga? Oikos 50: 353–365.

Hicks, S. 1994. Present and past pollen records of Lapland forests. In Review of Palaeobotany and Palynology 82: 17–35.

Laurila, T., Plathán, P., Hakola, H., Koskinen, T. & Lättilä, H. 1995. Pallas, a site for studies of photochemically-active trace species in European Arctic. In EUROTRAC Newsletter15: 2–4.

The Monitoring Programme for Arctic Monitoring and Assessment Programme, AMAP 1993. AMAP Report 3. Oslo, Norway. 141 p.

Vilén, K. 1976. Pallas-Ounastunturin kansallispuisto, hoito- ja käyttösuunnitelma. Metla. 98 p.

Pallas-Sodankylä, a Global Atmosphere Watch station

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Introduction

To improve our understanding of the behaviour of the atmosphere and its interaction with the oceans and the biosphere, we require data about the chemical composition and related physical characteristics of the global atmosphere. These data will enable us to predict the future states of the earth-atmosphere system. The purpose of the GAW programme is to provide these data. GAW also serves as an early-warning network for detecting changes in the atmospheric concentrations of greenhouse gases and long-range transportation of pollutants (Fig. 1).

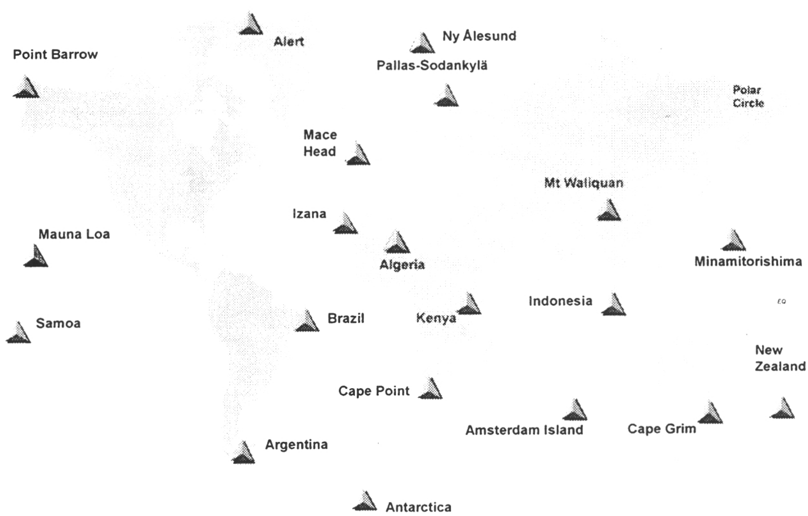

Figure 1. GAW stations (November 1994).

Arctic regions are predicted to be areas in which substantial environmental changes due to global greenhouse warming may take place. Air quality in the northern parts of Scandinavia is mainly influenced by arctic and oceanic air-masses. Occasionally, however, polluted air-masses are subject to long-range transportation from continental Europe and Eurasia.

Measurements at the Pallas-Sodankylä GAW station are made at two locations: radionuclides, ozone soundings, climatological and other meteorological measurements and upper-air soundings at the Sodankylä observatory (67°22' N, 26°39' E), and tropospheric air composition and related boundary layer meteorological measurements at Pallas (67°58' N, 24°07' E). The ongoing measurements are listed in Table 1. The station at Pallas was established in 1991, and in 1994 it, together with the Sodankylä Meteorological Observatory, was adopted as part of the GAW programme.

Table 1. Ongoing measurements at Pallas-Sodankylä, November 1996.

Greenhouse gases	• flask sampling (twice a week) for CH_4 and N_20 • flask sampling (once a week) for CO_2 (with Environment Canada) • continuous CO_2 monitoring (with Environment Canada)
Ozone, total column and vertical distribution	• Sodankylä: O_3-soundings and total column O_3 measurements
Ozone, tropospheric	• O_3-monitor • Sodankylä: O_3-monitor
Reactive gases	• continuous SO_2, NO_X monitoring • SO_2, daily sampling (impregnated filter) • flask sampling (twice a week) for volatile organic compounds (VOCs) • mercury, one day / week, with the Swedish Environmental Research Institute (IVL) • POPs, one week / month (IVL) • Sodankylä: SO_2, monthly sampling
Physical and chemical characteristics of atmospheric particles	• condensation nuclei and black carbon monitoring • daily filter sampling of sulphate, nitrate and nitric acid, ammonium and ammonia • heavy metals, weekly samples • mercury, weekly samples (IVL)
Precipitation chemistry	• bulk precipitation sampling on daily basis: pH, conductivity, major ions • bulk precipitation collector on monthly basis: heavy metals, mercury (IVL), persistent organic pollutants (POPs) with Finnish Environment Institute. • bulk collector: POPS, one week / month
Radionuclides	• continuous ^{222}Rn monitoring • Sodankylä: daily ^{210}Pb, ^{7}Be, continuous ^{222}Rn monitoring
Solar radiation	• global solar radiation, $J(NO_2)$, J(O1D) • Sodankylä: global, diffuse and reflected radiation, radiation balance, CIE-weighted UV-dose and spectral UV-B
Meteorological parameters	• three automatic weather stations at 300 m, 560 m and 790 m a.s.l., present weather sensor, weather camera • Sodankylä: synoptic weather observations and upper-air soundings

2 The Sodankylä Meteorological Observatory

The Sodankylä Meteorological Observatory is located in a subarctic pine forest area in Central Lapland, 7 km from the centre of Sodankylä (6000 inhabitants). The main activities carried out at the observatory are synoptic and climatological observations, upper air soundings (twice a day), ozone soundings (once a week), total ozone measurements, UV-B spectral (290 to 325 nm), continuous CIE-weighted total UV-dose, and solar radiation measurements. Radionuclide (^{210}Pb, ^{7}Be, ^{222}Rn) and air quality measurements (SO_2, O_3) are also made at the observatory.

Sodankylä has one of the longest radio-sounding records (since 1949) and ozone-sounding records (since 1986) in the European Arctic region. The observatory has also hosted several international Arctic ozone campaigns during the recent years.

3 Pallas

The main criteria for selecting the Pallas area as the site for tropospheric measurements were its remoteness, absence of local and regional pollution sources, expected land-use of the surrounding areas, and maintenance of the station. The station is located in the Pallas-Ounastunturi National Park, where the main site for monitoring tropospheric air composition is on top of the Sammaltunturi fell, at an altitude of 560 m a.s.l., and over 300 m above the surrounding area. Some filter and bulk samples are collected at Matorova, at an altitude of 330 m a.s.l.

The Pallas station is maintained in co-operation with the Finnish Forest Research Institute, which is responsible for the maintenance of the national park.

3.1 Air Quality Measurements at Pallas

A schematic picture of the measuring site locations and measured components at Pallas area is presented in Fig. 2. Continuous recordings of ozone, sulphur dioxide, nitrogen oxides (NO, NO_2), aerosol concentration, and aerosol black carbon are made using computer-controlled automatic analysers. Recordings of volatile organic compounds (VOC), methane and nitrous oxide are made using canister samples taken at the station twice a week. The air in the canisters is analysed by gas chromatography at the laboratory in Helsinki.

In addition, since October 1996, FMI has recorded CO_2 in co-operation with Environment Canada, Air Quality Research Branch. The station has continuous CO_2 monitoring, and flask samples are taken once a week for laboratory analysis of CO_2 (analysis conducted by Environment Canada).

According to ozone (O_3) and sulphur dioxide (SO_2) levels recorded and the EMEP model calculations of long-range transportation of pollutants, the station is located in one of the cleanest areas in continental Europe (e.g. Mylona 1993). The recorded yearly averages of SO_2 concentrations are about 1 $\mu g/m^3$. The highest hourly sulphur dioxide concentration in 1991–1994 was 56 $\mu g/m^3$, but on average the concentration is generally low; 90% of the hourly values are below 2.5 $\mu g/m^3$. The occasional brief episodes of high sulphur dioxide concentrations are mainly due to long-range transportation from sources in the Kola Peninsula, 300 km north-east from Pallas. Most of the long-range transportation episodes take place in winter and spring.

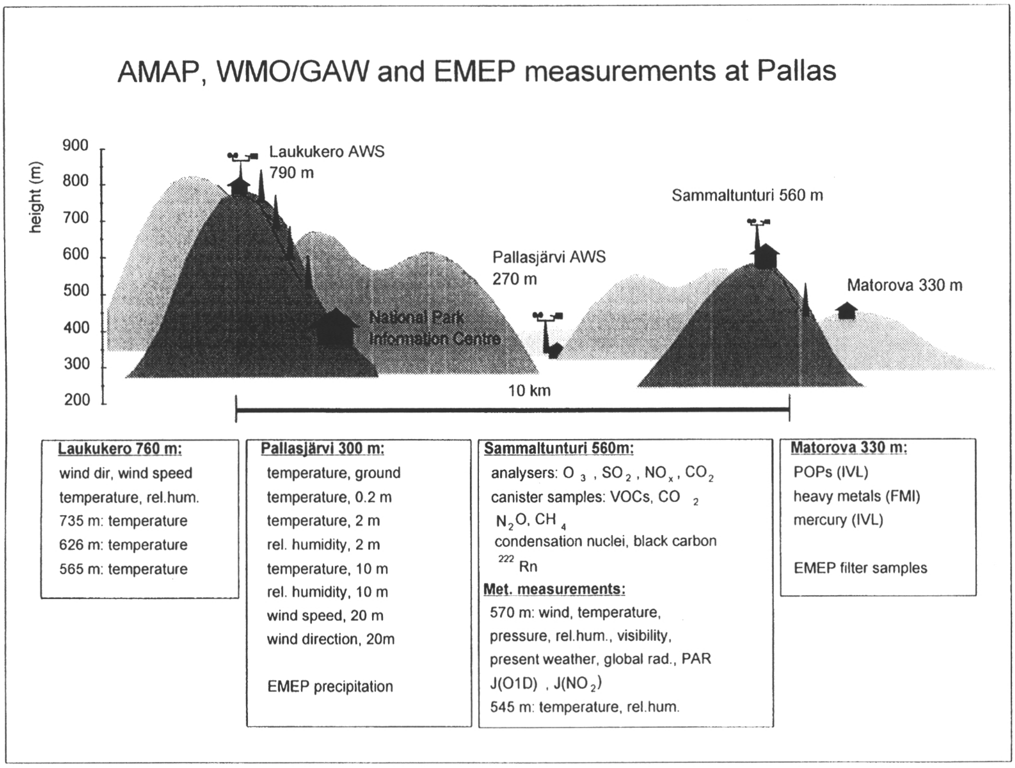

Figure 2. Relief of the Pallas area, showing measuring locations and components (AWS = automatic weather station).

4 Meteorological Measurements at Pallas

The highest fells at Pallas are over 500 m above the surrounding ground. This enables the recording of temperature and wind profiles near the station to yield information about the structure of the boundary layer conditions in the area. Meteorological recordings are carried out using three automatic weather stations (AWS) and a current weather sensor. The monitoring station at Pallas is also equipped with a weather camera, which is connected to a time-lapse video-cassette recorder. The imagery are digitised using a computer for downloading by FMI's weather service, for example.

References

Mylona, S. 1993. Trends in sulphur dioxide emissions, air concentrations and depositions of sulphur in Europe since 1980. EMEP/MSC-W Report 2/93.

Arctic Monitoring and Assessment Programme (AMAP): Atmosphere

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Arctic environmental protection strategy

Measurements have shown that pollutants originating from anthropogenic activities outside the Arctic are transported into the region by atmospheric processes, ocean currents, and rivers. Some persistent organic pollutants appear to accumulate in the arctic environment (Wania and Mackay 1993, 1996). Due to the low temperatures in the Arctic, the degradation of pollutants in the environment is much slower than at lower latitudes. Particularly at the top of the food chain (including humans), contaminants have been detected at relatively high levels.

As a response to the threat of anthropogenic pollution of the Arctic environment, the arctic countries adopted the Arctic Environmental Protection Strategy (AEPS) in June 1991 at a ministerial meeting held in Rovaniemi, Finland. The member countries are Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden, and the United States. Countries merely carrying out research in the Arctic (Germany, the Netherlands, Poland, and the United Kingdom) participate as observers, as do also international indigenous arctic organisations and international organisations involved in monitoring and regulatory activities, assessment and research.

2 AMAP Programme

The Arctic Monitoring and Assessment Programme (AMAP) was established to implement the relevant components of AEPS. The aim of AMAP is to monitor the levels, and assess the effects of anthropogenic pollutants in all compartments of the Arctic environment. These compartments are as follows: the atmosphere, the terrestrial environment, the freshwater environment, the marine environment, and human health.

During the first stage of its development, AMAP focuses on persistent organic pollutants (POPs), heavy metals, radionuclides, and acidification/arctic haze (The Monitoring Programme for... 1993). Furthermore, the environmental consequences of global climate change and depletion of the stratospheric ozone layer, as well as oil pollution and eutrophication, are issues of great importance within AMAP.

POPs are organic compounds that are resistant to photolytic, biological, or chemical degradation. Many POPs are characterised by low water solubility and high lipid solubility, leading to their bioaccumulation in fatty tissues. POPs with these characteristics are typically semi-volatile and able to travel long distances and condense over colder regions of the earth.

The institutes in Finland participating in the implementation of the AMAP programme are the Ministry of the Environment, the Lapland Regional Environment Centre, the Finnish Environment Institute, the Geological Survey of Finland/Rovaniemi, the Finnish Meteorological Institute, the Provincial Government of Lapland, the Finnish Centre for Radiation and Nuclear Safety/Rovaniemi, and the Finnish Forest Research Institute/Rovaniemi Research Station.

3 Atmospheric monitoring within AMAP

The Finnish Meteorological Institute is responsible for the atmospheric part of the AMAP programme in Finland. Conventional air quality and deposition data from five stations in northern Finland (Pesosjärvi, Oulanka, Pallas, Sevettijärvi and Vuoskojärvi, Fig. 1) and radioactivity data from four monitoring stations (Sodankylä, Ivalo, Kilpisjärvi and Kevo, Fig. 1) are reported to the AMAP database.

The persistent organic pollutants and heavy metals included in the AMAP programme (The Monitoring Programme... 1993) are listed in Tables 1 and 2 with some information on their sources or usage (State of Knowledge... 1994, Task Force on Heavy Metals... 1995).

The measurements of POPs and mercury were started at the beginning of this year at the AMAP master station of Pallas in cooperation with the Swedish Environment Research Institute (IVL, Göteborg), which is responsible for the analyses. The funding is provided by the Swedish and Finnish environmental authorities. The analyses of POPs in particular are very expensive, being about SEK 5000 or FIM 3500 per sample. Due to the cost, POPs are only sampled one week per month, although according to the AMAP programme they should be collected as successive weekly samples. Mercury measurements are made using two parallel monthly precipitation samples. Filter samples for the measurement of particulate mercury are collected weekly and gold trap samples for gaseous mercury as daily samples once a week.

Weekly filter samples, as well as monthly precipitation samples, have also been collected since the beginning of 1996 at Pallas for measurements of heavy metals in air and rainwater and snow.

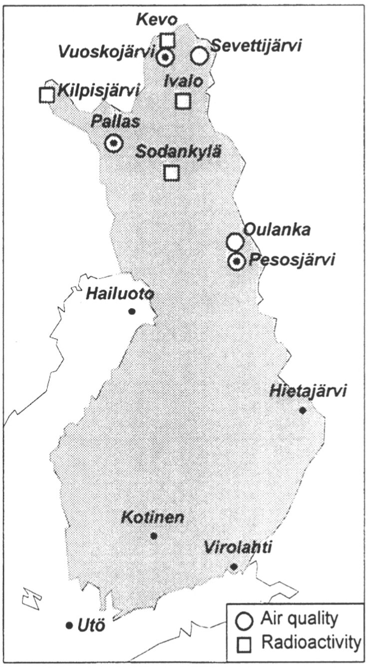

Figure 1. Air quality and radioactivity monitoring stations of the Finnish Meteorological Institute reporting to the AMAP database. Additionally, dots indicate the stations monitoring heavy metals in precipitation in Finland (see Fig. 2.).

Table 1. The persistent organic polutants included in the AMAP programme, with information on emission sources (State of Knowledge... 1994).

Compound	Main sources/usage
PCB	fires, spills, leakages, incineration
DDT/DDE/DDD	pesticide; DDE and DDD are metabolites of DDT
HCH	pesticide (insecticide, rodenticide, fungicide)
Chlordane	pesticide (insecticide)
Dieldrine	pesticide
Toxaphene	pesticide
PAH	incomplete combustion of organic matter (particularly fossil fuels), vehicle traffic and residential combustion (especially coal and wood), use of tar products, production of coke, aluminium, iron and steel
HCB	production and processing of some chlorinated hydrocarbons (pesticides and solvents), incineration
Dioxin	some paper bleaching processes, chemical synthesis of chlorinated compounds, combustion processes, waste incineration, vehicle operation, primary and secondary metal production
Dibenzofuran	some paper bleaching processes, chemical synthesis of chlorinated compounds, combustion processes, waste incineration, vehicle operation, primary and secondary metal production
Mirex	pesticide (insecticide)

Table 2. The heavy metals included in the AMAP programme (which also includes aluminium), with information on emission sources (Task Force on Heavy Metals... 1995). Relevant source sectors are marked "x" while major source sectors are represented by "xx".

Source	Cd	Hg	Pb	Cu	Zn	Cr	Ni	As	Se
Public power, cogeneration and district heating	x	xx	x	xx	x	x	xx	xx	xx
Commercial, institutional and residential combustion	x	xx	x	x	x	x	x	x	x
Industrial combustion	x	xx	x	x	x	x	x	x	x
Production processes	xx	xx	xx	xx	xx	xx	x	xx	x
Extraction and distribution of fossil fuels			x	x	x		x		
Road transport	x		xx	x	x		x		
Other mobile sources and machinery	x		xx	x	x		x		
Waste treatment and disposal	xx	xx	x	x	xx	x	x	x	x
Agriculture					x			x	
Nature		x	x	x	x			x	x

4 Deposition of heavy metals at Pallas

In order to give an idea of the deposition of some airborne toxic contaminants in the Pallas area compared to other parts of Finland, the preliminary volume-weighted mean values and deposition values of arsenic, cadmium and nickel during the first half-year of 1996 are presented in Fig. 2. The monthly samples were collected with bulk collectors, which means that the collectors were open continuously. The samples were analysed in the laboratory of the Geological Survey of Finland by ICP-MS.

The stations in Fig. 2 are displayed in order from south to north, and it can be seen that, apart from the two island stations of Utö and Hailuoto, the deposition of arsenic and cadmium decreases northwards. On the said islands, the deposition is smaller than on the mainland mostly due to the smaller precipitation in marine areas. The low precipitation recorded at Vuoskojärvi also explains a lot of the smaller deposition of arsenic and cadmium compared to Pallas. The volume-weighted mean concentrations in precipitation were about the same at both sites, while at Vuoskojärvi the precipitation amount was about half of that obtained at Pallas. The figure shows that a little more nickel was deposited at Vuoskojärvi than at Pallas during this first half-year of measurements at Pallas. This is not surprising, because the nickel most probably originated from the Kola (Russia) metallurgical industries further away from Pallas than from Vuoskojärvi.

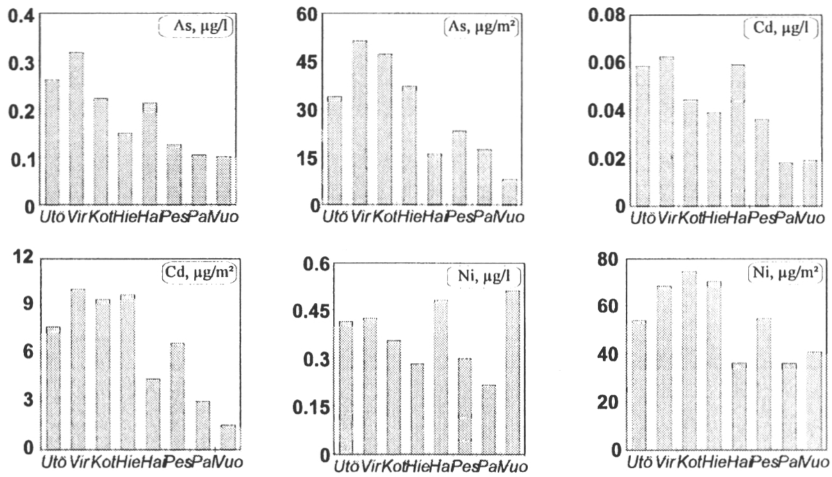

Figure 2. Volume-weighted mean concentration and deposition of arsenic, cadmium and nickel in January – June, 1996 in Finland. (see Fig. 1: Vir = Virolahti, Kot = Kotinen, Hie = Hietajärvi, Hai = Hailuoto, Pes = Pesosjärvi, Pal = Pallas, Vuo = Vuoskojärvi).

5 Future work

In September 1996 the eight arctic countries established the Arctic Council, in which the AEPS is one of the key components. The Arctic Council will build upon the work of the AEPS and encourage a more action-oriented approach to arctic environmental issues. AMAP will continue to have the same role under the Arctic Council.

The first assessment report by AMAP is currently under preparation. The State of the Arctic Environment Report, to be presented at the ministerial meeting in the summer of 1997, will provide appropriate information on the threats posed by pollution to the arctic environment, including recommendations for action to be taken. Based on the information in the assessment report, the ministers will decide on the future work within AMAP.

The preparation of protocols for the international control of POPs and heavy metals is under way in two working groups under the Convention on Long-Range Transboundary Air Pollution of the United Nations Economic Commission for Europe (State of Knowledge... 1994, Task Force on Heavy Metals... 1995). Heavy metals and POPs have not yet been included in the monitoring programme of EMEP (the European Monitoring and Evaluation Programme), but, as a first step, EMEP established in summer 1996 a database for these compounds. There is close co-operation between international organisations measuring POPs and heavy metals, and AMAP is one of the participants.

For a comprehensive data analysis of the AMAP measurements at Pallas, more results are needed. Up until now, no results of POPs or mercury have been available. The first results will be presented in a project meeting in November 1996. The said meeting will consider the measuring programme of airborne toxic contaminants at Pallas in 1997. The measurements will probably continue in very much the same way as during this first year.

References

State of Knowledge Report of the UN ECE Task Force on Persistent Organic Pollutants For the Convention on Long-range Transboundary Air Pollution. 1994. For Presentation to the Meetings of the Working Groups on Technology and on Effects 28 June – 1 July, 1994, Geneva. 99 p.

Task Force on Heavy Metals Emissions. 1995. State-of-the-Art Report. Economic Commission for Europe. Executive Body for the Convention on Long-range Transboundary Air Pollution. Working Group on Technology. Prague. 266 p.

The Monitoring Programme for Arctic Monitoring and Assessment Programme, AMAP 1993. AMAP Report 3. Oslo, Norway. 141 p.

Wania, F. & Mackay, D. 1993. Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions. Ambio 22(1): 10–18.

— 1996. Tracking the distribution of persistent organic pollutants. Environmental Sci. Technol. 30(9): 390 A–396 A.

Timberlines: Research in Europe and North America

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Introduction

Not only are timberlines the most conspicuous vegetation boundary in high mountains, but they are also an important ecological boundary. No wonder then that timberlines have always attracted researchers for both scientific and practical reasons. In the Alps, for example, the restoration of the climatic timberline and the establishment of an effective protective forest are the two principal objectives of high-mountain forest management. Also in this connection, the potential response of timberlines to expected climatic change has begun to be a matter of interest.

The present paper is mainly based on my fieldwork in the Alps, in northernmost Europe, and in many high-mountain ranges of western North America. In the following, I shall set out to highlight some aspects of timberlines in Europe and North America.

2 General characteristics of timberlines

2.1 Floristic aspects

The timberlines in Europe and North America are floristically closely related to each other. They are mainly formed by different species of the genera *Picea*, *Abies*, *Pinus* and *Larix*. In North America, the species *Tsuga mertensiana* and *Chamaecyparis nootkatensis* (north of 42°N) occur at the upper timberline. Aspen (*Populus tremuloides*) forms the timberline on the Steens Mountains in Oregon (Faegri 1960, Price 1978) and on some isolated mountains in the basin range province of Nevada (Critchfield and Allenbaugh 1969). Neither aspen nor fir occur at the upper timberline in Europe. On the other hand, *Fagus*, which occurs at the upper timberline in the outer ranges of the Alps, in the Pyrenees, and in some other mountain ranges of southern Europe, does not occur at the upper timberline in North America.

In northernmost Europe, it is the mountain birch (*Betula tortuosa*) that forms the timberline, which is an altitudinal limit. South of the northern limits of Scots pine (*Pinus silvestris*) and Norway spruce (*Picea abies*), birch may occur together with these conifers at the timberline, as is the case in the Pallastunturi area, for example. In general, the upper timberline at a particular place is formed by 2–3 (4) species differing in their ecological requirements and properties.

2.2 Types of timberline

Although timberlines exhibit a great physiognomic and ecological variety, there are, generally speaking, three different main types that can be distinguished (Fig. 1). Timberlines may occur as a line, a more or less wide ecotone (transitional belt, cf. Fig. 4), or as high-boled forest is replaced by a *Krummholz* belt of woody species such as *Pinus mugo* or *Alnus viridis*, the prostrate growth of which is genetically predetermined (Fig. 2). These species also replace the coniferous forest in avalanche chutes, because their elasticity enables them to resist avalanches better than upright-growing conifers, which are normally eliminated from such sites.

Moreover, alder is able to regenerate by basal sprouts following mechanical injury. This kind of a *Krummholz* belt is typical of the Alps, the Carpathian Mountains and the Dinarides, for example. In North America, the use of the term "*krummholz*" is somewhat different; there, also the crooked and twisted growth forms caused by climate in the upper timberline ecotone are referred to as called "*krummholz*" (Figs. 3 and 6). Nevertheless, this "*krummholz*" is usually formed by species that also form the upper mountain forest, and this what makes it quite different from the true *Krummholz* belt in the Alps, for example (Holtmeier 1981).

In Alaska, on the other hand, dense thickets of *Alnus sitchensis* occur at altitudes above the closed high-boled coniferous forest (Arno 1984). They also replace the high-boled conifers along avalanche tracks. So does *Alnus sinuata* on the very steep mountain slopes in Glacier National Park in Montana, for example. Thus, these alders form true *Krummholz* stands comparable to those formed by green alder (*Alnus viridis*) in the Alps.

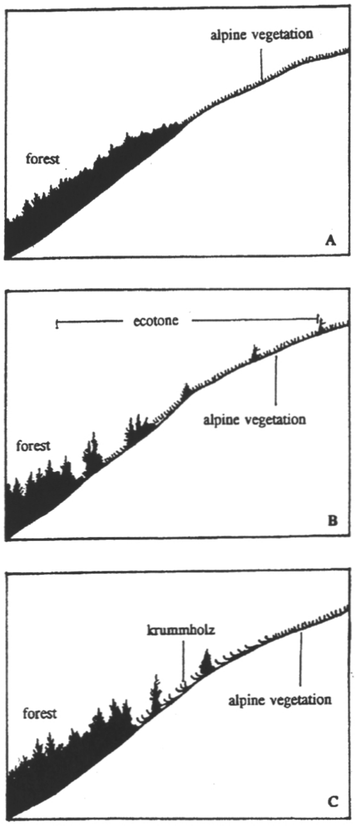

Figure 1. Main types of upper timberline

The discussion over whether the natural climatic forest limit would be a sharply defined one rather than a transitional zone has been going on for a long time (cf. Holtmeier 1985, 1989, and other references). The existence of a transitional belt is explained in terms of unfavourable pedological conditions and/or human influence. However, with my own experience gained in mountain areas in and out of Europe forming the basis, I would say that all the aforementioned timberline types can occur under natural conditions. In fact, the closed forest in certain high mountain regions not influenced or only randomly influenced by humans ends abruptly at its upper limit.

Be as it may, the climatic timberline in many other high-mountain areas, as well as in the subarctic, forms a more or less wide ecotone, extending from the closed forest to the most advanced, usually crippled, trees. These ecotones are the result of the complex influence of the current and previous climate, fire, biotic factors, and site history on tree growth and ecological temporal and spatial dynamics. The ecological conditions within the ecotone are totally different from the alpine belt or the closed forest, which is mainly due to the influence of the mosaic of islands of tree and open meadows on the distribution of snow (Fig. 4).

Figure 2. True Krummholz belt (Pinus mugo) with some flagged spruce (Picea abies) above the upper forest limit in the High Tatra Mountains near Stray Smokovec. Photo August 1970.

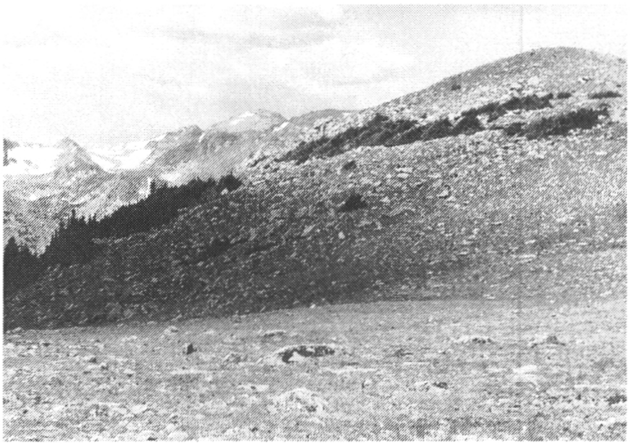

Figure 3. Uppermost part of the timberline ecotone on Tombstone Ridge (Rocky Mountain National Park, Colorado) at about 3500 m. The wedge- and mat-like "krummholz" growth forms (right) and the high-boled tree islands (left) are formed by the same species (Picea engelmannii and Abies lasiocarpa) Photo 13.7.1994.

Figure 4. Timberline ecotone on the west slope of Rollins Pass (Front Range, Colorado at about 3470 m). While the snow has already gone in the alpine belt and in the closed forest, snow cover still exists in the ecotone due to the influence of scattered tree islands on windflow and accumulation. Photo 8.7.1979.

3 Influence of climate and other site factors

3.1 Altitude of timberline

Mainly controlled by low temperatures, timberlines rise from north to south due to the effect of latitude on temperatures, and from west to east because the thermal conditions are more favourable under continental climates than under maritime climates. Moreover, large mountain masses have a positive effect on the altitudinal position of the timberline, because they serve as a surface to be heated (i.e. the mass-elevation effect). Also, their central parts are relatively protected from the moisture-carrying air masses and thus enjoy a higher percentage of sunshine compared to mountain rims.

In the northern Alps, for example, at an altitude of 2000 m a.s.l., the snow cover usually lasts 280 days, whereas in the central parts the winter snow does not stay on the ground for more than 200 days. Thus, less energy is used in snow melting and evaporation, and the growing season is longer and warmer at any given elevation compared to the outer ranges (Fig. 5). Consequently, the upper timberline in the United States reaches its highest position in the southern Rockies at about 3500–3600 m a.s.l. but at ca. 4000 m in Mexico. In Europe, the timberline climbs highest in the Central Alps (to a maximum of ca. 2400 m).

On the isolated fells in Finnish Lapland, the timberline rises to greater elevations than on the lower mountains. However, because of the high latitudinal position north of the Arctic Circle, this cannot be attributed to a more or less pronounced heating effect, but is instead explained by the varying microtopographical conditions (small valleys, convex topography alternating with concave topography), which provide better wind protection for the trees at a given altitude on the high fells when compared to lower fells (Hustich 1937, 1942, Holtmeier 1974).

The upper timberlines in Europe have been under intense influenced by humans since prehistoric times. This is also the case in many other Eurasian high-mountain regions. In the Alps, for example, there is no untouched forest left. In consequence of human activities, e.g. alpine pasturing, logging, and mining, the upper timberline became cam down by ca. 150–400 m, and only the remnants of forests survived on steep and inaccessible slopes, while on gentler slopes and in almost level terrain the forests have been totally removed. In northern Europe, mainly reindeer grazing has persistently influenced the timberline forests (Holtmeier 1974). In North America, however, many remote timberline areas have not been disturbed at all, or they have been disturbed only relatively little, by humans, and thus they offer good opportunities for the study of climatically formed timberlines.

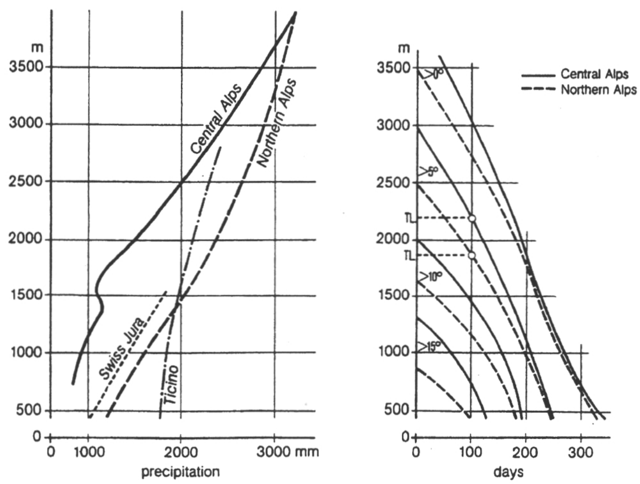

Figure 5. Amount of annual precipitation (left) and number of days with temperatures above 0 °C, 5 °C, 10 °C and 15 °C (right) in the central Alps and in the outer ranges (TL=timberline) (after Ellenberg 1978).

3. 2 Growing conditions

In the middle and high latitudes, the upper (climatic) timberline is usually caused by low temperatures. Heat deficiency affects tree growth in different ways; directly through low temperatures during the growing season, through shortness of the growing season, and through sub-zero temperatures. Heat deficiency can also be implied by other site factors such as wind and duration of winter snow cover, for example.

Generally, southern aspects are more favourable to tree growth than northern aspects, provided there is sufficient soil moisture. Above the closed forest and within the timberline ecotone, the microtopography controls microclimates and thereby other site conditions. The effects of microtopography, and of the distribution pattern of trees and islands of trees, on solar irradiation and wind flow near the surface may become factors of greater importance to site conditions than the altitudinal zonation of the climate on mountain slopes (Fig. 6, see also Fig. 4).

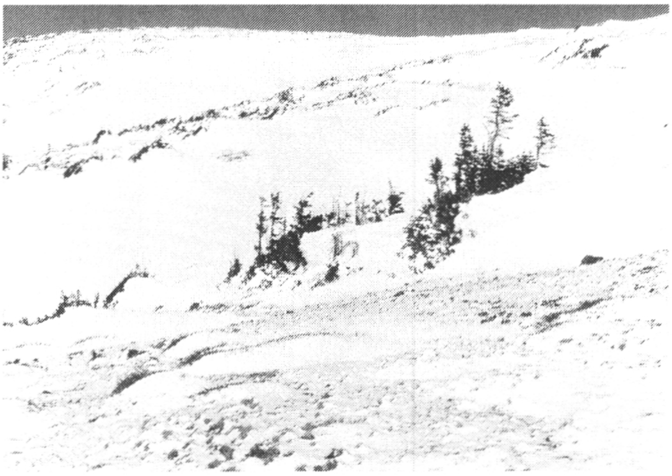

Figure 6. Tree islands (Picea engelmannii) influencing wind-mediated distribution of snow on a wind-exposed site (view to the west) on Niwot Ridge (Front Range, Colorado) at about 3450 m. The distribution pattern of snow deeply influences other site conditions (soil temperatures, soil moisture, decomposition and pedogenesis).

Trees at the timberline grow slowly, and, on approaching the timberline, the production of organic matter is impeded. This is reflected in the decrease in height and diameter increment. Theoretically, the altitudinal position of timberline can be controlled in the long term by a carbon imbalance. In the case of bristlecone fir (*Abies venusta*), for instance, in the White Mountains of California, negative winter carbon balances have been observed (Schultze et al. 1967). At the timberline in northern Lapland, negative carbon balances due to high carbon loss by respiration have occurred occasionally under cloudy weather conditions in the summer (Ungerson and Scherdin 1968). Normally, however, trees succumb to injurious climatic influences prior to reaching the upper limit caused by long-term zero net production. In case of growing seasons that are too short and/or otherwise unfavourable, new needles and shoots fail to fully develop, and become then easily victims to the first strong frosts of the late summer, for example, and/or by frost-drought in winter (Larcher 1957, 1963, 1972, 1980, 1985, Wardle 1965, 1968, 1971, 1981, Holtmeier 1971, 1984; Baig et al. 1974; Tranquillini 1974, 1976, 1979, Platter 1976, Baig and Tranquillini 1980, Delucia and Berlyn 1983, Havranek and Tranquillini 1995).

Needles damaged by mechanical forces, such as abrasion of the cuticle and wax layer by wind-driven ice particles, are predisposed to water loss and drought on wind-exposed sites (Marchand and Chabot 1978, Holtmeier 1980, Marchand 1980, Wardle 1980, Perkins et al. 1991, Hadley and Smith 1986, Dahms 1992). On sites covered for too long by snow and parasitic snow fungi, brown snow-felt fungus (*Herpotrichia juniperi*), for example, causes serious damage to conifer needles and may entirely prevent restocking. Under semiarid and arid climates, such as in the basin-range provinces, low precipitation and insufficient soil moisture may be additional factors hampering tree growth and regeneration at the timberline.

The high-mountain ranges of western North America are mainly north-south oriented and thus run perpendicular to the prevailing wind direction. At high altitudes, very strong winds (maximum velocities in winter), mainly from the west, are common throughout the year. They primarily control site conditions, tree growth, and growth forms (Fig. 7) in the timberline ecotone (Marr 1961, 1977, Holtmeier 1978, 1980, Benedict 1984). Thus the situation is somewhat different from the European timberline areas, where the impact of wind is not that pronounced. In the timberline ecotone, the influence of tree stands (clumps of trees, scattered trees) on the microclimatic pattern, and thereby on site conditions and timberline dynamics, is very important (Fig. 6, Holtmeier 1985, 1987 a, 1987 b, 1993). These effects, however, have hardly been considered so far in the timberline literature concerning the timberlines in Europe.

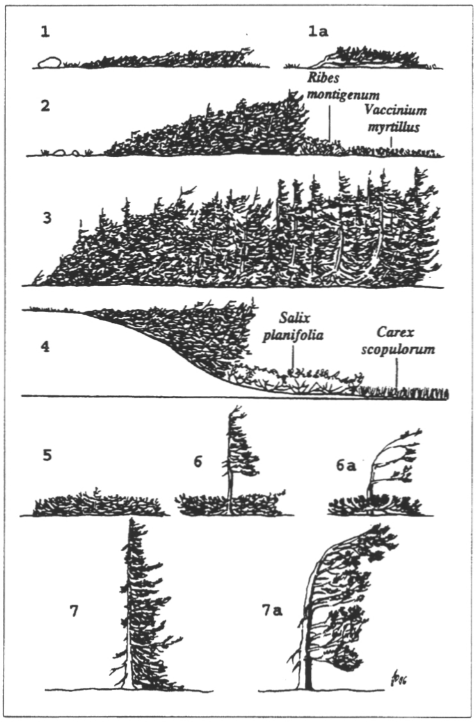

Figure 7. Wind-shaped growth forms of Picea engelmanni, Abies lasiocarpa and Pinus flexilis. 1 Mat - 1a Mat (Pinus flexilis) - 2 Wedge - 3 Hedge - 4 Cornice - 5 Table - 6 Flagged table tree - 6a Flagged table tree (Pinus flexilis) - Flagged tree - 7a Flagged tree (Pinus flexilis). Mats, wedge- and cornice-like growth forms may be formed by individual trees. Hedges, however, originate from elongation by layering at the leeward end (from Holtmeier 1996).

With regard to timberline dynamics, regeneration appears to be the most important factor. Though trees at the timberline occasionally produce large quantities of seed, the percentage of viable seeds is usually very low because of incomplete morphological differentiation (Table 1). In general, the upper limit in the production of viable seeds is located below the physiological limit of tree growth. In case of a general cooling, sexual regeneration fails first. If regeneration does not occur for a long time, the existing forest will become over-aged and begin to decay. However, even abundant production of viable seeds does not necessarily mean successful regeneration. First, seeds must reach a suitable seed bed, and second, the seedlings must survive. Thus, all sites covered for too long with snow are unfavourable both to germination and seedling survival (low soil temperature until early summer, short growing season, infections by snow fungi).

Table 1. Quality and germination capacity of seeds of Picea engelmannii on Niwot Ridge, Colorado Front range.

	upper montane (3150-3350 m)	subalpine (3350-3500)
- endosperm and embryo missing	52,9 %	60,3 %
- endosperm present, embryo missing or less than 50 %	18,3 %	32,7 %
- necrosis, embryo not viable	4,8 %	66,0 %
- germination capasity	24,0 %	0,4 %

On the other hand, sites receiving high amounts of solar radiation are also unfavourable. These sites quickly dry up after the snow melt and may experience excessive soil temperatures (Turner 1958, Noble and Alexander 1977). Only a few seedlings will survive. Most of them become a victim to climatic factors, fungal infections, mechanical damage by the snow cover, root competition, and grazing by wild game and livestock. On passing the height of the protecting snow cover, another critical phase of survival seedling begins. Thus, regeneration can be compared to a very difficult "hurdle race" (Fig. 8). As a rule, regeneration is most successful on convex topography, except for semi-arid (arid) and very windy climates, where such sites may be too dry.

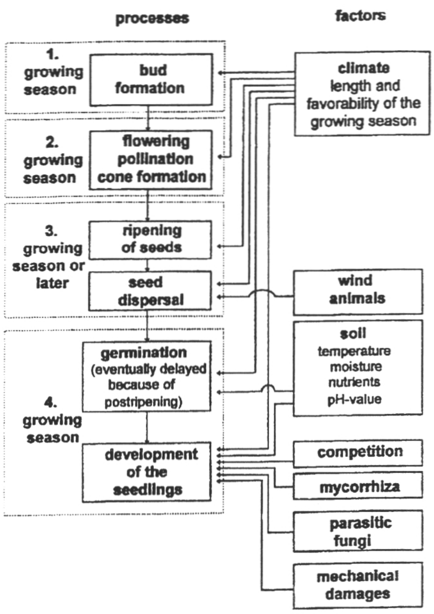

Figure 8. Regeneration by seeds under the influence of some selected site factors at the upper timberline (from Holtmeier 1993, modified).

Trees may survive as long as they are able to physiologically resist the severe climatic environment. Layering is far less impeded by unfavourable climatic conditions than by sexual reproduction. Thus, with regard to the preservation of the forest, reproduction by layering is much more effective. Timberline studies in the Rocky Mountains, for example, have revealed that the upper forest-alpine tundra ecotone initially established itself under climatic conditions more favourable to sexual regeneration than at is the case at present (Ives 1973, Hansen-Bristow and Ives 1985).

The islands of trees originating from layering can survive as long as the climate does not prevent vegetative growth (s. also Griggs 1934). Layering occurs only with some conifer species, e.g. fir, spruce, hemlock, and to a less extend also larch. It is not common with pines. In the timberline ecotone of some North American high, mountain ranges, clone groups of spruce and fir are more typical of the ecotone than is the case in the European Alps or at the timberline in northern Europe. This may be explained by the enhanced ability of North American tree species to layer. In the Alps, the uppermost forest, where layering was probably more common under natural conditions (higher timberline), has been removed by humans.

Another important factor for regeneration is the way of seed dispersal – either by wind or by animals. Wind-mediated seed dispersal (e.g. spruce, fir, larch, Scots pine and mountain pine) is highly irregular and it is a matter of chance whether the wind-borne seeds reach a suitable seed bed. The heavy, wingless seeds of some subalpine pine species (e. g. *Pinus cembra* in the Alps, *Pinus albicaulis* and *P. flexilis* in the Rocky Mountains) are dispersed by animals, mainly by nutcrackers (*Nucifraga caryocatactes* – in the Alps and Carpathian Mountains, for example: and *Nucifraga columbiana* – in North America). Nutcrackers establish food caches of seeds 2–4 cm deep in the soil or humus layer not only within the forest but also far beyond the timberline and even the tree line (Holtmeier 1966, Tomback 1977, 1982, Mattes 1978, 1985, Hutchins and Lanner 1982, Lanner 1982, 1996).

Nutcrackers cache seeds usually on sites where the winter's snow cover disappears relatively early. Moreover, they only hoard seeds of good quality rich in nutrients. Above the forest limit, most of the seed caches remain unused and may give rise to seedling clusters. With regard to the successful germination of seeds and seedling survival, seed dispersal and seed caching by nutcrackers appear to be more effective than wind-mediated distribution of seeds. This makes nutcrackers a decisive biotic factor in regeneration, in the advance of the timberline, and also in natural reforestation of high-mountain burn areas or abandoned alpine pastures, as in the Alps, for example (Holtmeier 1993). There is no comparable mutualism between nutcrackers and trees at the timberline in northern Europe.

4 Timberline fluctuations

At present, the potential response of timberlines to the changing climate is being increasingly discussed within the scientific community and also by the public (Holtmeier 1994 b and other references). Actually, impressive maps and other graphs showing the future position of vegetation zones and altitudinal belts have already been presented (e.g. Ozenda and Borel 1991). However, these predictions are based on simple linear extrapolations of the coincidences of the present position of the timberline (and other vegetation zones) with actual thermal conditions, usually described by means of effective temperature sum accumulation or number of growing degree days. From the ecological point of view, and for different reasons, these scenarios can disguise rather than clarify this very complex phenomenon.

It is time to move away from the common misunderstanding of the timberline as being a line, and that the advance of the timberline would run parallel with an altitudinal shift of any isotherm considered to be essential to tree growth. The timberline is a biological boundary, an ecotone, that has to be understood as a space- and time-related phenomenon, and one that does not respond linearly to changing temperatures or any other environmental factor. Moreover, we have also got to realise that the current situation at the timberline is a reflection of long-term site history rather than of the present climate. Thus, for example, the present position of the timberline in many high mountains of western North America seems to be out of balance with the present climate (Ives 1973, Hansen-Bristow and Ives 1985). Although abundant natural regeneration can be observed within many subalpine meadows, almost no seedlings and saplings occur at the very upper tree limit, usually formed by climatically-shaped, low-growing tree individuals reproducing mainly by layering.

Figure 9. Scots pines (Pinus sylvestris, left) and Norway spruce (Picea abies, right) at tree line on the west slope of Lommoltunturi (Pallastunturi area, Finnish Lapland) at about 510 m. a.s.l. These individuals became established during 1920–1930.Their normal development was prevented by severe climate-indused injuries. Photo 2.6.1969.

In many cases these outposts became established under a more favourable past climate. Thus, the tree limit has not changed yet, because the recent warming has not been large enough to encourage the invasion of trees at this great altitude. In northern Europe, one finds many trees at the treeline that originated from seeds during the relatively favourable decades in the middle of the present century. Meanwhile, many of the young trees that have invaded the ecotone have been heavily damaged or even killed by climate-induced injuries – despite the continued advance of young growth into the ecotone (Fig. 9). Moreover, regeneration differ by tree species forming timberline. In many high mountains of the western United States, for example, there is more young growth of *Picea engelmannii* than of *Abies lasiocarpa*, and in places *Pinus flexilis* and *Pinus albicaulis*, whose seeds are dispersed by *Nucifraga columbiana*, are advancing more successfully than the other two wind-mediated conifers. Altogether, successful regeneration and increase in tree population within the forest-alpine tundra ecotone and beyond the present tree limit has to be considered a key factor for the advance of the timberline.

There is no doubt that the timberline will respond to a general warming in one way or another – provided that the warming continues for a long time. However, tree growth and reproduction are primarily controlled by strongly contrasting microclimatic and soil-ecological conditions within the ecotone itself rather than by the altitudinal gradients of temperature and thus they usually vary spatially and temporally. It can be taken for a fact that the contrast in site conditions, for example, caused by exposure to wind and solar radiation, will not be changed very much by a slight rise in the mean air temperature.

Compared to the upper timberline in North America, the ecological situation at the timberline in Europe is particularly complex because in Europe anthropogenic disturbances have strongly interfered with natural factors since prehistoric time. In the Alps, for example, where the timberline has come down considerably from its uppermost position during the postglacial thermal optimum, the limit of tree growth is located above the actual forest limit, and this is clearly evidenced by the invasion of abandoned or rarely used alpine pastures by trees. This invasion has been probably facilitated by the climatic warming during the present century.

However, above the closed forest, tree growth is hampered more by unfavourable site conditions than one would expect at the present level of the timberline. This becomes particularly apparent when one attempts to afforest abandoned alpine pastures and to restore the climatic timberline. This can be explained by the site conditions, which have deteriorated considerably in the previously forested area (Fig. 10). Thus, man-made timberlines have become pronounced ecological boundary in the way that natural timberlines were before. All in all, the invasion of alpine pastures by trees is primarily the consequence of the decrease in grazing rather than a response to global climatic change.

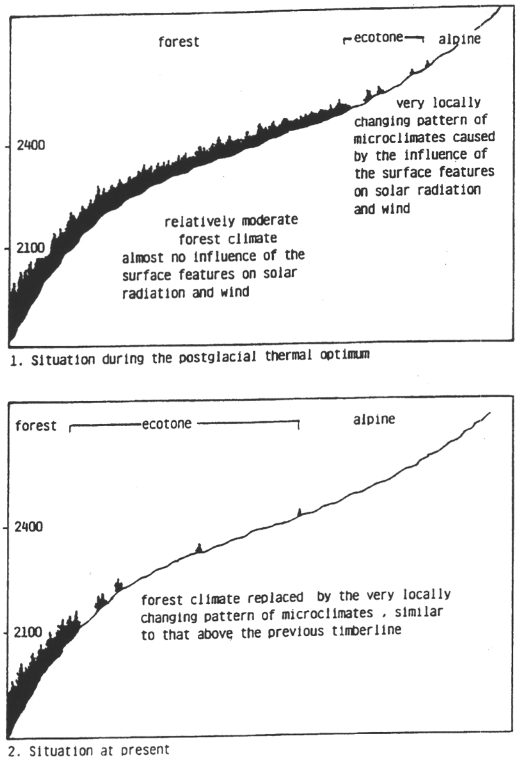

Figure 10. Change of microclimatic conditions in the upper subalpine after the removal of the uppermost forest by humans (from Holtmeier 1994 a).

5 Concluding remarks

It can be said that after more than 100 years of scientific research focusing on timberlines more to-be-answered issues have arisen than have been answered. This becomes particularly apparent nowadays when discussion turns to the potential response of timberlines to changing climate. Tremendous ecological field work on tree growth, regeneration, competition, climatic and biotic injuries, decomposition, nutrients and pollutants, has to be done in many high mountains areas locally and regionally. This research must be supported by physiological investigations.

Regional and local studies on the timberline must also include the historical aspect, because the actual situation within the timberline ecotones reflects site history and cannot be explained by the present climate only. Solid field data will help to improve models, which in turn will help us to achieve a better understanding of the complex interactions of ecological factors controlling location and dynamics of the upper timberline.

From this point of view, the Pallastunturi area, which still has the cleanest air in Europe, offers an excellent opportunity for monitoring the ongoing changes and their effects on the timberline ecotone.

References

Arno, St. F. 1984.Timberline – mountain and arctic frontiers. Seattle.

Baig, M. N., Tranquillini, W. & Havranek, W. 1974. Cutikuläre Transpiration von Picea abies- und Pinus cembra-Zweigen aus verschiedener Seehöhe und ihre Bedeutung für die winterliche Austrocknung der Bäume an der alpinen Waldgrenze. Centralblatt für das gesamte Forstwesen 91: 95–124.

— & Tranquillini, W. 1980. The effect of wind and temperature on cuticular transpiration of Picea abies and Pinus cembra and their significance in desiccation damage at the alpine timberline. Oecologia 47: 252–256.

Benedict, J. B. 1984. Rate of tree island migration, Colorado Rocky Mountains, USA. Ecology 65 (3): 1159–1164.

Critchfield, W. B. & Allenbaugh, G. L. 1969. The distribution of pinaceae in and near northern Nevada. Madrono 20 (1): 12–25.

Dahms, A. 1992. Wachstumsbeeinträchtigungen bei Picea engelmannii (Parry) Engelm. und Abies lasiocarpa (Hook) Nutt. an unterschiedlich windexponierten Standorten im Waldgrenzbereich der Colorado Front Range, U.S.A. Dissertation, University of Münster.

Delucia, E. H. & Berlyn, G. P. 1983. The effect of increasing elevation on leaf thickness and cuticular transpiration in balsam fir. Canadian Journal of Botany 62: 2423–2431.

Ellenberg, H. 1978. Vegetation Mitteleuropas mit den Alpen in ökologischer Sicht. Stuttgart.

Faegri, K. 1960. A botanical excursion to Steen's Mountains, S. E. Oregon: 71–89.

Griggs, R. F. 1934. The edge of the forest in Alaska and the reason for its position. Ecology 15: 80–96.

Hadley, J. L. & Smith, W. K. 1986. Wind effects on needles of timberline conifers: seasonal influence on mortality. Ecology 67(1): 12–19.

Hansen-Bristow, K. J. & Ives, J. D. 1985. Composition, form and distribution of the forest-alpine tundra ecotone, Indian Peaks, Colorado, USA. Erdkunde 39 (4): 286–295.

Havranek, W. & Tranquillini, W. 1995. Physiological processes during winter dormancy and their ecological significance. In Smith, W. K. & Hinckley, Th. M. (eds.) Ecophysiology of forest. p. 95–124.

Holtmeier, F.-K. 1966. Die ökologische Funktion des Tannenhähers im Zirben-Lärchenwald und an der Waldgrenze im Oberengadin. Journal für Ornithologie 4: 337–345.

— 1971. Waldgrenzstudien im nördlichen Finnisch-Lappland und angrenzenden Nordnorwegen. Report Kevo Subarctic Research Station 8: 53–62.

— 1974. Geoökologische Beobachtungen und Studien an der subarktischen und alpinen Waldgrenze in vergleichender Sicht (nördliches Fennoskandien/Zentralalpen). Erdwissenschaftliche Forschung VIII.

— 1978. Die bodennahen Winde in den Hochlagen der Indian Peaks Section (Colorado Front Range). Münstersche Geographische Arbeiten 3: 5–47.

— 1980. The influence of wind on tree physiognomy at the upper timberline in the Colorado Front Range. New Zealand Forest Service, Technical Paper 70: 247–261.

— 1981. What does the term "krummholz" really mean? Observations with special reference to the Alps and the Colorado Front Range. Mountain Research and Development 1/3–4: 253–260.

— 1984. Climatic stress influencing the physiognomy of trees at the polar and mountain timberline. Eidgenössische Anstalt für das forstliche Versuchswesen, Berichte 270: 31–40.

— 1985. Die klimatische Waldgrenze – Linie oder Übergangssaum (Ökoton)? – Ein Diskussionsbeitrag unter besonderer Berücksichtigung der Waldgrenzen in den mittleren und hohen Breiten der Nordhalbkugel. Erdkunde 39 (4): 271–285.

— 1987 a. Der Baumwuchs als klimaökologischer Faktor an der oberen Waldgrenze. Münstersche Geographische Arbeiten 27: 145–151.

— 1987 b. Ökologische Untersuchungen über den Ausaperungsverlauf und einige Folgewirkungen in "ribbon forests" an der oberen Waldgrenze in der Front Range, Colorado. Phytocoenologia 15 (3): 373–396.

— 1989. Ökologie und Geographie der oberen Waldgrenze. Berichte der Reinhold Tüxen-Gesellschaft 1: 14–45.

— 1993. Der Einfluß der generativen und vegetativen Verjüngung auf das Verbreitungsbild der Bäume und die ökologische Dynamik im Waldgrenzbereich – Beobachtungen und Untersuchungen in Hochgebirgen Nordamerikas und den Alpen. Geoökodynamik 14: 153–182.

— 1994 a. Introduction to the upper Engadine and its forest. USDA Forest Service, Intermountain Research Station, General Technical Report, Report INT-GTR 309: 9–17.

— 1994 b. Ecological aspects of climatically-caused timberline fluctuations. Review and outlook. In: Beniston, M.(ed.) Mountain environments in changing climate. London and New York. p. 220–233.

— 1996. Der Wind als landschaftsökologischer Faktor in der subalpinen und alpinen Stufe der Front Range, Colorado. Arbeiten aus dem Institut für Landschaftsökologie 1: 19–45.

— & Broll, G. 1992. The influence of tree islands and microtopography on pedoecological conditions in the forest-alpine tundra ecotone on Niwot Ridge, Colorado Front Range, U.S.A. Arctic and Alpine Research 24 (3): 216–228.

—, Müterthies, A. & Stevens, G. E. 1996. Effektive Verjüngung und Zuwachs der Kiefer (Pinus sylvestris) und Fichte (Picea abies) an ihrer Höhengrenze in Finnisch-Lappland während der letzten 100 Jahre. Arbeiten aus dem Institut für Landschaftsökologie 1: 85–99.

Hustich, I. 1937. Pflanzengeographische Studien im Gebiet der Niederen Fjelde im westlichen Finnischen Lappland. Teil I. Acta Botanicae Fennicae 19.

— 1942. Pflanzengeographische Forschungen und Probleme aus Finnisch-Lappland. Botanikai Közlemények 36 (15): 233–246.

Hutchins, H. E. & Lanner, R. M. 1982. The central role of Clarks Nutcracker in the dispersal and establishment of whitebark pine. Oecologia 55: 192–201.

Ives, J. D. 1973. Studies on high-altitude geoecology of the Colorado Front Range. A review of the research program of the Institute of Arctic and Alpine Research. Arctic and Alpine Research 53 (3, pt. 2): 67–75.

Lanner, R. M. 1982. Adaptions of whitebark pine for seed dispersal by Clarks Nutcracker for regeneration. Arctic and Alpine Research 20 (3): 358–362.

— 1996. Made for each other. A symbiosis of birds and pines. New York and Oxford.

Larcher, W. 1957. Frosttrocknis an der alpinen Waldgrenze und in der alpinen Zwergstrauchheide. Veröffentlichungen des Museums Ferdinadeums 37: 49–81.

— 1963. Zur spätwinterlichen Erschwerung der Wasserbilanz von Holzpflanzen an der Waldgrenze. Berichte des Naturwissenschaftlichen Vereins zu Innsbruck 53: 125–137.

— 1972. Der Wasserhaushalt immergrüner Pflanzen im Winter. Berichte der Deutschen Botanischen Gesellschaft 85: 315–327.

— 1980. Klimastreß im Gebirge – Adaptionstraining und Selektionsfilter für Pflanzen. Rheinische Akademie der Wissenschaften, Vorträge 291: 49–88.

— 1985. Winterstress in high mountains. Eidgenössische Anstalt für das forstliche Versuchswesen, Berichte 270: 11–19.

Marchand, P. J. 1980 Causes of coniferous timberline in the northern Appalachian Mountains. New Zealand Forest Service, Technical Paper 70: 231–246.

— & Chabot, B. F. 1978. Winter water relations of the treeline plant species, New Hampshire. Arctic and Alpine Research 10 (1): 105–116.

Marr, J. W. 1961. Ecosystems of the east slope of the Front Range of Colorado. University of Colorado Studies, Series in Biology 8.

— 1977. The development and movement of tree islands near the upper limit of tree growth in the southern Rocky Mountains. Ecology 58: 1159–1164.

Mattes, H. 1978. Der Tannenhäher im Engadin – Studien zu seiner Ökologie und Funktion im Arvenwald. Münstersche Geographische Arbeiten 2.

— 1985. The role of animals in cembra pine forest regeneration. Eidgenössische Anstalt für das forstliche Versuchswesen, Berichte 270: 197–205.

Noble, D. L. & Alexander, R. R. 1977. Environmental factors affecting natural regeneration of Engelmann spruce in the central Rocky Mountains. Forest Science 23 (4): 420–429.

Ozenda, P. & Borel, J.-L. 1991. Les conséquences possible des changements climatiques dans l'arc alpine. Rapport FUTUTALP 1.

Perkins, T. D., Adams, G. T. & Klein, R. M. 1991. Desiccation or freezing? Mechanisms of winter injury to red spruce foliage. American Journal of Botany 78 (9): 1207–1217.

Platter, W. 1976. Wasserhaushalt, cutikuläres Transpirationsvermögen und Dicke der Cutinschichten einiger Nadelholzarten in verschiedenen Höhenlagen und nach experimenteller Verkürzung der Vegetationsperiode. Dissertation, University of Innsbruck.

Price, L. W. 1978. Mountains of the Pacific Northwest, U.S.A: A study in contrasts. Arctic and Alpine Research 10 (2): 465–478.

Schultze, E. D., Mooney, H. A. & Dunn, E. L. 1967. Wintertime photosynthesis of bristlecone pine (Pinus aristata) in the White Mountains of California. Ecology 48: 1044–1047.

Tomback, D. F. 1977. Foraging strategies of Clark's Nutcracker. The Living Bird 16: 123–161.

— 1982. The behavioral ecology of Clark's Nutcracker: A mutualism hypothesis. Journal of Animal Ecology 51: 451–467.

Tranquillini, W. 1974. Der Einfluß von Seehöhe und Länge der Vegetationszeit auf das cutikuläre Transpirationsvermögen von Fichtensämlingen im Winter. Berichte der Deutschen Botanischen Gesellschaft 87: 175–184.

— 1976. Water relations and alpine timberline. Ecological Studies 19: 473–491.

— 1979. Physiological ecology of the alpine timberline. Ecological Studies 31.

Turner, H. 1958. Maximaltemperaturen oberflächennaher Bodenschichten a der alpinen Waldgrenze. Wetter und Leben 10 (1/2): 11–22.

Ungerson, J. & Scherdin, G. 1968. Jahresgang von Photosynthese und Atmung unter natürlichen Bedingungen von Pinus sylvestris L. an der Nordgrenze in der Subarktis. Flora, Abteilung B 157: 391–434.

Wardle, P. 1965. A comparison of alpine timberlines in New Zealand and North America. New Zealand Journal of Botany 3 (2): 113–125.

— 1968. Engelmann spruce (Picea engelmannii Engel.) at its upper limits on the Front Range, Colorado. Ecology 49: 483–495.

— 1971. An explanation for alpine timberline. New Zealand Journal of Botany 9(3): 371–402.

— 1980. Tree species and growth forms at timberlines in different parts of the world. New Zealand Forest Service, Technical Paper 70: 175–177.

— 1981. Winter desiccation of conifer needles simulated by artificial freezing. Arctic and Alpine Research 13: 419–423.

The relationship of modern pollen deposition to local and regional vegetation in the Pallas area using high accuracy numerical vegetation mapping

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Introduction

In 1974 a pollen monitoring project was started the aim of which was to use annual pollen deposition data (grains cm^{-2} year^{-1}) to establish pollen analogues for the different regional forest types which occur in Finnish Lapland, in order to have a more objective basis for interpreting fossil pollen diagrams. As part of this project a pollen trap (Tauber 1974, 1977) was placed on the summit of Palkaskero and collections were obtained for the years 1974–77 and 1980–81. At the end of this sampling period the monitoring structure was reassessed, the Lapland network enlarged and a modified pollen trap introduced (Hicks and Hyvärinen 1986). The monitoring station for the Pallas-Ounastunturi area was moved from Palkaskero to a lower altitudinal position in a mire near the southern limit of the National Park (Fig. 1). Within the Lapland network this station represents spruce dominated forest (Hicks 1994).

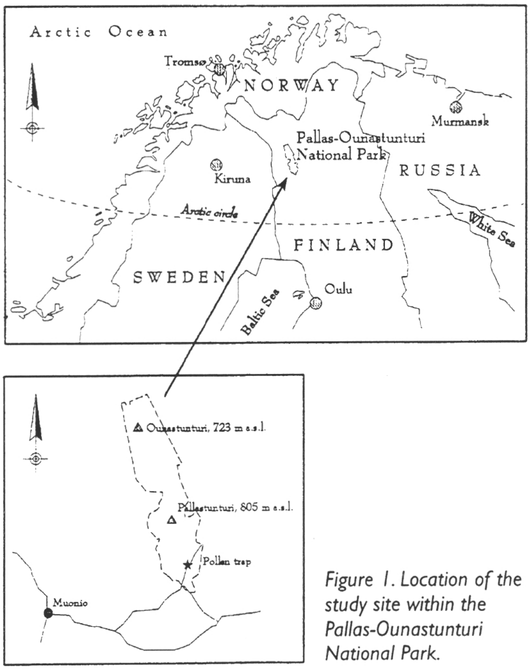

Figure 1. Location of the study site within the Pallas-Ounastunturi National Park.

An essential step in establishing pollen analogues is to relate the annual pollen deposition value to the surrounding vegetation. That is, to determine the size and nature of the catchment area of the sampling site. Since the fossil samples to be interpreted inevitably represent a period of several years, it is necessary to calculate an average modern deposition value over a number of years to obtain a reliable pollen analogue. It has long been known that, due to differences between species in both pollen production and pollen dispersal, there is no simple one-to-one relationship between the amount of a specific pollen type and the number of plants of the species producing it. In addition to this variation in pollen deposition between species it is obvious that there is enormous variation in deposition from year to year for one and the same species. The annual pollen deposition value, therefore, encompasses both an indicative element of the vegetation producing it and a climatic signal relevant to the time of deposition. Something of this complexity is illustrated in Fig. 2.

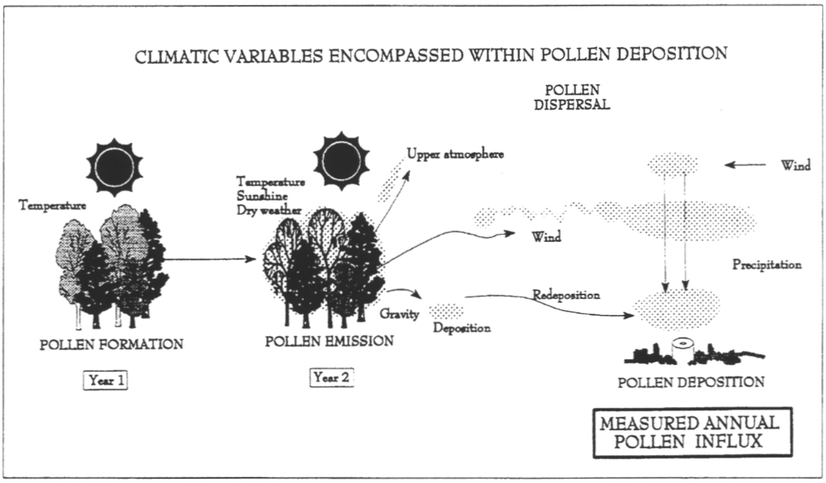

Figure 2. Schematic illustration of the climate factors influencing the pollen which is eventually deposited in the pollen trap.

For the southernmost part of the Pallas-Ounastunturi National Park both annual pollen data and vegetation cover data exist, together with nearby meteorological records, thus enabling a pilot study involving the numerical analysis of pollen deposition / catchment size relationship, plus the possibility of taking into account one of the meteorological parameters (wind). The methods developed in the course of this study will later be applied to the whole Lapland network as part of two international projects, the INQUA working group “European Pollen Monitoring Programme” (EPMP) and the EU project “Forest response to environmental stress at timberlines” (FOREST).

2 Materials and methods

2.1 Study area

The Pallas-Ounastunturi National Park is situated in the north-western part of Finnish Lapland (Fig. 1). A fifty-kilometre long mountain range runs through the park. The highest peaks of the fells reach 800 m a.s.l. and rise over 500 meters above the surrounding areas.

The park lies in the northern boreal vegetation zone. The main vegetation categories are forests, treeless mountain heaths and peatlands. In the lowlands coniferous forests dominate. In the southern part of the park two conifers are represented: Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). In the northern part, however, Norway spruce is almost totally absent since the northern forest limit of this species runs through the park. The forests are usually mixed with pubescent birch (*Betula pubescens*) or mountain birch (*Betula pubescens* subsp. *czerepanovii* (syn. *tortuosa*)). In the southern part there are also old broad-leaved forests, where pubescent birch dominates. The peatlands are mainly located in the lowlands. These are mostly treeless types, but forested mires can be found at the margins of the peatlands and along streams.

Because of the altitudinal variation, the vegetation changes from the coniferous forests in the lowlands to mountain birch forests on the fell summits. Mountain birch usually forms the forest line (appr. 400-500 m a.s.l.), but in the southern part of the park pine and spruce are the forest line species. Between the forests and the treeless mountain tops, there is a belt of scattered trees, the orohemiarctic zone. The tops of the highest fells are usually treeless, and characteristically support dwarf shrubheaths.

2.2 Pollen deposition

Pollen deposition is measured with a modified Tauber trap (Hicks and Hyvärinen 1986) which is located in the centre of an unforested mire in the southernmost part of the park (Fig. 1). The trap is sunk into a *Sphagnum fuscum* tussock such that its opening is level with the surface of the tussock, so that it simulates deposition at the surface of the mire. The trap is emptied annually in September/October, at the end of the flowering season.

In the laboratory the trap contents are first sieved and filtered to remove any macroscopic remains and excess water and then prepared by a standard treatment consisting of heating in 10% KOH followed by acetolysis in a mixture of 9 parts acetic anhydride and 1 part concentrated sulphuric acid. The final preparation is mounted in silicone oil. Tablets containing a known number of *Lycopodium* spores (Stockmarr 1971) are added to each sample at the beginning of the preparation so as to enable the pollen concentration to be calculated. A minimum pollen sum of 500 AP (Arboreal Pollen) is used.

The results presented here are for the years 1984, 1986 and 1988–1996, that is a total of 11 years. The annual pollen influx values (grains cm^{-2} $year^{-1}$) of selected pollen taxa are illustrated in Fig. 3 together with the average influx value for this 11 year period. The results are also expressed as percentages of total pollen (excluding spores) in Table 1. Here only the averages for the 11 years are given. More detailed data of the pollen representation for this sampling station, but for a shorter period of time, are given in Hicks (1994).

2.3 The vegetation map and its analysis

The Finnish Forest Research Institute carried out a vegetation mapping project in the park in 1987 and 1992 (Eeronheimo et al. 1992, Eeronheimo and Sippola 1992). Mapping was based on black and white aerial photographs at a scale of 1:10 000 which were used as an information-rich base map to help delineate vegetation compartments. The vegetation classification and the final definition of the boundaries were made in the field. In addition to the vegetation types other information was also recorded. For example, with respect to the tree layer in the forests, the canopy coverage of each tree species and the height of the dominant tree layer was estimated and the basal area of the tree layer was measured. Using black and white aerial photographs it is difficult to distinguish broad-leaved trees from conifers, and this has some effect on the reliability of the delineation of compartments within the forests. The data from the vegetation mapping project are stored in geographic information system (Eeronheimo et al. 1992, Eeronheimo 1993). This enables the data to be used in a variety of ways. They can be combined with other data and can be reproduced and extracted for different purposes.

The numerical database was processed by MapInfo, which allows coverage data and attribute data to be matched simultaneously. The numerical vegetation mapping used for the assessment of vegetation consists of numerous variables attached to each field of the database. The variables considered here were vegetation type, mean tree height (m), tree ground coverage (m^{-2} ha^{-1}) and canopy cover % for each tree species. The canopy cover represents the amount of each tree species in each field.

2.4 The delimitation of the catchment

As is evident from Fig. 2, the pollen ultimately deposited in the pollen trap can potentially come from a variety of sources. It can be directly deposited from the surrounding vegetation by gravity or it may have been deposited close to its source and then refloated by wind action to be redeposited in the trap. In both of these cases the source is relatively local. However some pollen has travelled much further, being brought by the wind from the surrounding region or even further afield. Rain has the effect of cleaning the air and bringing suspended pollen down to the ground but this pollen may be local or regional in origin or, if in the upper layers of the atmosphere, may have been transported over very great distances (Tauber 1977). In order to match the pollen assemblage in the trap with the surrounding vegetation in a way which is significant for interpreting fossil pollen assemblages it is necessary to experiment with different shapes and sizes of catchment area. Obviously it is desirable to separate out the local and regional pollen from the long distance transported pollen and to have some idea of the relative proportions of these sources in the final assemblage. Wind, as an agent of long distance transport, will be most significant at the time of year when flowering is taking place. Some aspects of this phenomenon have been analysed with respect to birch at Kevo (Hicks et al. 1994) where it was demonstrated that, on occasions, the long distance transported part of the pollen assemblage can form up to 20% of the annual deposition.

Considering these factors, two sizes of circular catchment were experimented with, one 300 m in diameter which was considered in terms of local vegetation, and the other 1000 m in diameter to provide a more regional aspect. These were then changed in shape to take into account the prevailing wind direction and wind speed (Fig. 4), (see section 5 following). Vegetation analyses are, therefore, presented for four different catchments (Table 1).

2.5 Aeolian data and their application

The aeolian data for the Muonio recording station located 17 km southwest of the study area were obtained from the Finnish Meteorological Institute (FMI). Only data for the months of May, June and July were used as these are the normal flowering months for the tree species present in the park. The data consist of percentage wind direction divided into eight cardinal points, mean monthly wind speed (m/s), and calm.

In order to take both the wind speed and wind direction into account a wind rose was constructed in which the percentage wind direction was weighted by the mean wind speed. This is expressed by the following equation:

$$W\%d = \%d \cdot v$$

In this $W\%d$ is the weighted percentage wind direction, $\%d$ is the percentage wind direction and v is the wind speed (m/s). If the wind direction alone is used in constructing the wind rose and the catchment, then the influence of strong winds is neglected. The stronger the wind speed, the further the pollen is likely to be transported before it is deposited. The weighted percentage wind speed intensifies the southwestern and northern wind directions since these are normally the strongest. The weighting of the percentage wind direction, however, does not really change the relative proportions of the winds because the trend of the curves % wind direction and weighted % wind direction is similar and has a positive correlation of 0.97713.

A weighted wind rose was determined for the whole monitoring period 1986–1996 and then separately for two years of abundant pollen deposition, 1986 and 1989, and for one of low pollen deposition, 1990 (see below).

Since the pollen trap is located in a valley oriented in a south-north direction, easterly winds are effectively blocked. Consequently, the importance of northerly and southerly winds is increased. Topographic features were not taken into account in delimiting the shape of the catchment, however, as no useful method could be devised. The wind rose was already stretched in a south-north direction on the basis of the aeolian data.

3 Results

3.1 Annual pollen deposition

The first thing which is evident from the diagram (Fig. 3) is the great annual variation in the amount of pollen being deposited. Whereas for over half of the monitoring period the total pollen deposition is between 3000 and 4000 grains cm^2 year^{-1}, in 1986 and 1989 values were dramatically higher, over 8000 and 11000 respectively, while in 1988 and 1990 annual deposition was scarcely more than 2000 cm^{-2} year^{-1}. This variation is related to climate although the precise relationship is still unknown (Hicks et al. 1994, Hicks in press). Only the wind parameter is considered here.

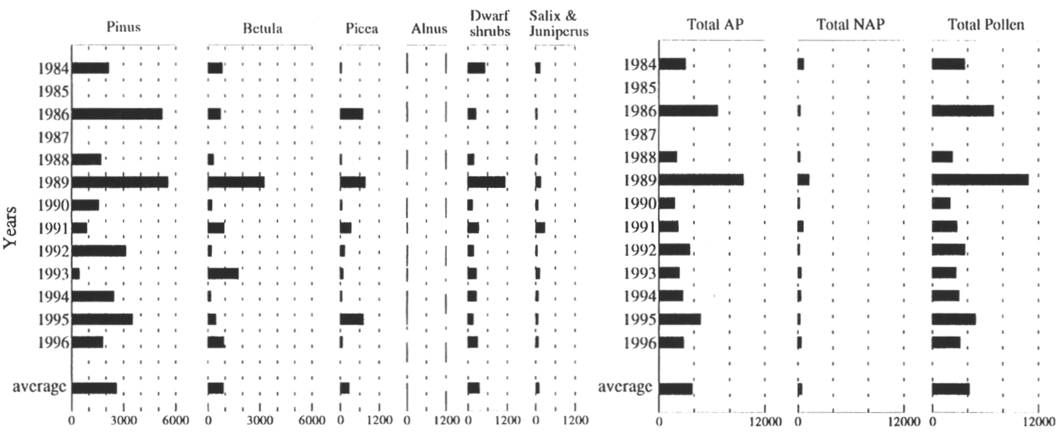

Figure 3. Annual pollen deposition grains per square cm, Pallastunturi 1984–1996

The pollen deposition of *Picea*, the most characteristic tree in the park has exceeded values of 500 grains cm^{-2} year^{-1} in only three out of the 11 years monitored, 1986, 1989 and 1995. Observations of flowering which have been carried out in the park (Hokkanen, pers. comm.) have concentrated on the female flowers rather than the male ones so it is not possible to use this as a control as to whether the higher pollen deposition values illustrated here reflect specifically local male flowering or pollen which has been transported to the trap from outside the region. There is a good correlation between local female flowering and pollen deposition for all years except 1988 and 1994. In both of these the number of female flowers was good (30 and 46 per tree respectively) but the pollen deposition was low. There is an observation, however, that for 1994 the number of cones was very low — obviously the flowers remained unfertilized. This may indicate that the spruce pollen being deposited is mainly from the surrounding region rather than from further south. Indeed *Picea* pollen is sufficiently large and heavy that it is not normally transported over great distances in any quantity.

The results of the 11 years illustrated are averaged to produce a figure which can be more realistically compared both the surrounding vegetation cover. This average is illustrated as the lowermost bar in Fig. 3. Pollen deposition is dominated by arboreal pollen (more than 80% of total pollen). This, confirms (Tauber 1977) that the trapped pollen reflects the more regional vegetation type and not just the immediate local surroundings (mature trees are all 25–30 m distant). In the visible surroundings of the trap the three tree species *Pinus, Picea* and *Betula* are equally represented whereas in the pollen assemblage *Pinus* is by far the most abundant (69% of the total arboreal pollen) and *Picea* the least (only 6% of the total arboreal pollen). The low values for *Picea* are due to its very low pollen production, a feature which is known from other sources (Hicks 1986).

3.2 Distribution of vegetation types and species within the catchment

All the vegetation types within the four catchment areas delimited were either forest or mire, with the exception of the roads to Pallasjärvi and Pallastunturi (Fig. 4). Since one factor of interest is the relative amounts of forested versus unforested land, the road and the mire classes were combined. The typical forest types delimited were moist spruce/birch forest HMT (*Hylocomium - Myrtillus* type) and dry spruce/birch forest EMT (*Empetrum - Myrtillus* type). Typical mean tree height was between 12–17 meters and tree ground coverage 17 m^{-2} ha^{-1}. Typical canopy cover percentages in the mapped data were: *Picea* 20 %, *Betula* 30 %, *Pinus* 1 %, *Populus* 5 % and *Salix* 1 %.

The species representation within the catchment areas was assessed by transforming the canopy cover percentage given on the map for each tree species into hectares. The difference is seen by comparing the figure given above with those in Table 1. Although the percentage canopy cover for *Betula* is 30 %, the percentage catchment cover in ha is only 20 % because birches have a widespreading canopy relative to their abundance in the vegetation. *Picea* shows the opposite situation, the subspecies *obovata*, having a typical candle form, has a smaller percentage canopy cover than its percentage vegetation cover in the catchment.

Since there were no quantitative data for the mire vegetation fields, one 'unforested' class combining both mire and road was formed. In this way the different species in each catchment area were allocated vegetation cover percentages (Table 1). The percentage cover for *Pinus* as calculated from the digitised map is remarkably low, only 1 % in the 7.1 ha catchment. When viewed from the pollen trap the immediate surrounding forest is seen to contain a much higher proportion of pine and there are also several pines growing at the margin of the mire. The

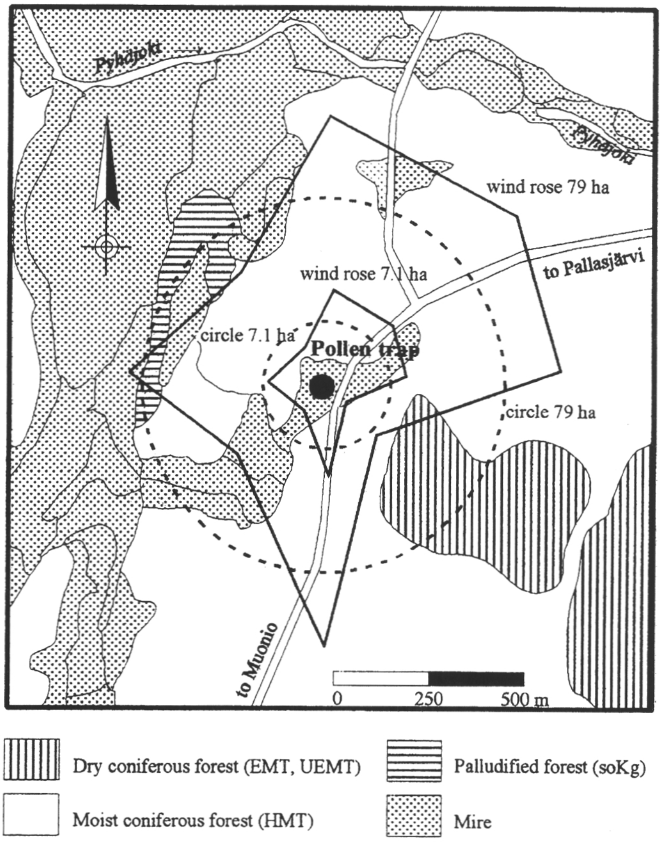

Figure 4. Vegetation map of the area immediately surrounding the pollen trap with four different catchment areas delimited.

Table 1. Percentage vegetation cover in each catchment area compared with average pollen influx and average percentage representation of pollen types.

Average pollen inglux $cm^{-2}year^{-1}$	*Vegetation class*	*circle 7.1 ha*	*rose 7.1 ha*	*circle 79.0 ha*	*rose 79.0 ha*	*Average pollen percentages*
640	Mirc&road	42	45	25	19	14
2580	Pinus	1	1	3	2	57
360	Picea	31	29	22	26	8
880	Betula	20	20	43	44	19
5	Populus	1	1	5	7	+
25	Salix	5	4	2	2	1
3920	Total forest	58	65	75	81	86
4560	Total	100	100	100	100	100

vegetation classification used in the mapping into HMT and EMT forest types possibly underemphasises the presence of individual scattered pine trees.

4 Discussion and conclusions

The relationship between the percentages of forested /unforested land and the percentages of arboreal/non-arboreal pollen is illustrated in Fig. 5. From this it is evident that for this rather coarse measure the best fit is seen with the 79.0 ha windrose shaped catchment. For the smaller catchment areas the unforested areas are over represented relative to the pollen and the forested areas underrepresented.

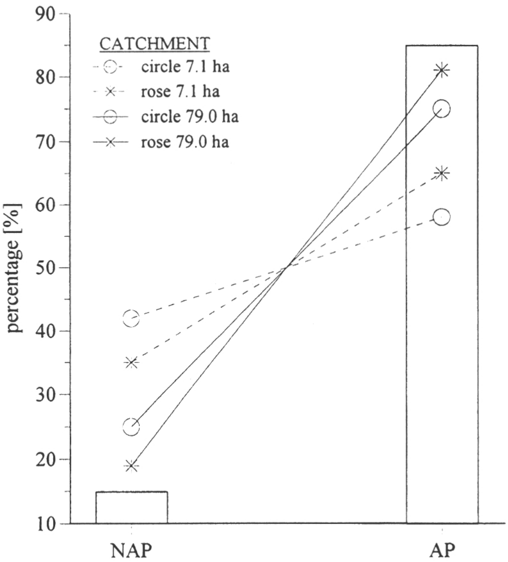

Figure 5. Relationship between percentage vegetation cover for four catchment areas and NAP/AP percentage in the pollen deposition at the centre of these.

The breakdown of the forested area into individual tree species is given in Table 1 where the percentage vegetation cover (in ha) in each of the catchments is compared with both percentage values and influx values for the relevant pollen taxa or groups of taxa. The pollen taxa included in the mire and road class comprise shrubs (*Juniperus, Salix*), dwarf shrubs (*Empetrum, Vaccinium, Calluna*) and selected herbs (*e.g. Poaceae, Cyperaceae, and Filipendula,* the latter reflecting anthropogenic influence along the road sides), while the forest category includes the forest herbs, in addition to the tree species.

There is no clear correlation between pollen percentages and vegetation cover percentages of the trees. *Populus* and *Betula* pollen percentages would seem to be reflect the vegetation percentages from the 7.1 ha catchments while *Salix* pollen percentages are closer to the vegetation percentages for this species in the 79.0 ha catchments. There is no correlation at all for the two main coniferous trees *Pinus* and *Picea.* This can primarily be explained by their very different pollen production and pollen dispersal properties. *Pinus* pollen is produced in abundance and distributed widely and easily while the pollen production of *Picea* is low and its distribution more restricted. An additional explanation is the possible underemphasis in the mapping of the amount of pine actually present in the forest, as mentioned above.

Since pollen percentage values of any one taxon are dependent on the abundance of the other pollen taxa present in an assemblage it is desirable to consider pollen deposition which is an independent variable. The pollen deposition value for *Picea* of 360 grains cm^{-2} $year^{-1}$ is typical of forests in which spruce is present or even dominant (Hicks 1994), although it should be noted that the values presented in Hicks 1994 for spruce dominated forest include the results from this same Pallas trap! The deposition value for *Pinus* of 2580 grains cm^{-2} $year^{-1}$, on the other hand is more characteristic of pine dominated forests. Pollen from the pines growing at the edge of the mire may be particularly well represented in the Pallas trap because of their proximity and the absence of any filtering vegetation (Tauber 1977). At any rate the figure is higher than expected from monitoring results elsewhere in Lapland.

There may be other aspects involved, however. Reference was made earlier to the great annual variation in pollen influx which is in some way related to climate. Fig. 3 shows that 1986 and 1989 were very high pollen deposition years whereas 1990 was a particularly low pollen deposition year. In both 1986 and 1989 a high proportion of this pollen was *Pinus*. If the weighted wind directions are calculated separately for these abnormal years then an interesting fact is observed (Fig. 6).The wind direction in May, June and July differed strongly between 1986, 1989, and 1990. In 1989 for example, southerly winds (SE, S SW) comprised 45 % of the winds, during the summer but only 28 % in 1990. Northerly winds (NW, N, NE), on the contrary, were infrequent in 1989 (30 %) but numerous (50 %) in 1990. When analysing monthly values for 1989, it is seen that those from the south were exceptional, not only in percentage terms but also in terms of wind speed, which was 4 m/s. The year 1990, however, was a relatively normal year from the point of view of wind direction, but winds from the north were more numerous than usual. This incidence of southerly winds during the time of the year when flowering is taking place can be interpreted in two ways. Either these winds are transporting large quantities of pollen from areas further south, or the warm southerly winds provide excellent conditions for local pollen release into the atmosphere. When northerly winds dominate conditions are least favourable for pollen emission and it is also less probable that pollen would be available in areas further to the north for transportation. Some idea of which of these alternatives is the more likely can be gained by looking at the situation with respect to *Betula* in the Kevo area (Hicks *et al,* 1994). Here it was observed that although warm conditions at the beginning of the summer favour pollen emission the actual quantity of pollen ready inside the plant for emission is determined primarily by the temperature at the end of the previous summer (Fig. 2). In this case the alternative of pollen being transported from further south by winds seems the more plausible.

When attempting to relate pollen values to different sizes and shapes of catchment area, therefore, it may be necessary to consider only those years with evenly distributed wind directions during the flowering period and omit obviously aberrant years. The average pollen deposition values presented here were recalculated with the years 1986 and 1989 omitted. This, in fact, makes no difference at all to the percentage representation. This is comforting when considering that fossil pollen assemblages usually represent averages of some tens of years and there is no way of separating out aberrant years in this fossil situation. The average deposition values are naturally reduced but all still remain within the range delimited so far for spruce dominated forests with a varying admixture of *Pinus.* This indicates that the high *Pinus* deposition values are characteristic of this type of spruce forest even if it is not possible to match them with pine vegetation values within the same region.

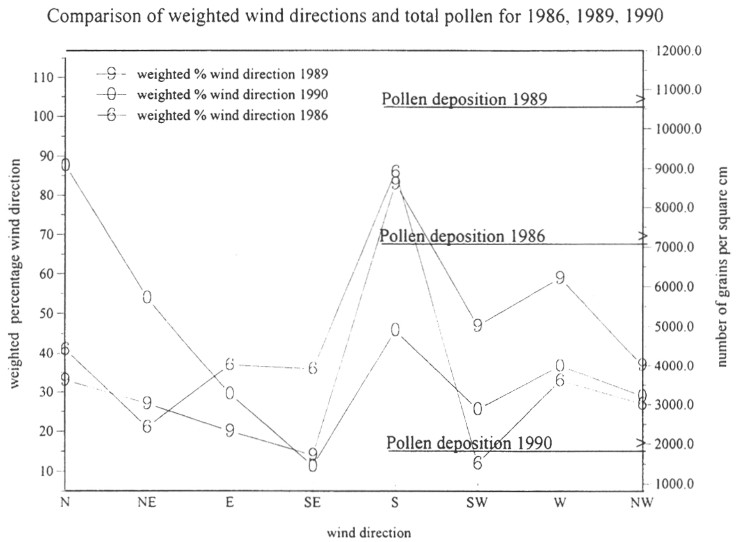

Figure 6. Weighted wind direction for the months of May, June and July for the years 1986, 1989 and 1990 together with the total pollen deposition for these years.

The results presented here are far too few to enable any far reaching conclusions to be drawn. As emphasised in the introduction this is a pilot project to explore both the use of high accuracy numerical mapping in investigating different possible catchment areas and to consider the role of wind in overall pollen deposition. Both of these aspects will be developed using a larger data set in the EPMP and FOREST projects.

Acknowledgments

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References

Eeronheimo, H. 1993. Paikkatietojärjestelmien käyttö luonnonsuojelualueiden peruselvityksissä – esimerkkinä Pallas-Ounastunturin kasvillisuuskartoitus. In Nikula, A., A. Ritari & M.-L. Lahti (eds.): Paikkatiedon ja satelliittikuvainformaation käyttö metsäntutkimuksessa. Tutkimuspäivä Rovaniemellä 1993. Metsäntutkimuslaitoksen tiedonantoja 479:42–51.

— & Sippola, A-L. 1992. Pallas-Ounastunturin kansallispuiston numeerinen kasvillisuuskartta. In: Nikula, A., Varmola, M. & Lahti, M-L. (eds.). Metsäntutkimuspäivä Rovaniemellä 1992. Metsäntutkimuslaitoksen tiedonantoja 437:102–111.

—, Sippola, A-L. & Virtanen, R. 1992. Vegetation mapping and its possibilities as reference material for remote sensing interpretations in the Pallas-Ounastunturi National Park, Northern Finland. Abstracts of 2nd Circumpolar Symposium on Remote Sensing of Arctic Environments, Tromsø, 4-6 May 1992. Akvaplan Niva, FORUT, Tromsø Satellite Station, Universitet i Tromsø. pp. 45–46.

Hicks, S. 1986. Modern pollen deposition records from Kuusamo, Finland. II. Establishment of pollen: vegetation analogues. Grana 25: 183–204.

— 1994. Present and past records of Lapland forests. Review of Palaeobotany and Palynology 82: 17–35.

— The feasibility of using pollen deposition data as climatic indices. Paläoklimaforschung.

— & Hyvärinen, V.-P. 1986. Sampling modern pollen deposition by means of "Tauber traps": some considerations. Pollen et Spores 28: 219–242.

—, Helander, M. & Heino, S. 1994. Birch pollen production, transport and deposition for the period 1984–1993 at Kevo, northernmost Finland. Aerobiologia 10: 183-191.

Stockmarr, J. 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13: 612–621.

Tauber, H. 1974. A static non-overload pollen collector. New Phytologist 73: 359–369.

— 1977. Investigation of aerial pollen transport in a forested areas. Dansk Botanisk Arkiv 32: 1–121.

The rodent project at Pallasjärvi

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Introduction

The Pallasjärvi area in the southern part of the Pallas-Ounastunturi National Park has been a core place for a most intensive rodent research since 1970. There are several reasons why this area in particular is so suitable for intensive long-term ecological research on small rodents, voles and lemmings; these have traditionally been called *microtine rodents* although in accordance with the present taxonomy the phrase *arvicoline rodents* is more appropriate. The population cycles of voles and lemmings have been a very characteristic feature in northern Fennoscandia. These cycles are, in turn, reflected in many other componenets of northern nature, like small game and vegetation. The very special feature of the Pallas rodent assemblage is the high number of syntopic species. The rodent fauna includes three species of *Clethrionomys* (*C. glareolus, C. rutilus* and *C. rufocanus*), two *Microtus* (*M. agrestis* and *M. oeconomus*), two lemmings (*Lemmus lemmus* and *Myopus schisticolor*) and the water vole (*Arvicola terrestris*). These species have, however, different habitat characteristics and diets. In addition, the small mammal fauna consists of four species of *Sorex* shrews (*S. araneus, S. caecutiens, S. minutus* and *S. minitissimus*) and the water shrew (*Neomys fodiens*). The high number of species allows for studying dynamical processes both at the community and population level, in other words, it is possible to differentiate between the factors affecting simultaneously the whole rodent assemblage or only populations of single species (see Fig. 1). Basically this is the difference between extrinsic vs. intrinsic population regulation, i.e. predation, food and diseases against social stress and behavioral mechanisms (self regulation).

The high number of rodent species is partly a result of the encounter of northern and southern faunal elements, but, as we have suggested, it may be partly facilitated by the pronounced population cycles of the rodent species (Henttonen and Hansson 1984, Hanski and Henttonen 1996). The habitats selection of many of these rodent species overlap, and interspecific competition at least for space during the population peaks is a common phenonmenon (Henttonen et al. 1977, Henttonen 1980, Henttonen and Hansson 1984, Jortikka 1990, Hanski and Henttonen 1996). The deep population crashes affecting all species could be one factor promoting species coexistence.

There are also some simple logistic reasons for the superiority of Pallas as a research area. The protected habitats in the National Park and managed ones in the Pallasjärvi Forest Research Area are side by side. This offers an interesting comparison of virgin and man-made habitats. And most of all, a protected environment like that in a national park is a necessity for long-term ecological research. In spite of this, in the the southern part of the park, around the Pallasjärvi area, the network of some roads allows for meaningful distribution of both long-term monitoring as well as shorter-term experimental grids. Last but not least, the Pallasjärvi field station of the Finnish Forest Research Institute, at one of the most beautiful sceneries in Finland, has provided the necessary accommodation.

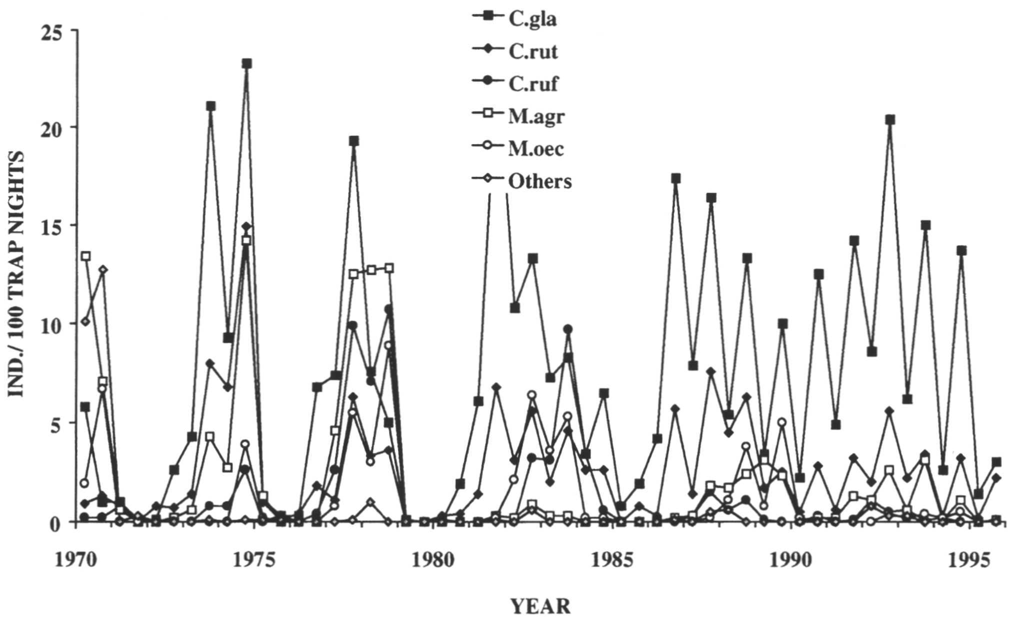

Figure 1. The populations fluctuations of voles and lemmings at Pallasjärvi. Curves are based on spring and autumn snap trappings. Density indices for clethrionomys are from old taiga forests, and those for microtus and others from open habitants (peatlands and clear-cuts). Full name of the species are in the introduction.

2 Basics of the methods

The basic monitoring on three main habitats (old taiga forests, bogs and mires, and clear cuts) is done with snap trapping on permanent sites twice a year (Fig. 1). 30 small quadrats (grids of 15 x 15 m with three snap traps at each corner) on each of the main habitats have been used. Trappings have been done immediately after the snow melt at the turn of May and June, and again in September. The main purpose of these basic monitoring trappings has been to describe the general features of the population dynamic patterns on a larger area, to obtain estimates of population densities on the main habitats, to collect data on demographic and reproductive parameters, as well as material for parasite studies.

Intensive live-trapping studies have been used to follow the populations of individually marked animals. Depending on the purpose of the specific study, a variable number of study grids varying in size from 1 to 4.5 ha have been in use. Depending on the number of replicates, a 10 x 10m or 15 x 15m grid pattern has been marked on the study site in the field. Thus, the number of live traps per site has usually been 80–130. The trapping routine and the number of trap checkings per trapping period has also depended on the number of replicated sites. Of course, within a specific experiment or program the protocol has been permanent.

The live trapping studies have had (at least) the following purposes:

1. To give real density values in comparison to estimates obtained with snap trappings. Live trappings are much more laborous to do than snap trappings, and therefore these kinds of intensive data can be obtained only in restricted sites. As a contrast, with snap trappings larger areas can be covered, but snap trappings give only indices. Combining these two approaches is fruitful (Henttonen et al. 1987, Hanski et al. 1984).
2. In experiments with supplemental food, the monitoring of real densities is necessary. Also, the performance of individual animals in relation to treatment gives valuable information. The purpose of supplemental feeding is to study the role of food in the population dynamics of rodents. The main finding is that extra food usually increases the densities at a moment but it does not affect the long-term dynamics (Henttonen et al. 1987, Laakkonen 1990).
3. As told, interspecific competition among the rodent species is common. This is especially so between the breeding individuals of *Clethrionomys* species. Breeding females of *Clethrionomys* species have exclusive territories also between the species, and this is directly related to the space available to a species in accordance with the competitive interspecific hierarchy (Henttonen et al. 1977, Henttonen and Hansson 1984, Jortikka 1990, Hanski and Henttonen 1996).
4. We have studied experimentally e.g. whether helminth parasites can affect the survival and dynamics of the bank vole *(C. glareolus)* by medicating voles in the experimental populations in the field. Also in these experiments individual performance and worm burden (measured by counting the worm eggs in the feces of individual voles) had to be monitored.

In addition to rodent and parasite monitoring, we have followed the abundance of small mustelids (least weasels *Mustela nivalis* and stoats *M. erminea*). In summer time we have used live trapping and in winter mainly snow tracking (Henttonen et al. 1987, Oksanen and Henttonen 1996).

3 Some basic conclusions on microtine cycles at Pallasjärvi

The very characteristic feature of the rodent cycles in northern Fennoscandia is (or at least has been) the synchronous deep crash in all species. This is the reason why emphasize the community approach in the research of rodent cycles. These synchronous crashes cannot be explained by intrinsic factors alone. Of course it is possible that the population increase of rodents is first slown down by social factors, but this does not mean that these same factors cause the crash. Why would all species commit a suicide together? The only reasonable explanation for the synchronous crashes is a common extrinsic factor, and the most probable factor is the predation by small mustelids. This is further corroborated by other field (work by Korpimäki and Norrdahl; see references in Hanski et al. 1993) and theoretical studies (Hanski et al. 1993).

Some other features in the Pallasjärvi data set speak for community approach, too. Because the abundances of species change from cycle to another (e.g. 1970–1983), very different densities of a species during successive cyclic peaks normally lead to similar total crashes. Furthermore, the second high density year during the peak phase (like in 1970, 1974, 1978, 1982) does not automatically lead to crash as found during the extended peak in 1983. In other words, direct density-dependent intrinsic mechanism does not alone cause the cycle (Henttonen et al. 1987). This is futher supported by the data from the last ten years when the pattern of rodent dynamics at Pallasjärvi (and in Lapland generally) has changed. Even though the bank voles now regularly reach the same autumn densities as they earlier did only during the cyclic peak phases, their dynamics remain multiannually rather stable.

In mid 1980's and at the turn of 1980's and 1990's, a drastic change in the dynamics of small rodents has occurred in northern Fennoscandia. The large scale geographic synchrony broke down, and the dynamics of some species turned much more stable (e.g. *C. glareolus*) while some earlier abundant species have become much less common (e.g. *C. rufocanus* and *M. agrestis*). This change was first observed at Pallasjärvi where the exceptional cycle in 1981–85 was paid special attention to (Henttonen et al 1987). Since then this "Pallasjärvi syndrome" has occurred elsewehere in Lapland and in northern Sweden. Henttonen (1987) and Henttonen et al. (1987) suggested that the simultaneous long-term phase of low densities in *M. agrestis*, the favored foor item of least weasels, resulted in poor reproduction in weasels, and the change in weasel abundance and dynamics caused the change in rodent dynamics. Hanski and Henttonen (1996) and Oksanen and Henttonen (1996) have discussed the problem further. Models with a specialist predator and two competing prey species, the dominant of which is the preferred prey, yield patterns similar to those observed at Pallasjärvi (Hanski and Henttonen 1996).

It remains to be seen how long this "exceptional" phase in Lapland will last. However, the change in dynamics have several consequences. First of all, the high spring densities characterizing cyclic rodent peaks are now missing. The breeding of many predators and and birds of prey depends crucially on the high peak spring densities of rodents. It is probable that the numbers of some birds of prey in Lapland have already declined. Another consequence of missing cyclic peak densities and subsequent heavy grazing pulses may be that the bottom and field layer on habitats favored by voles and lemmings may change; species abundances may change if the most preferred plant species escape heavy grazing for long periods.

4 Long-term dynamics of the Norwegian lemming *(Lemmus lemmus)*

The Pallastunturi mountain group, including Lommol- and Keimiötunturi, is the southernmost area in western Lapland where *Lemmus* is permanently found, and therefore *Lemmus* is a very interesting part of the local rodent fauna. It should be remembered that the dynamics of *Lemmus lemmus* differ drastically between south-central and northern Fennoscandia. Instead of the regular 3–4 year cycles found in the southern Norway, the pattern is much more irregular in Lapland. There the lemming peaks coincide with those of voles, but there are not lemming peaks during every vole peak. In Fig. 1, the others primarily refer to lemmings. Either lemmings totally miss some of the vole peaks, or the increase in lemmings is so minor that we do not observe it. Furthermore, lemming peaks occur more often in the northern mountain areas than further south in the boreal zone.

The great lemming outbreaks, with highly visible long-distance movements south into the boreal taiga, show a surprisingly regular long-term pattern (Henttonen and Kaikusalo 1993). These great lemming years, extending even south of the Arctic Circle in Finnish Lapland, have occurred 1970, 1938 (not quite to the AC), 1902–03, 1872, 1840, 1810, 1787, 1755. After the intensive movements into the taiga, lemmings seem to survive there for some time. After the 1938 movement local lemming peaks and movements were observed, especially in southern and south-eastern Lapland, in 1942 and 1946, synchronously with the vole peaks. After early 1950's, lemmings were not observed in southern and Central Lapland until with the advancing movement in autumn 1970. After the 1970 large-scale movements, local lemming peaks were again observed in rhythm with the vole dynamics in 1974, 1978, and 1982. For example in forests and mires at Pallasjärvi, lemmings were found in 1974 and 1978 (Fig. 1). Since then no lemmings movements have been seen in southern and central Lapland. If the long-term pattern is maintained, the next great outbreak should occur early in next decade.

The periodic disappearance of lemmings from the taiga has been explained by at least three ways (Henttonen and Kaikusalo 1993: 1) winter food supply in taiga is not satisfactory to lemmings, 2) large and clumsy lemmings are more sensitive to predation than sympatric voles, and 3) a parasite (like *Babesia*) or pathogens occurring in other rodents in taiga could be harmful to lemmings. The present low-density period can be considered normal within the range of lemming dynamics in northern Fennoscandia. However, if there is no lemming peak within the next 10 years, then we could start to suspect that the vole syndrome (disappearance of vole cycles in northern Fennoscandia) has been transmitted to the lemmings.

5 Parasitological research

Since the late 1970's intensive research on parasites of rodents and shrews has been going on at Pallasjärvi with Voitto Haukisalmi. This work started by faunistical and taxonomical analyses, but one of the main purposes has been to monitor the long-term dynamics of vole helminths (intestinal worms) in their fluctuating host populations. The recent change in the vole dynamics has introduced an additional interesting element into the parasite dynamics. The interacting role of moisture and previous host density seem to be the critical factors (Haukisalmi and Henttonen 1990). The role of rainfall is understandable because all the helminths have stages in their life cycle that have to survive outside of the host. We have not been able to demonstrate that helminths affect the population dynamics of rodents.

From the original work on the impacts of parasites on rodents the parasite research has expanded to analyze various other aspects in the population dynamics of helminths. These include interspecific relation of helminth species in a very restricted space, the intestine, and the general dynamic strategies of so-called common and rare (core and satellite) helminth species. The last mentioned aspect has a strong connection to biodiversity problems: a great proportion of existing species are parasites, and therefore understanding of factors affecting the abundance and dynamics of parasites is of great importance.

Literature

So far, the material of Pallasjärvi rodent project has been used in about 50 refereed publications as well as in a number of Finnish articles, congress abstracts and academic theses – altogether some 150 items. In the following, a list of refereed publications and theses are given. Some earlier publications dealing with rodents of the area have been cited in Henttonen et al. (1987).

Hannunen, S. 1993. *Eimeria*-suvun kokkidien dynamiikka lapinmyyräpopulaatiossa. (The dynamics of *Eimeria* coccidians in a root vole *Microtus oeconomus* population). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 42 p.

Hanski, I. & Henttonen, H. 1996. Predation on competing species:a simple explanation of complex patterns. J. Anim. Ecol. 65: 220–232.

—, Hansson, L. & Henttonen, H. 1991. Specialist predators, generalist predators, and the microtine rodent cycle. J. Anim. Ecol. 69: 353–367.

—, Henttonen, H. & Hansson, L. 1993. Temporal variability of population density in microtine rodents: a reply to Xia and Boonstra. American Naturalist 144: 329–342.

—, Turchin, P., Korpimäki, E. & Henttonen, H. 1993. Population oscillations of boreal rodents: regulation by mustelid predators leads to chaos. Nature 364: 232–235.

Hansson, L. & Henttonen, H. 1985. Gradients in cyclicity of small rodents: importance of latitude and snow cover. Oecologia (Berlin) 67: 394–402.

— & Henttonen, H. 1985. Regional differences in cyclicity and reproduction in *Clethrionomys* spp.: Are they related? Ann. Zool. Fennici 22: 277–288.

— & Henttonen, H. 1988. Rodent dynamics as community processes. Trends Ecol. Evol. 3: 195–200.

Haukisalmi, V. 1985. Matomaisten sisäloisten yhteisörakenteesta ja populaatiodynamiikasta syklisissä myyräpopulaatioissa. (Community structure and population dynamics of helminths in cyclic vole populations) M.Sc. Thesis, Dept Zool., Univ. Helsinki, 64 p.

— 1986. Frequency distributions of helminths in microtine rodents in Finnish Lapland. – Ann. Zool. Fennici 23: 141–150.

— 1988. Sisäloisten populaatiodynamiikka syklisissä myyräpopulaatioissa. (Helminth dynamics in cyclic vole populations). Phil. Lic. Thesis, Dept. Zool., Univ. Helsinki, 19 p. + 3 publ.

— 1989. Intestinal helminth communities of *Sorex* shrews in Finland. Ann. Zool. Fennici 26: 401–409.

— 1991. Commonnes and rarity in parasitic helminths of voles. Dept. Zool., Univ. Helsinki, 10p. + 5 publ.

— & Henttonen, H. 1990. The impact of climatic factors and host density on the long-term population dynamics of vole helminths. Oecologia (Berlin) 83: 309-315.

— & Henttonen, H. 1993. Co-existence in helminths of the bank vole *Clethrionomys glareolus*. I. Patterns of co-occurrence. J. Anim. Ecol. 62: 221–229.

— & Henttonen, H. 1993. Co-existence in helminths of the bank vole *Clethrionomys glareolus*. II. Intestinal distributions and interspecific interactions. J. Anim. Ecol. 62: 230–238.

— & Henttonen, H. 1993. Population dynamics of *Taenia polyacantha* metacestodes in the bank vole *Clethrionomys glareolus*. Ann. Zool. Fennici 30: 81–84.

— & Henttonen, H. 1994. Distribution patterns and coexistence of helminths in *Sorex* shrews. Oecologia (Berlin) 97: 236–242.

— & Tenora. F. 1993. *Catenoteania henttoneni* n. sp. (Cestoda, Catenotaeniidae), a parasite of voles *Clethrionomys glareolus* and *C. rutilus* in Finnish Lapland. Folia Parasitol. 40: 29–33.

—, Henttonen, H. & Mikkonen, T. 1994. Parasitism by gastrointestinal helminths in the shrews *Sorex araneus* and *S. caecutiens*. In: Merritt, J.F., Kirkland, G.L., Jr. and Rose, R.K. (eds), *Advances in the Biology of Soricidae,* Carnegie Mus. Nat. Hist. Spec. Publ. 18: 97–102.

—, Henttonen, H. & Tenora, F. 1987. Parasitism by helminths in the grey-sided vole *Clethrionomys rufocanus* in northern Finland: influence of density, habitat and sex of the host. J. Wildl. Dis. 23: 233–241.

—, Henttonen, H. & Tenora, F. 1988. Population dynamics of common and rare helminths in cyclic vole populations. J. Anim. Ecol. 57: 807–826.

—, Henttonen, H. & Vikman, P. 1996. Variability of sex ratio, mating probability and egg production in an intestinal nematode in its fluctuating host population. Int. J. Parasitology 26: 755–764.

Heinonen, H. 1985. Histologisia tutkimuksia Pohjois-Suomen luonnonvaraisista *Clethrionomys*-myyristä: naaraiden maturoituminen ja dispersaali. (Histological studies on *Cethrionomys* voles in Lapland: maturation of females and dispersal). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 69 p.

Henttonen, H. 1980. Tunturisopuli. (Norway lemming, in Finnish with English summary). Luonnon Tutkija 84: 23–25.

— 1980. Pohjois-Suomen pikkujyrsijöiden yhteisörakenne ja lajien välinen kilpailu. (Community structure and interspecific competition among small rodents in northern Finland). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 65 p.

— 1983. Pikkujyrsijöiden kannanvaihtelut ja lajien välinen kilpailu Pohjois-Fennoskandiassa. (Population cycles and interspecific competition of rodents in northern Fennoscandia). Phil. Lic. Thesis, Dept Zool., Univ. Helsinki, 21 p. + 3 publ.

— 1985. Predation causing extended low densities in microtine cycles: further evidence from shrew dynamics. Oikos 45: 156–157.

— 1986. Causes and geographic patterns of microtine cycles. Ph.D. Thesis, Univ. Helsinki, 9 p.+ 6 publ.

— 1987. The impact of spacing behavior in microtine rodents on the dynamics of least weasels *Mustela nivalis*. Oikos 50: 366–370.

— 1989. Metsien rakenteen muutoksen vaikutuksesta myyräkantoihin ja sitä kautta pikkupetoihin ja kanalintuihin – hypoteesi. (Does an increase in the rodent and predator densities, resulting from modern forestry, contribute to the long-term decline in Finnish tetraonids? In Finnish with English summary:) Suomen Riista 35: 83–90.

— 1991.Ilmastonmuutos ja pienriistakannat. (Climatic change and population dynamics of small game and small mammals in northern Europe. In Finnish with English summary). Suomen Riista 37: 79–85.

— & Hansson, L. 1984. Interspecific relations among small rodents in European boreal and subarctic environments. Acta Zool. Fennica 172: 61–65.

— & Kaikusalo, A. 1985. An additional note on albinism in *Sorex araneus*. Z. Säugetierk. 50: 382.

— & Kaikusalo, A. 1993. Lemming movements. In: Stenseth, N.C. and Ims, R.A. (eds). The Biology of Lemmings - Academic Press for the Linnean Society, pp. 157–186.

— & Peiponen, V. 1982. Polarrötelmaus *Clethrionomys rutilus*. Niethammer, J. und Krapp, F. K (her.), Handbuch der Säugetiere Europas, Vol 2/1, pp. 165–176, Akademische Verlagsgesellschaft, Wiesbaden.

—, Hansson, L. & Saitoh, T. 1992. Rodent dynamics and community structure: *Clethrionomys rufocanus* in northern Fennoscandia and Hokkaido. Ann. Zool. Fennici 29: 1–6.

—, McGuire, A.D. & Hansson, L. 1985. Comparisons of amplitudes and frequencies (spectral analyses) of density variations in long-term data sets of *Clethrionomys* species. Ann. Zool. Fennici 22: 221–228.

—, Haukisalmi, V., Kaikusalo, A., Korpimäki, E., Norrdahl, K. & Skaren, U.A.P. 1989. Long-term population dynamics of the common shrew *Sorex araneus* in Finland. Ann. Zool. Fennici 26: 349–355.

—, Kaikusalo, A., Tast, J. & Viitala, J. 1977. Interspecific competition between small rodents in subarctic and boreal ecosystems. Oikos 29: 581–590.

—, Oksanen, T., Jortikka, A. & Haukisalmi, V. 1987. How much do weasels shape microtine cycles in the northern Fennoscandian taiga? Oikos 50: 353–365.

—, Tast, J., Viitala, J. and Kaikusalo, A. 1984. Ecology of cyclic rodents in northern Fennoscandia. Mem. Soc. Fauna Flora Fennica 60: 84–92.

Jortikka, A. 1990. Metsämyyrän *Clethrionomys glareolus* ja punamyyrän *C. rutilus* lajien välisestä kilpailusta. (Interspecific competition between the bank vole *Clethrionomys glareolus* and red vole *C. rutilus)*. M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 33+8 p.

Laakkonen, J. 1990. Lisäruokinnan vaikutus metsämyyrän *Clethrionomys glareolus* populaatiodynamiikkaan Pallasjärvellä. (Impact of supplemental feeding on the population dynamics of the bank vole *Clethrionomys glareolus* at Pallasjärvi). - M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 36+14 p.

— 1993. Lajienväliset ja vuodenaikaiset erot *Pneumocystis carinii*-loisen esiintymisessä pikkunisäkkäissä. (Interspecific and seasonal variation of *Pneumocystis carinii* in small mammals). Phil. Lic. Thesis, Dept. Zool., Univ. Helsinki, 16 p. + 3 publ.

— 1996. Diagnostics and dynamics of *Pneumocystis carinii* in wild small mammals. Dept Ecol. and Syst., Univ. Helsinki, 10 p. + 5 publ.

—, Henttonen, H., Soveri, T. & Niemimaa, J. 1995. *Pneumocystis carinii* in arvicoline rodents: seasonal, interspecific and geographic differences. Can. J. Zool. 73: 961–966.

—, Sukura, A. Haukisalmi, V. & Henttonen, H. 1993. High prevalence of *Pneumocystis carinii* in *Sorex* shrews. J. Wildl. Dis. 29: 273–277.

—, Soveri, T. & Henttonen, H. 1994. Prevalence of *Cryptosporidium* sp. in peak density *Microtus agrestis, M. oeconomus* and *Clethrionomys glareolus* populations. J. Wildl. Dis. 30: 110–111.

Laitinen, L. 1987. Sympatristen ja allopatristen metsä- ja punamyyräpopulaatioiden hammasmittojen muuntelu Suomessa. (Variation in molar characteristics in sympatric and allopatric populations of the bank and red vole in Finland). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 51 p.

Martikainen, T. 1988. Metsä- ja punamyyrän kallomorfologinen muuntelu Suomessa. (Variation in skull morphology of the bank and red voles in Finland). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 59 p.

Niethammer, J. & Henttonen, H. 1982. Waldlemming, *Myopus schisticolor*. In: Niethammer, J. und Krapp, F. (eds.), Handbuch der Säugetiere Europas, Vol 2/1, p. 70–86, Akademische Verlagsgesellschaft, Wiesbaden.

Oksanen, T. & Henttonen, H. 1996. Dynamics of voles and small mustelids in the taiga landscape of northern Fennoscandia in relation to habitat quality. Ecography 19: 432–443.

Plyusnin, A., Vapalahti, O., Lehväslaiho, H., Apekina, N., Mikhailova, T., Gavrilovskaya, I., Laakkonen, J., Niemimaa, J., Henttonen, H., Brummer-Korvenkontio, M. & Vaheri, A. 1995. Genetic variation of wild Puumala viruses within the serotype, local rodent populations and individual animals. Virus Res. 38: 25–41.

Soveri, T., Rudbäck, E. & Henttonen, H.1994. Histopathology of the common shrew *Sorex araneus* in Finland. - In: Merritt, J.F., Kirkland, G.L., Jr., and Rose, R.K. (eds.), *Advances in the Biology of Soricidae,* Spec. Publ. Carnegie Mus. Nat. Hist. 18: 151–153.

Tenora, F., Henttonen, H. & Haukisalmi, H. 1983. On helminths of rodents in Finland. Ann. Zool. Fennici 20: 37–45.

—, Haukisalmi, V. & Henttonen, H. 1985. *Andrya kalelai* sp.n. and (?) *Anoplocephaloides* sp., Cestoda, Anoplocephalidae, parasites of *Clethrionomys*-rodents in Finland. Ann. Zool. Fennici 22: 411–416.

—, Henttonen, H. & Haukisalmi, V. 1985. New findings of helminths in rodents in Finland. Folia Parasitol. 32: 33.

—, Haukisalmi, V. & Henttonen, H. 1986. Cestodes of the genus *Anoplocephaloides* Baer, 1923 (Anoplocephalidae), parasites of rodents in Finland. Acta Univ. Agric. (Brno) 34: 213–217.

—, Haukisalmi, V. & Henttonen, H. 1986. Cestodes of the genus *Andrya* Railliet 1893 (Anoplocephalidae), parasites of rodents in Finland. Acta Univ. Agric. (Brno) 34: 219–227.

Tynkkynen, R. 1984. Dispersaali syklisissä *Clethrionomys*- ja *Microtus*-myyräpopulaatioissa. (Dispersal in cyclic *Clethrionomys* and *Microtus* vole populations). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 141 p.

Vantunen, L. 1988. Lapinmyyrän *Microtus oeconomus* kallon mittojen ja epigeneettisten ominaisuuksien maantieteellinen muuntelu Fennoskandiassa. (Geographic variation in size and epigenetic characteristics of skull of the root vole *Microtus oeconomus* in Fennoscandia). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 45 + 5 p.

Vikman, P. 1994. Sukkulamatojen vaikutus metsämyyrän säilyvyyteen ja populaatiotiheyteen: kokeellinen kenttätutkimus. (Impact of nematodes on the survival and population density of the bank vole: an experimental field study). M.Sc. Thesis, Dept. Zool., Univ. Helsinki, 47 p.

European Programme for the Intensive Monitoring of Forest Ecosystems

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Introduction

Finland has been participating since 1985 in the European Forest Condition Monitoring Program (ICP Forests). The Finnish Forest Research Institute (Metla) has been responsible for monitoring the health and vitality of the forests in Finland by carrying out an annual survey of the overall condition of the trees on a permanent network of systematically selected sample plots (so-called level I, totalling 490 plots) using internationally standardised methods. The parameters that are estimated on the individual trees include defoliation, needle discoloration and biotic and abiotic damage. A survey of needle chemistry on the plots was started in 1987, and a soil survey carried out during 1985–89 (supplemented in 1995). In addition to meeting national requirements, the monitoring programme has also provided valuable information about annual variation in forest condition throughout Europe. Despite the extensive scope of this program, it has not been able to provide enough information about the factors affecting forest vitality under different pollution loads, climate and soil conditions. In order to correct this situation, the European Union and the ICP Forests organisation together initiated a new intensive monitoring program (level II) for investigating the causal relations of forest vitality. The techniques and measurement methods to be used, which have been drawn up by different expert groups, have been included in the ICP Manual, as well as in the EU regulations covering the monitoring work carried out by EU member states.

The level II monitoring program is based on an observation network covering the whole of Europe. So far a total of 440 forested observation plots have been established in the EU countries, and 203 in countries outside the EU (Fig. 1). The wide range of monitoring activities, which are planned to continue for 20 years, covers the following topics:

<u>Mandatory on all plots</u>
- overall tree condition, annual inventory
- needle chemistry, sampling every second year
- soil condition, sampling every fifth year
- tree growth, measured every fifth year
- deposition (outside and inside the stand), continuous

<u>Optional</u>
- soil solution quality, continuous on selected plots (mandatory from 1997)
- meteorological measurements, continuous on selected plots (started in 1995)
- ground vegetation, every five years (mandatory from 1997)

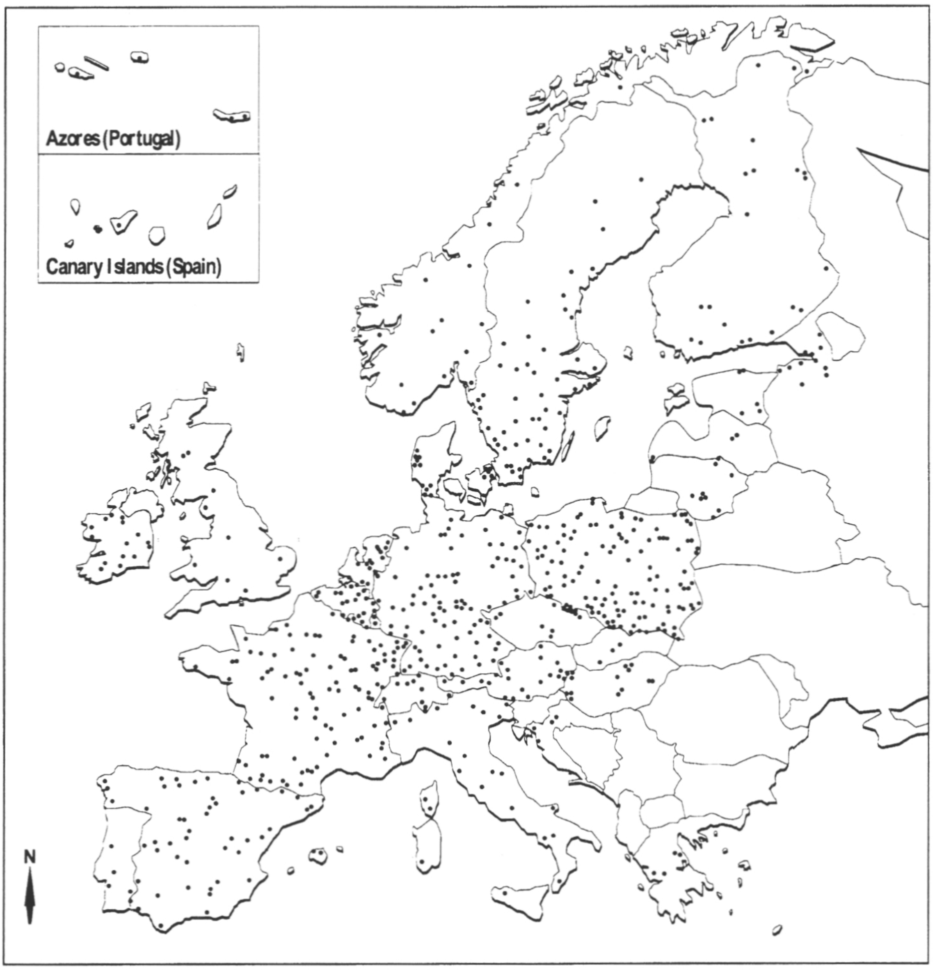

Figure 1. Location of the Intensive Monitoring Plots

2 The observation plot network in Finland

At the present time (autumn 1996), there are 24 monitoring plots in different parts of the country (Fig. 2). All the plots are on mineral soil sites; 15 have stands comprising Scots pine (*Pinus sylvestris*) and 9 Norway spruce (*Picea abies*). All the plots, except the four Integrated Monitoring (IM) plots, are located in commercially exploited forest. The IM plots represent natural stands in catchment areas. A number of the plots are located close to background, air quality monitoring stations primarily run by the Finnish Meteorological Institute.

The stands on the plots represent the main tree species and prevailing growing conditions in Finland. The stand age ranges from 40 to 70 years old. Information has been obtained about the previous history of the site and tree stand. In addition to the main tree species, the stands also contain scattered individuals of other tree species.

2.1 The observation plots and location of the sub-plots

The observation plots proper consists of three sub-plots and a surrounding mantle. The sub-plots are square in shape (30 x 30 m); if the stand density is low, the area of the sub-plots is greater (Fig. 3). A 5–10 m wide strip has been left between the sub-plots for possible future use in special studies and for additional sampling. Sampling methods that may have a detrimental, long-term effect on the soil or stand, e.g. soil sampling, deposition and soil water collection, needle and litter sampling etc., are concentrated on one sub-plot. One of the other two sub-plots is reserved for vegetation studies, and the other for tree growth measurements.

The centre point of the observation plot, the corners of the sub-plots and the outer edge of the mantle area (sub-plot 4) have been marked with wooden posts. The mantle is surrounded by a buffer zone (sub-plot 5). The width of the mantle and buffer zones varies from 10–30 m. All the sub-plots are at least 30 m away from the outer edge of the stand. The minimum distance between the sub-plots, as well as the minimum width of the buffer zone, is 5 m.

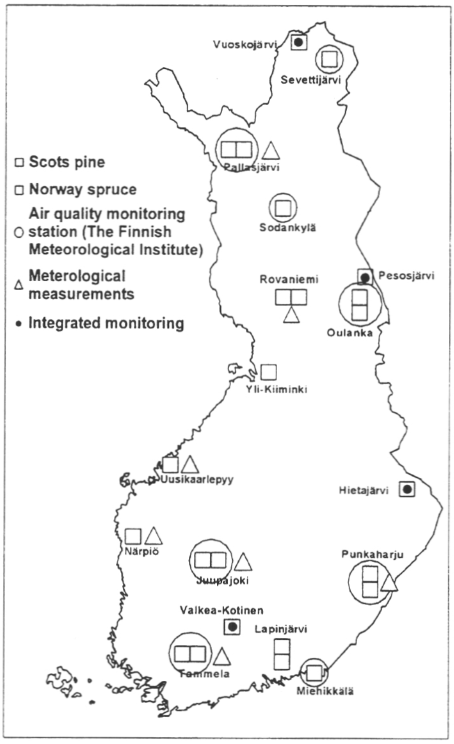

Figure 2. Intensive and continuous monitoring of forest ecosystems in Finland.

2.2 Basic stand measurements and mapping

All the trees on the observation plot have been numbered at a height of 1.3 m on the side of each tree facing the centre point.

The following parameters have been recorded or measured on each tree: tree species, canopy layer, diameter at 1.3 m, height and length of the living crown. The measurements have been performed on the trees on sub-plots 1–3 and those located in the mantle area (sub-plot 4). Twenty additional trees representing different diameter classes have been selected and numbered on the buffer zone (sub-plot 5). In addition to the above measurements, bark thickness has been measured and increment cores taken at 1.3 m height for determining earlier growth and tree age. The forest site type of the observation plot has also been determined.

The location and elevation of all the trees on the observation plots have been mapped using a tachymeter. The exposition and gradient of each sub-plot have also been determined. Care has been taken during the field work to avoid causing unnecessary trampling of the ground vegetation or other forms of damage. Wooden walkways have been laid on the sub-plot used for collecting deposition and soil water.

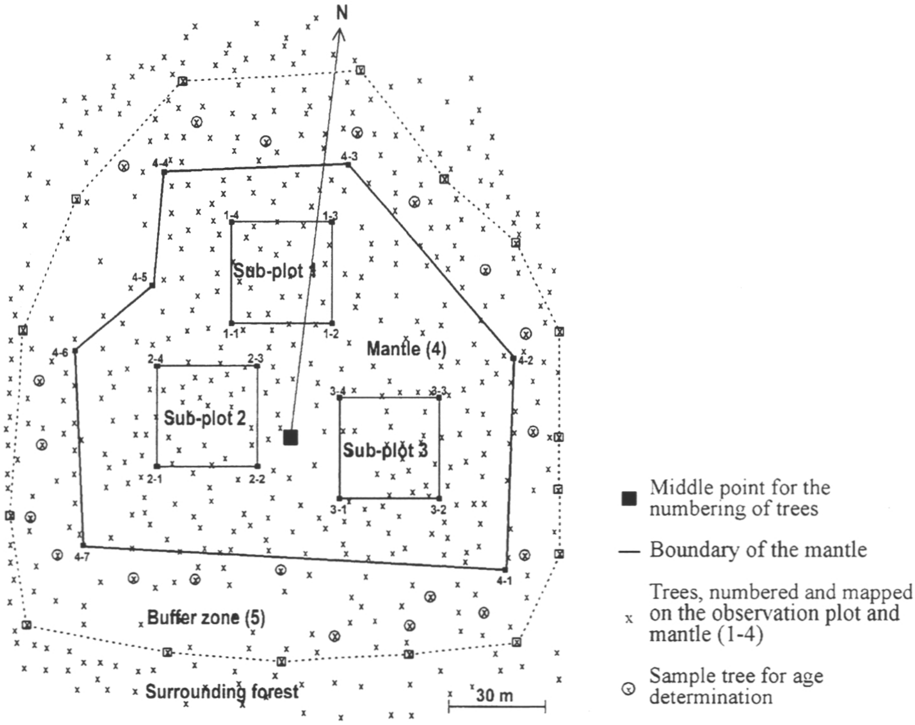

Figure 3. Obsevation plot consists of 3 sub-plots: soil and deposition, Increment assessment and ground vegetation. Mantle sample trees for the inventory of crown condition and the foliage inventory.

3 Mandatory monitoring

3.1 Tree condition

Defoliation, needle discoloration and easily identifiable types of damage are estimated each year on 20 trees from each sub-plot, as well as on the 20 needle sampling trees. The total number of trees to be estimated per plot is 80.

3.2 Needle chemistry

Needle samples are taken in November every second year from a total of 20 trees. Two sets of 10 sample trees have been selected from each observation plot. Sample branches are taken from 10 of these trees every second year. The two tree sets are sampled in rotation, i.e. each set is sampled every 4 years. This arrangement is being employed in order to minimise damage to the trees resulting from branch removal. Whenever possible, the sample trees are the same as those used for continuous stem growth monitoring using girth bands. The following criteria have been taken into account in selecting the needle sampling trees:

- Trees on which the defoliation estimation proper (i.e. the 60 trees on the sub-plots) is being performed are not to be selected.
- The sample trees are to be either dominant or co-dominant trees.
- The sample trees are to be located as close as possible to the points where soil samples have been taken.
- The sample trees are to be as representative as possible of the average defoliation degree in the observation stand.
- In other respects the sample trees are to be representative of the average state of health of the observation stand.

3.3 Soil condition

Soil samples are taken at five-year intervals on all the observation plots. Both horizon samples and depth samples have been taken. Horizon samples (O, E, B, BC and C) were taken at 20 systematically located points, and combined to give 4 bulk samples per horizon. Depth samples (humus, 0–5, 5–10, 10–20, 20–40 cm mineral soil layers) were taken from 8 of the above 20 points, and combined to give 4 bulk samples per depth horizon. A soil pit was dug at the corner of the sub-plot (outside the plot) and detailed measurements made of the genetic horizons for soil classification purposes. Bulk density and 40–80 cm mineral soil samples were also taken from this soil pit. Stoniness was measured at 60 points on the sub-plot by pushing a graduated steel rod down into the soil and recording the penetration depth.

The following parameters are analysed on the soil samples. Humus: pH($CaCl_2$), total C and N, total P, K, Ca and Mg, exchangeable acidity (titration), exchangeable K, Ca, Mg and Na ($BaCl_2$), cation exchange capacity. Mineral soil: pH($CaCl_2$), total C and N, exchangeable acidity (titration), exchangeable K, Ca, Mg and Na ($BaCl_2$), cation exchange capacity. In addition, a wide range of additional soil analyses are performed on these samples as part of Metla's own research activities.

3.4 Tree growth

The diameter at breast height of all the trees on the plots was measured, and tree height, crown length and crown diameter on 30–40 selected trees. Periodical diameter measurements are to be carried out every five years. Increment cores were taken from 10–20 trees in the buffer zones in order to determine volume growth during the preceding 5-year period, and to date a possible growth decline in trees suffering from defoliation.

3.5 Deposition measurements

Free bulk deposition and stand throughfall have been monitored on 18 plots since the beginning of July, 1995, and on the six additional plots since July, 1996. Samples are collected monthly using 3 rainfall collectors in an adjacent open area, and 20 systematically located collectors on one of the observation sub-plots. During the snow period there are 2 snow collectors in the open and 6 inside the stand. The number of snow collectors is lower than that of rainfall collectors owing to the fact that snow samples cannot be bulked in the field, but must be taken to the laboratory for melting and mixing. The rainfall collectors are constructed in such a way that the samples are stored underground in the cool and dark before collection.

The monthly samples are sent in cold boxes by post to the pretreatment centres at Parkano and Rovaniemi. All the chemical analyses are performed at the Rovaniemi Research Station. The following parameters are determined: pH, electrical conductivity, Ca, Mg, K, Na, metals, NO_3^-, NH_4^+, SO_4^{2-}, Cl^- and dissolved organic carbon (DOC).

4 Optional monitoring

4.1 Meteorological measurements

Meteorological measurements are being carried out continuously on 7 of the spruce observation plots: Pallasjärvi and Rovaniemi (north Finland), Närpiö and Uusikaarlepyy (west Finland), Punkaharju (east Finland), and Juupajoki and Tammela (south Finland). The following parameters are being measured. Above the crown canopy: wind speed and direction, air temperature and relative humidity, photosyntheically active radiation (PAR); inside the stand: air temperature, relative humidity, soil temperature and ground frost depth. Precipitation is measured continuously in an open area.

4.2 Cooperation

In 1993, five international organizations – FAO, ICSU, UNEP, UNESCO and WMO – decided to co-sponsor the planning process for a Global Terrestrial Observing System (GTOS). GTOS is intended to provide the data basis and observational framework needed to understand and address the impacts of global change on terrestrial, including freshwater, ecosystems. The Terrestrial Ecosystem Monitoring Sites (TEMS) database, which is an international directory of meta-data about monitoring stations and their activities, has been established to document existing long-term monitoring sites that may be suitable for inclusion in the GTOS network once it has been established. The Finnish ICP level II monitoring plots are included in the TEMS database.

The data collected on the monitoring plots in northern Finland will be regularly submitted for inclusion in the database of the Arctic Monitoring and Assessment Programme (AMAP).

5 Pilot studies completed or currently underway

5.1 Crown condition inventory sampling techniques (1995)

A pilot study has been carried out on the sampling techniques used for the crown condition inventories. The "fixed number of sample trees per plot" sampling method was compared with the "fixed area of sample plots" system. Crown condition inventories carried out as part of the Finnish National Forest Inventory have been based on fixed area sampling plots, while the EU regulations propose using sample plots with fixed numbers of trees. Comparison of the sampling methods was based on field measurements and sampling theory analysis. The measurements were used to investigate the effects of Finnish conditions on the properties of the methods, and have permitted an empirical comparison to be made of the compatibility of the results given by the two methods. An area encompassing about 30 plots was selected from the annual forest vitality network for the study. A four-point cluster grid fulfilling the criteria of the EU regulations was superimposed on this area.

5.2 Lysimeter compatibility study (1995–96) (6 plots)

The use of gravity and suction-cup lysimeters is being compared on 6 of the observation plots (spruce and pine stands at Rovaniemi, Juupajoki and Tammela). Gravity lysimeters collect percolation water filtering down through the soil profile; the chemical composition of percolation water plays an important role in soil formation processes. Suction-cup lysimeters sample the soil solution, as well as to some extent percolation water. Soil solution quality provides a measure of soil acidification and the capacity of the soil to neutralise acidic deposition. Special attention is being paid in the soil water analyses to the organic matter and aluminium concentrations, as well as acidity. Sampling from the suction-cup lysimeters is being performed using an automated system running off solar panels.

5.3 Continuous monitoring of stem diameter growth (1995) (3 plots)

Growth-band equipment has been developed at the FFRI for continuously monitoring the radial growth of forest trees. The aim has been to produce a relatively cheap, accurate device that can be coupled to a datalogger for continuous measurements in the field. The growth band device measures changes in the circumference of the tree trunk. Part of these changes are due to meteorological factors, and part to growth in the tree tissue. The accuracy of the device is 0.05 mm. The devices were installed in three spruce stands where meteorological measurements are carried out. The aim of the study was to analyse the factors affecting changes in the circumference of tree stems and to investigate the connection between meteorological factors and changes in the circumference of tree stems.

5.4 Seasonal variations in the size and chemical composition of Scots pine and Norway spruce needles in different weather conditions (1996) (6 plots)

The chemical composition of tree foliage is a parameter that is extensively used in surveying the state of health of the forests and in determining the causal effect relationships involved in the outbreak of forest damage. At the present time, however, there are some shortcomings in the interpretation of the results. For instance, the number of needle age classes (i.e. amount of needles) is not taken into account in the interpretation, even though conifers can regulate the nutrient status of their needles e.g. by reducing total needle biomass (i.e. fewer needle age classes). The aim of the study is to investigate the seasonal variation in the size and chemical composition of Scots pine and Norway spruce needles under different climatic conditions. The results will be used in formulating a model that takes into account the effects of temperature sum and precipitation when interpreting the results of needle analysis.

5.5 Determination of aluminium fractions and organic matter components in soil water (1996)

Soil water aluminium concentrations and the molar Ca/Al ratio are widely used in estimating soil acidification and the exceedance of critical loads of acidifying nitrogen and sulphur compounds. These parameters are normally based on total aluminium concentrations in soil water and not on the labile aluminium fraction (Al^{3+}), which is the aluminium species considered responsible for the toxic effects on roots and mycorrhizas. Most upland forest soils in Finland are podzolic and have a high organic matter content in the rooting zone, and it is to be expected that a relatively high proportion of the total aluminium in the soil and soil water will be in an organically complexed, non-toxic form. The aims of the pilot study are 1) to determine a suitable method for determining different aluminium species in soil water from humus-rich podzolic soils, 2) to develop methods for transporting and storing soil water samples prior to analysis, 3) to estimate the proportion of toxic Al^{3+} out of total soil water aluminium, 4) and to elucidate the contribution of dissolved organic matter to soil water acidity.

5.6 Sampling strategy for assessment of temporal changes in ground vegetation in boreal forests (1996) (20 plots)

Changes in plant populations and communities have great indicative value in monitoring forest environments. The effect of air pollution and climatic change on the abundance of sensitive understorey species is detectable at an earlier stage than the effects on tree stands. The purpose of this pilot study is to select the most appropriate sampling method for the long-term monitoring of forest understorey vegetation. The first priority in the study is to determine how large an area and how many quadrats should be used to obtain representative data on plant community structure. The second stage is to compare different sampling techniques: the Braun-Blanquet method, and determination of percentage cover, cover classes, species presence/absence and point quadrat frequency.

6 Proposed pilot studies (1997–)

1. The use of LAI–2000 devices for determining leaf area index as an indicator of forest vitality in coniferous stands

   The aim of this pilot study is to evaluate the precision of the estimates given by the LAI–200 device concerning changes in the needle area of a stand of Norway spruce. In addition, the leaf-area index values obtained with the LAI–200 device will be compared with other stand vitality parameters in order to determine the applicability of the method in forest vitality monitoring work.

2. The ecological response of ground vegetation to increasing nitrogen deposition

   The aim of this preliminary investigation is to study experimentally the response of forest understorey plant species to different levels of available nitrogen. The results of the experiments will help in evaluating the effects of an increasing nitrogen load on the vegetation and in defining the critical load limits of different species. The response of species with different nutrient demands to increasing nitrogen deposition will be determined. Species benefitting from the nitrogen load will be compared with declining species. Because southern and northern populations may be genetically adapted to different ecological conditions, the dependence of the reaction norms on geographical location will also be studied.

3. Variation in throughfall amount and quality during the growing season in relation to collector type and arrangement

   The aim of this pilot study is to quantify the spatial variability in the quantity and quality of throughfall during one growing season in relation to the type, number and arrangement of collectors used. This will help in determining the compatibility and comparability of the results obtained in forest ecosystem monitoring programmes.

4. Development and evaluation of techniques for determining deposition in the form of snow within the stand

   The aims of the pilot project are 1) to determine the minimum number and size of snow collectors needed to obtain a reliable estimate of snowfall within the stand, 2) to follow the spatial and temporal development of the snow cover within the stand, 3) to follow temporal variation in the chemical composition of the snow cover, and 4) to develop a snow collector for use in open areas that restricts evaporation losses of snow (as water vapour).

5. Real-time telemetric data transfer from the field to the office

   The aim of the project is to develop and construct a wireless data transfer system for field measurements in the forest. The method must be independent of the type of electronic sensors used, and data transfer from field experiments to the office must be close to real time. The prototype system will be used to transfer girth band measurements to the respective research stations. The results calculated from the telemetric data will be used for monitoring annual tree growth and for studying the impacts of environmental factors on tree growth.

Haloacetic acids in a timber-line ecosystem

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Introduction

There are numerous indications suggesting that present ambient air levels of volatile organic compounds (VOC's) in Europe are tenfold to hundredfold higher than in pristine atmosphere. VOC's are not only high in regions of high industrial activity and of population density, but also over rural regions, in particular those compounds which have medium and high atmospheric lifetime; i.e. several halogenated solvents and their oxidation products. Some of them are known as herbicides, such as mono- (MCA) and trichloroacetic acid (TCA). Although lists of organic compounds considered harmful to the environment exist, only little information is available on deposition mechanisms, bioconcentration and bioaccumulation as well as on the metabolic fate of VOC's in plants and in forest ecosystems. Volatile xenobiotics are transported over long distances and represent a burden for sensitive remote ecosystems (e.g. Frank et al. 1992) by dry or wet deposition processes, i.e. direct uptake of gases and particles by the surface or any input via precipitation.

There is increasing evidence that volatile halogenated hydrocarbons, in particular C2-halocarbons (Frank and Frank 1985) and halons (Schröder and Debus 1991), may be rapidly taken up and metabolized, which in turn affects plant metabolism. Equally relevant in respect to phytotoxicity are secondary air pollutants, such as haloaliphatic acids from halocarbons; various haloacetic acids are presently being detected in relatively low-polluted atmosphere and in precipitation. Chloroacetic acids derived from C2-chlorocarbons, i.e. 1,1,1-trichloroethane, tri- and tetrachloroethene; the respective oxidation products mono-, di- and trichloroacetic acid are found in samples from all areas of Europe, in particular in conifer needles, but they also occur regularly in air, precipitation and surface waters (Frank et al. 1994). Especially the monohaloacetic acids are among the strongest toxicants to photoautotrophic organisms and are also known as the toxicogenic principle in herbicides such as Alachlor or Metazachlor (Frank et al. 1994). Another source of haloacetic acids are the fluoroethanes which are being introduced as CFC-alternatives, giving rise to the atmospheric formation of trifluoroacetic acid (TFA), an acid of high environmental persistence. TFA is presently found in rain and surface waters at levels up to 200 ng/l in Central Europe and expected to rise with the increased release 1,1,1,2-tetrafluoroethane (HFC 134a), the most important CFC-alternative (Frank et al. 1996, Reimann et al. 1996).

TCA is a hydrophilic organic acid taken from soilwater into trees via transpiration stream (Sutinen et al. 1995, 1996), but a minor fraction may also pass from the atmosphere through needle surface, possible via the stomata as found experimentally by Sutinen et al. (1995). Furthermore, the uptake of TCA into needles may occur via cuticle in the form of the lipophilic precursor chlorocarbons which may be matabolised to TCA in the needle tissue as suggested by Frank et al. (1992) and Plümacher and Schröder (1994). Less is known about the uptake of TFA, MCA and monobromoacetic acid (MBA), although preliminary data show that these compounds are actively taken up by plant cells (Frank, H. pers. commun.).

A positive correlation between the TCA concentration in the conifer needles and the defoliation degree of the trees in a forest environment has been presented (Frank et al. 1994, Norokorpi and Frank 1995). Experiments with conifer seedlings have shown that TCA exposure may influence photosynthesis by changing the chloroplast structure as well as may cause several other physiological and morphological changes (Sutinen et al. 1995, 1996). Even though halogenated acetic acids (HAA's) occur in plants in micromolar concentrations these compounds cause many kinds of growth disturbances in trees. The effects of HAA's at molecular or enzymatic levels are poorly known. Hence, detailed knowledge of the atmospheric-chemical properties as well as morphological, physiological, metabolic, enzymological and genetic principles governing the differences in susceptibility, resistance and adaptation of trees to organic xenobiotics is necessary to understand and predict atmospheric levels of xenobiotics tolerable to forest ecosystems. The potential role of adaptation of trees to chemical stress, either via accelerated metabolic elimination of xenobiotics (induction of mono-oxygenase and other phase-I and phase-II enzymes), by activation of protective systems for scavenging reactive intermediates (epoxide hydrolases, glutathione transferases, glutathione peroxidases) involved in protection of basic cellular processes has not been studied yet.

The fate of organic halogen compounds in forest and water ecosystems is poorly known. In trees these compounds are further metabolised and partly accumulated. As needles and leaves drop, they are degraded in soil. Finally, the soil humus is transported to lakes, where it forms a lake humus pool before getting sedimented (Suominen et al. 1995). This may be one possible source of organic halogen in the water environment. These metabolic pathways and products are important to study in situ.

2 Pilot study on Pallas

A preliminary study was conducted on Pallastunturi fells in the autumn of 1995 with the aim of determining the level of TCA concentrations in Scots pine needles. The needle samples were collected by the main compass direction and at three altitudes as follows: lower level = 270–280 m, middle level = 330–360 m, and upper level = 380–480 m a.s.l, i.e. within the zone between the timberline and the treeline. Every sample plot was accessed to obtain six sample pine trees. Furthermore, the needles were collected from eighteen pine trees located on the control plot in the vicinity of the forest meteorological station at 285 m a.s.l. and representing the lower level. The method applied in taking and analysing the samples was the same described by Juuti et al. (1996). The needles were taken solely from the third needle age class (1993). The analyses were carried out at the University of Kuopio.

The median for all the analysed samples (n = 89) was 28.5 ng/g (fresh weight). The range was 6–159 ng/g (Fig. 1). The median for the control area was 29.5 ng/g (range 10–64 ng/g). The highest concentration was found to occur at middle altitude on the south-facing slope and the value obtained is among the highest TCA concentrations recorded in Finland to date (cf. Juuti et al. 1996). The trend was for

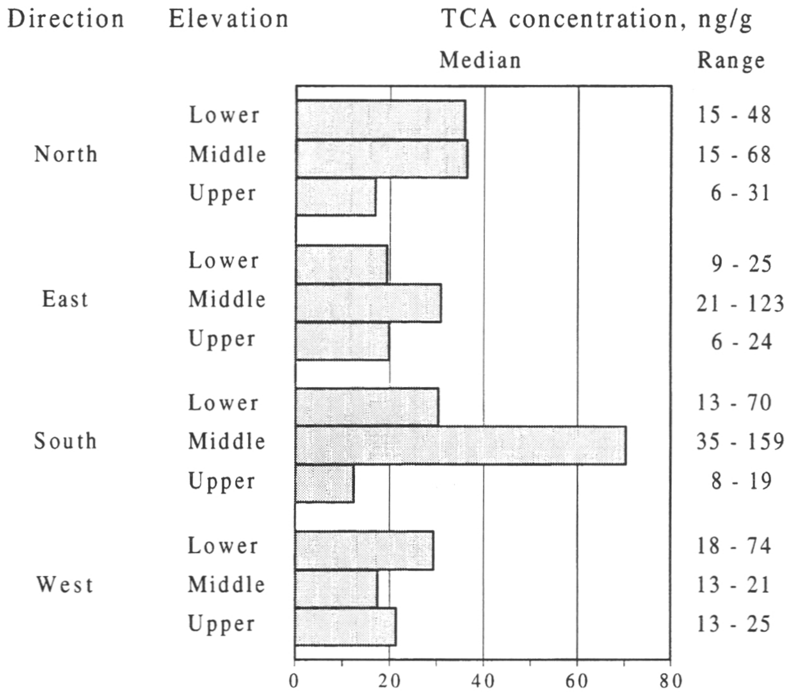

Figure 1. TCA consentrations in Scot pine needles (mean and range, ng/g fresh weight) at different elevetions and expositions on Pallastunturi fells.

the TCA concentration to rise from the lower level to the middle level and then to fall from there to the treeline and for the south-facing slope to have the highest concentration. Due to the large deviation, the differences in concentration were not statistically significant. The median for the entire material is a little higher than the medians reported in earlier studies representing background areas in Finland. Juuti et al. (1996) reported a median value of 23 ng/g and 90% of the values fell within the range 5–70 ng/g.

3 A plan for further research

A cooperative research plan for further studies has been made together with the following partners: Finnish Forest Research Institute, Rovaniemi and Suonenjoki Research Station; University of Oulu, Department of Botany; University of Helsinki, Department of Applied Chemistry and Microbiology; University of Kuopio, Department of Environmental Sciences; University of Bayreuth, Chair of Environmental Chemistry and Ecotoxicology, Germany and Finnish Meteorological Institute, Air Quality Research. Most of the in-situ measurements and experiments are planned to be conducted in the Pallas region because it represents timber-line conditions very well and the facilities for environmental and ecological research are good.

The goals and hyphotheses for the research project are as follows:

1. Assessment of air levels, deposition and uptake into trees of halo- and nitrocarbons and their interaction with acid rain and ecological factors

   The first objective is to establish a data base for determining representative ambient air levels and deposition of halo- and nitrocarbons in relation to the in-situ biological state of the trees. As benchmark compounds for determination of representative ambient air levels the four major C2-halocarbons; trichloroethene, tetrachloroethene, 1,1,1-trichloroethene (precursors of MCA, DCA and TCA) and 1,1,1,2-tetrafluoroethane (precursor of TFA) as well as aromatic compounds toluene and xylene potentially involved in tropospheric ozone and nitrophenol formation are selected. While there is already an extensive data base for selected VOC's and their derivatives in Central Europe (Frank et al. 1991, 1996, Reimann et al. 1996) the halogenated hydrocarbons have not been measured in Finland earlier. In northern Finland TCA levels in pine needles have been found to be as high as in needle samples from strongly affected mountain forest regions in Germany (Frank et al. 1994, Juuti et al. 1996). It is not expected because atmospheric levels of the most abundant C2-halocarbons may be lower in Finland. The relative high burden of haloacetic acids may be an example of the global cryogenic condensation of volatile ubiquitous pollutants in the colder subarctic climate zones.

   A major part of haloacetic acids may come into forest ecosystems with wet deposition, and rain water is commonly used for monitoring these compounds (Reimann et al. 1996). It is important to correlate the air levels and concentrations in precipitation and canopy run-off from the trees. The deposition of TCA by canopy run-off is expected to be higher than by rain in the open field. This may be explained by dry deposition onto trees with subsequent rinsing. On the other hand, for MCA and DCA the concentrations in the canopy run-off may be smaller because these acids are probably taken up by trees because of their lower acidity and polarity. There are probably differences in uptake through the roots in transpirational water between haloacetic acids. TFA is the most watersoluble but MCA, DCA or MBA are so at all; TCA is intermediate. The acidity of rain may have an important role in uptake of halo- and nitrocarbonds.

   The results show that there can be clear differences in TCA concentrations between adjacent stands (Norokorpi and Frank 1993, Juuti et al. 1995) or within a forest stand. The deposition and uptake of xenobiotics depend also on several ecological factors such as wind passage, solar radiation and some other microclimate parameters (Weathers et al. 1995). It is necessary to monitor, compare and analyse the main ecological factors in connection with indicative xenobiotics in control stands.

2. Identification the key biological process involved in metabolism, activation, detoxification and elimination of halo- and nitrocarbons and their impacts on the tree health

   These xenobiotics have many kinds of impacts on forest trees at different levels of biosystems. Many of these effects are not specific and in-situ, there are several interactive factors. Specific effects of xenobiotics can be studied in exposure experiments with accurate, intensive measurements along the metabolic pathways. Key biological processes involved in metabolism, activation, detoxification and elimination of selected xenobiotics are important in this study.

   Some inorganic compounds are known to have specific symptoms of damage to ultrastructure of tissue and cells. Specific alterations are also searched for haloacetic acids and nitrophenols (Sutinen et al. 1995).

In several crop plants a group of detoxifying enzymes capable to metabolize halogenated organic xenobiotics, the glutathione S-transferase (GST) has been observed (Schröder and Rennenberg 1992). An enhancement of GST-activity indicates a possible role of GST in the detoxification after fumigation.

MCA may exert its toxicity in a similar manner as fluoroacetate, i.e. by attenuation of the mitochondrial citric acid cycle via formation of halocitrate and subsequent inhibitation of aconitase. The speculation that alternated mitochondrial energy output may be one of the biochemical lesions underlying some forest decline symptoms is supported by the fact that phosphoenol pyryvate carboxylase (PEPC) is consistently induced in declining conifers, perhaps an attempt of the affected plants to overcome the block in mitochondrial energy production by elevating the pro-substrate oxaloacetate (Frank et al. 1994). TCA could also influence the tricarboxylic acid cycle (TCAC) which starts by the combination of acetic acid to oxalacetic acid to form citrate in mitochondria. The key enzyme in the beginning of the TCAC is citrate synthetase. TCA could competite with normal acetic acid on citrate synthetase or other close enzymes in the beginning of TCAC and lead to inhibition of the cycle.

TCA affects as a herbicide increasing growth at first but leading then to tissue damage. It could be supposed to simulate the effects of indoleacetic acid (IAA), a natural hormone. One of the main effects of IAA is to induce degradation of cell wall cellulose by cellulases (ß-glucosidases) and then to induce synthesis of new cellulose molecules. This leads to increased local growth. TCA can disturb the hormonal balance.

3. Identifications of bioindicators for the presence and effects of halo- and nitrocarbons in the environment

Since 1972, bioindicative methods have been employed for studies on variable effects caused by air pollutants. Scots pine has been found a particularly suitable bioindicator and it is most commonly used because needles live for several years, it is widely distributed and sensitive to many air pollutants. Some of the xenobiotics are very reactive. MCA, for instance, metabolizes rapidly and goes further along its pathway (Frank et al. 1994). TCA may be an indicator for other halocarbons. Some specific enzymes and hormones may indicate the presence of very reactive xenobiotics.

4. Assessment of the metabolic pathways and fates of halocarbons from trees into litter, humus and waters (Fig. 2)

Part of organic halogen compounds are degradable in the environment. The rest of them accumulates in soil and sediments. Sediments act as a sink of recalcitrant compounds. When the sediment profile of a lake is dated, it is possible to study the history of the lake and its drainage area and make conclusions about the fate of different chemicals in the nature. By analysing organic halogen compounds and their properties (molecule size distribution, log k_{ow}) in terrestrial ecosystem and in lake sediment the fate of these compounds in the environment can be studied.

Lipophility of organic compounds can be measured with water-octanol partition coefficient (log k_{ow}). Lipophility influences in many chemical and biological properties of a compound. Lipophilic compounds can go through cell wall and they are more bioavailable for organisms than hydrophilic compounds. Water-octanol partition coefficients are widely used in correlations concerning pollution

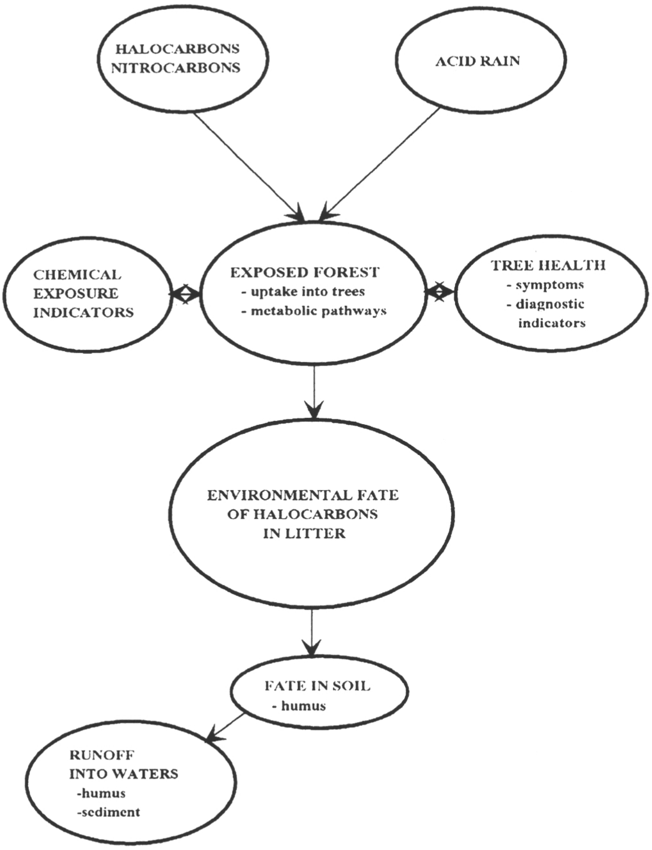

Figure 2. The assessment of the metabolic pathways and fates of halo- and nitrocarbons in the ecosystems.

partitioning between water and sediments, in aqueous solubility relationships, in bioconcentration factor determination and in toxicity relationships.

Molecule size distribution influences the bioavailability of organic compounds. Large molecules are less bioavailable than smaller ones. Molecule size distribution gives also information about the metabolism and environmental fate of organic material (Suominen et al. 1995).

References

Frank, H. & Frank, W. 1985. Chlorophyll bleaching by atmospheric pollutants and sunlight. Naturwissenschaften 72: 139–141.

—, Frank, W., Neves, H.J.C & Englert, R. 1991. Levels of airborne halocarbons at urban and mountain forest sites in Germany and at Atlantic coast. Chemosphere 23: 609–623.

—, Scholl, H., Sutinen, S. & Norokorpi, Y. 1992. Trichloroacetic acid in conifer needles in Finland. Annales Botanici Fennici 29: 263–267.

—, Scholl, H., Renschen, D., Rether, B., Laouedj, A. & Norokorpi, Y. 1994. Haloacetic acids, phytotoxic secondary air pollutants. Environmental Science and Pollution Research 1(1): 4–14.

—, Klein, A. & Renschen, D. 1996. Environmental trifluoroacetate. Nature 382:34.

Juuti, S., Norokorpi, Y. & Ruuskanen, J. 1995. Trichloroacetic acid (TCA) in pine needles caused by atmospheric emissions of kraft pulp mills. Chemosphere 30: 439–448.

—, Norokorpi, Y., Helle, T. & Ruuskanen, J. 1996. Trichloroacetic acid in conifer needles and arboreal lichens in forest environments. The Science of the Total Environment 180: 117–124.

Norokorpi, Y. & Frank, H. 1993. Effect of stand density on damage to birch (Betula pubescens) caused by phytotoxic air pollutants. Annales Botanici Fennici 30: 181–187.

— & Frank, H. 1995. Trichloroacetic acid as a phytotoxic air pollutant and the dose-response relationship for defoliation of Scots pine. The Science of the Total Environment 160/161: 459-463.

Plümacher, J. & Schröder, P. 1994. Accumulation and fate of C_1/C_2-chlorocarbons and trichloroacetic acid in spruce needles from an Austrian mountain site. Chemosphere 29: 2467–2476.

Reimann, S., Grob, K. & Frank, H. 1996. Chloroacetic acids in rainwater. Environmental Science & Technology 30(7): 2340–2344.

Schröder, P. & Debus, R. 1991. Responses of spruce trees (Picea abies L. Karst.) to fumigation with Halon 1211 – first results of a pilot study. In: Gorsuch, J.W., Lower, W., Lewis, M. & Wang, W. (eds.). Plants for toxicity assessment. ASTM, Philadelphia, pp. 259–266.

— & Rennenberg, H. 1992. Characterization of glutathione S-transferase from dwarf pine needles (Pinus mugo Turra). Tree Physiology 11(2): 151–160.

Suominen, K., Suominen, K.P., Elomaa, E., Jaakkola, T., Hakulinen, R. & Salkinoja-Salonen, M.S., 1995. Fate of organic halogens from a single discharge of spent bleaching liquor from a kraft pulp mill into a small lake. In: Saski, E., & Saarinen, T. (eds.) Proceedings, Second Finnish Conference of Environmental Sciences. Department of Applied Chemistry and Microbiology. University of Helsinki.

Sutinen, S., Juuti, S., Koivisto, L. Turunen, M. & Ruuskanen, J.1995. The uptake of and stuctural changes induced by trichloroacetic acid in needles of Scots pine seedlings. Journal of Experimental Botany. 46: 1223–1231.

—, Juuti, S. & Ryyppö, A. 1996. Needle and growth responses of Scots pine seedlings to longterm exposure of chlorinated acetic acids. Submitted to Experimental Journal of Botany.

Weathers, K.C., Lovett, G.M. & Likens, G.E. 1995. Cloud deposition to a spruce forest edge. Atmospheric Environment 29(6): 665–672.

The scientific programme of the Krkonose National Park and methods supporting research

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General description of the national park

Mount Krkonose is the highest point of the Sudeten chains of mountain ranges (500–1600 m a.s.l.) located in the north-eastern part of the Czech Republic, on the border with Poland. As to its biogeographical classification, the area belongs to the region of Central-European mountains (Palearctic 2.32.12).

The exceptional natural values of the mountain areas have been protected since 1963 by means of the Krkonose Mountains National Park and its transition zone covering a total of 54 800 ha, of which 36 800 ha are forest land. Since 1992, the Krkonose Mountains have been included in UNESCO's World Network of Biosphere Reserves as a bilateral Czech-Polish Krkonose/Karkonosze Biosphere Reserve. The subarctic peat bogs on the ridges of the Krkonose Mountains are listed among the Ramsar Convention sites.

This northernmost mountain range of Central Europe appears is a unique ecological island of alpine and subalpine ecosystems. The terrain is generally steep, with an elevation range of ca. 1000 m and highly pronounced microclimatic contrasts on slopes with different aspects. The area is highly heterogeneous in terms of ecological variables such as temperature, irradiation, and available water. All flora and fauna in the Krkonose Mountains include a high proportion of arctic or boreal elements. More than 1 250 taxa of vascular plants, including many endemic species and glacial relics, have been identified in the most valuable habitats, viz. alpine tundra, subarctic peat bogs, glacial corries, stands of dwarf pine, stands of mountain spruce, mountain meadows rich in flowers, and remnants of autochothonous mixed stands of beech and spruce. The diversity of plant life is decisive in maintaining a rich fauna. The proportion of glacial relics among animals (esp. invertebrates) is high, particularly in comparison to the neighbouring mountains. A great number of vertebrates have been registered recently: more than 150 breeding bird species and about 60 mammals.

The area is dominated by stands of Norway spruce (*Picea abies*). During the mid-1970s, a large-scale decline of forest ecosystems began and its was followed by extensive salvage felling of timber and rapid changes in the species-rich plant and animal communities. Explanations for this decline abound: increased atmospheric concentrations of harmful substances produced by nearby industrial centres in SE Germany, Poland and northern Bohemia, natural climatic changes, and forestry favouring monocultures.

The present tree species composition is as follows: 95% of coniferous stands and 5% of broadleaves, whereas the original natural composition was 75% of coniferous species and 25% of broadleaves.

The Krkonose Mountains National Park Administration, with its headquarters in Vrchlabi (130 km Northeast of Prague), is responsible for nature conservation and forest management within the park and its transition zone.

Zonation in the area follows the traditional model: several strict core zones are surrounded by three other zones with lower protective statuses.
• Zone I. (strict protection): 4 400 ha, alpine, partly subalpine belts
• Zone II. (ecological management): 4 000 ha, subalpine and upper montane belts
• Zone III. (altered ecosystems): 27 900 ha, montane to submontane belts mostly
• Transition zone of the national park: 18 400 ha, submontane belt mostly.

The Czech Republic is a Central European country undergoing a process of political and economic transition which began in 1989. This involves changes of ownership and moving away from centralised state management to private enterprise. The Krkonose Mountains National Park is a state institution subordinated directly to the Czech Ministry of Environment. The land within the park belongs to the state and only a small percentage of the forests and agricultural land are private owned following their privatisation. The new political orientation provides the Krkonose Mountains National Park with more latitude for scientifically-based decision making and ecological management instead of following political orders often aimed at immediate economic profit.

The fact that the Krkonose Mountains rank among the most frequently visited national parks in Europe, with more than 8 million visitors "overnighting" a year, gives rise to considerable ecological problems.

2 The Krkonose Mountains — among the most thoroughly researched mountains of Central Europe

People have been interested in the natural conditions of the Krkonose Mountains for four or five centuries already. These mountains were known especially for the occurrence of gold, silver, copper and precious stones. Schwenckfelt's "*The Catalogue of Silesian Plants and Fossils*", describing the nature as well, and published in Leipzig in 1601, is considered to be the first scientific work on the Krkonose Mountains. The botanical part of the book provides details on finding plant habitats, so that they can be identified and compared with the present state. In many cases, plants described in the book no longer occur in the Krkonose Mountains.

Investigation of the Krkonose area by representatives of many disciplines of natural sciences continued in the following centuries and a number of indisputable endemic and glacial relicts were discovered. One of them is *Rubus chamaemorus*, discovered by Sternberg growing on Krkonose bogs in 1815. Systematic climatic observations, started in 1824, have provided valuable data.

Since the establishment of the Krkonose Mountains National Park in 1963, the scientific activities pursued by the park staff have been highly diverse, ranging from basic inventories to monitoring and research representing various sectors of the natural sciences.

3 Present scientific programmes aimed at integrated research

Present-day research has been integrated in the form of extensive programmes such as FACE, GEF, see below. Apart from this, a number of individual research tasks have been and continue to be carried out by Czech and foreign scientific institutions. The integrated research projects are:

1. Long term Strategy of Sustainable Development and Carrying Capacity of the Area (GEF Programme Biodiversity 1994–1996)

   The project encompasses field investigations in the areas of agriculture, forestry, economics, and ecological auditing, a sociological survey of visitors to the Krkonose Mountains National Park, methodology of evaluation of the impacts on the Krkonose environment.

   This project was launched within the GEF Programme (Global Environmental Facility, Programme Biodiversity), financed by the World Bank. The Krkonose Mountains National Park and Biosphere Reserve were chosen as a pilot area markedly affected by air pollution and suitable for its geographical integrity, legal protection, and possibilities for co-operation between nature conservation and forest management. The main research organisations are: the Krkonose Mountains National Park, the Institute of Applied Ecology, the Czech Academy of Sciences/Department of Botany.

   The aim in these exemplary approaches is to achieve successful management of the foremost ecosystems (e.g. mountain forests and meadows) in order to preserve high biodiversity and to provide appropriate guidelines for the management of similarly affected areas.

2. Restoration of Forest Ecosystems within the Krkonose Mountains National Park (initiated by the Dutch foundation FACE, 1993–1997)

   This project is an example of linking research and management in a protected mountain area of Central-Europe (Biosphere Reserve) affected by air pollution. The purpose of research here is to describe the relationships between forest damage and environmental factors, and to predict the potential of forest ecosystem restoration. Partial results are being integrated into a single database. The follow-up analyses and syntheses of the data obtained will serve as a basis for decision-making regarding optimal forestry management measures. Co-ordination is necessary to harmonise different investigation methods so that a set of GIS layers and remote-sensed data can be combined for practical application purposes.

   This research work is financed by the Dutch foundation FACE (Forests Absorbing Carbon Dioxide Emissions), by the Ministry of Environment of the Czech Republic, and by the Krkonose Mountains National Park. The main research organisations are: the Krkonose Mountains National Park, the Czech Forestry Research Institute/Research Station Opoèno, the University of Amsterdam/Department of Physical Geography and Soil Science, the Forestry Faculty of Brno.

   The main goals of the project set by the Krkonose Mountains National Park are:
   - to determine the scope and nature of changes in the state of health of forest stands and the main causes of changes,
   - the categorisation of the area of the Krkonose Mountains National Park as to the priorities and methods of reforestation,

- the evaluation of possibilities and limitations in the regeneration of forest ecosystems under different emission levels and climatic change, and
- to make concrete proposals for the ecological management of the area and the biotechnical measures to be applied.

4 Sources of scientific information to be compiled and their quality reviewed

The information available on this mountain area has been summarised in thousands of published studies and papers, and in hundreds of unpublished reports.

Thematic bibliographies on the Krkonose Mountains, extracts numbering 350 scientific and popular periodicals, monographs and research reports, are included in 13 500 records. These were published by the Krkonose Mountains National Park over the period 1963–1989. However, this effort did not prove to be effective enough to be continued.

Due to poor co-ordination of the monitoring and research activities in the Krkonose Mountains during the recent decades, a huge amount of primary data has been scattered, and is almost without any use, in tens of places all over the country and abroad. These should be compiled and reviewed. Since the end of the 1980s, a database of completed and ongoing research tasks has been maintained. It gives a clear overview of the majority of tasks carried out within the territory of the Krkonose Mountains National Park and enables their co-ordination. Researchers can be provided with the following kinds of data:

- thematic database register of current research tasks and
- cartographic sources, satellite imagery, aerial photographs.

4.1 Digitised data available and managed under Geographic Information System (GIS)

So far, GIS has been used by the Department of Forest Management to determine the development of forest health and consequently in spatial and temporal planning of forest regeneration. For this reason, three basic groups of data have been processed into GIS layers:

- Analyses of immission loads
  - Bioindication of immission loads by lichens,
  - Total atmospheric deposition of ecologically active substances into forest ecosystems,
  - Average daily concentrations of SO_2 and SO_4, measured since 1980,
- Dynamics of forest stand damage
  - Dynamics of damage on permanent research plots,
  - Satellite imagery Landsat 1984 – 1995,
- Other data important for planning
  - Risk of intraskeletal erosion on block fields,
  - Genetic classification of forest stands,
  - Map of forest types,
  - Geobotanic map and
  - Important botanical and geomorphological areas.

The combination of the above data should lead to the identification of units relevant to management, in the form of suitability maps (Schwarz et al. 1996). Particular attention is paid to the scale, accuracy, and history of the current GIS layers, and their applicability in practical management. A huge amount of information stored in computers without acceptable accuracy is useless for any GIS application. External data users have to sign a formal agreement setting out the conditions under which they can be used, the obligations towards the owner of the data, and the copyright of the data.

4.2 Benefits of GIS for forest research

GIS enables the integration of obtained research information in a communicative evironment and the carrying out of analyses, and modelling using visual outputs. Three kinds of analyses are particularly relevant here: impact analysis, site-suitability analysis, and site-selection analysis. Utilising interpolation and extrapolation of point data into polygons can be carried out and isolines can be created.

The final results will be simulation models of the development of forest ecosystems under predicted air pollution impacts, instructions for time and spatial planning of their restoration, identification of optimal tree-species composition and technological management measures (e.g. artificial reforestation or natural regeneration, recommendation for tending of young stands, silvicultural works).

5 Forest Research within the Krkonose Mountains National Park

5.1 Assessing forest damage — temporal and spatial development

Damage status of Norway spruce stands affected by air pollution

The most visible impact of air pollution is the disintegration of the tree layer. The dynamics of forest decline are being investigated by two basic approaches: i.e. evaluation of the state of health of trees on permanent research plots and interpretation of satellite imagery.

Landsat 5 TM imagery is being used in multi-data analyses to assess the state of health of Norway spruce stands. The said imagery is especially useful in detecting long-term changes. However, terrestrial verification is still necessary. Image interpretation should be based on the knowledge of the tree-species composition. The classification accuracy is about 70% for homogenous stands older than 40 years, with at least 90% monocultural composition and 85% canopy density. Broadleaved trees as admixtures in coniferous stands may lead to misinterpretation, i.e. that the state of health is worse than it actually is (Sima 1993).

Assessing forest cover change-over time using satellite data

Landsat imagery covering the period from 1979 to 1995 has been acquired. Factors such as the influence of elevation and slope on forest decline have been investigated. The image data have been co-registered and geo-referenced to the S-1942 co-ordinate system and also to DTM. The forest cover map of the study area has been generated by performing supervised classification using spectral signatures of forests from training areas. The results indicate that ca. 20% of the forest present within the borders of the Krkonose Mountains National Park in 1979 has been lost to date (UNEP 1995). Similar techniques have been used involving clear-cut development.

Using lichens as bioindicators of emission impact on forest ecosystems

Ground surveys have been repeatedly conducted between 1980 and 1995. The results obtained have been presented as a topological map (scale 1:25 000) and digitised. An evaluation of the changes between the two monitored periods, as well as comparison with data on forest damage interpreted from satellite imagery and ground verification, has been carried out. The occurrence of lichen species indicates increased pollution impact during the past 15 years (Schwarz et al. 1996).

5.2 Investigation of factors causing forest damage

Measurement of total atmospheric deposition

In order to assess the impact of air pollution on individual components of the ecosystem (soil, herb vegetation, tree layer), it is essential to identify the entry of ecologically active substances into ecosystems.

Since 1994, thirty-six plots have been examined for changes in pH and electrical conductivity, and in the total atmospheric deposition of various elements and chemical compounds (NH, F, Cl, NO, SO, Na, K, Mg, Ca, Cr, Mn, Fe, Al, Pb, Cd, Be, As). The plots were selected according to aspect, altitude a.s.l., and geographical location with help of GIS SPANS. The network of monitoring plots represents the basic shape of the mountain range. It allows the study of the relationship between the results and the position of emission sources, wind circulation, and basic shape of the mountain range and vegetation cover. The results are presented as a series of isoline maps representing the deposition amounts of the measured substances and a general map of immission loads (Schwarz et al. 1996).

Spatial modelling of air-pollution impact — Sources of SO_2 and their negative impact on air quality and degradation of forest ecosystems

Power plants burning brown coal rich in sulphur are the predominant source of SO_2 emissions (80 – 98%). Power plants within the "Black Triangle", the industrial area along the borders of the Czech Republic, Germany and Poland, and affecting the Krkonose Mountains National Park, have been mapped. The most significant parameters are their capacity (expressed in MWs), height of chimney, distance from the Krkonose Mountains National Park territory, and altitude above sea level.

Since 1989, a reduction in emission capacities has been recorded in the Czech Republic, Poland and the eastern part of Germany. A decrease of roughly 30% in imissions has been estimated to have taken place in the Krkonose area (DRDA, 1995).

These data will be processed in a pollution-impact model taking into account the terrain's heterogeneity combined with distance and the capacity of the pollution sources, prevailing wind sectors, and atmospheric dispersion conditions. Related input information will take the form of an existing time series of data on daily concentrations of SO_2 measured at four stations and a time series of interpreted satellite imagery on the state of health of spruce stands. Thus, it will be possible to depict the most polluted and endangered sites, to determine the correlation of pollution concentrations on individual sites with tree condition, and to model changes under different scenarios of pollution. This will be done in co-operation with the Czech Hydro-meteorological Institute.

5.3 Ground survey and monitoring

Over two hundred plots have been established within the Krkonose Mountains National Park in the past, where monitoring of various phenomena has been carried out for decades. Major efforts have been made by the Forestry Research Station Opoeno dealing with the dynamics of the composition of the tree layer, herb layer and soils, as well as silvicultural techniques applicable in reforestation.

Assessing soil erosion risks

Intraskeletal erosion, i.e. falling of organic and inorganicsoil particles through the skeleton into the lower layers threatens 28 % of the National Park. It is evident especially on clearcuts on stony and boulder slopes. The loss of soil profile is practically irreversible. The threatened sites were mapped and classified according to the risk degree. The map serves as one of the basic documents for forest management, namely for assessing priority in regeneration. Sites threatened by intraskeletal erosion will be restored by special measures (underplanting) with respect to the dynamism of health conditions.

6 Management and co-ordination of research and monitoring

6.1 Research goals in the Krkonose Mountains National Park

1. To gain more knowledge about the ecosystems' processes and the kinds of impacts affecting them;
2. Help the management of the Krkonose Mountains National Park with decision making

a) either to define specific measures aimed at sustainable natural ecosystems together with methodical, temporal and spatial solutions; or
b) not to interfere with the natural processes except to protect ecosystems against human impact.

6.2 Prerequisites for efficient management of research

1. A comprehensive review of historic and recent research and monitoring in form of easy-to-survey database should be made available by the Krkonose Mountains National Park.
2. The quality and applicability of the data should be assessed.
3. A responsible research co-ordinator should be appointed from among the park staff to be a member of the Scientific Board of Krkonose Mountains National Park at the same time.
4. The requirements for new research to be formulated by the park's experts and external co-operating scientists and reviewed by the Scientific Board.
5. Research can be conducted in the form of integrated or individual projects and theses, financed from the budget of the Krkonose Mountains National Park, Ministry of the Environment, and other sources, such as grant agencies, foundations, international scientific programmes.
6. A selection procedure to take place organised by the Krkonose Mountains National Park in case more than one institution interested in conducting a certain research task.
7. Financing to be based on a financial agreement between the research organisation and the Krkonose Mountains National Park and to include as a condition the timely presenting of annual and final reports. These reports are to be evaluated by an external referee.

8. Each external research organisation conducting research in Zone I of the Krkonose Mountains National Park has to apply for permission of access. Such a permission will be subject to a condition of filling in a database form consisting of contact address, title of research undertaking, brief description of research. After finishing the research task, the party will be asked to provide a final report. Apart from this, there is usually a national park professional as the co-ordinator, who is in personal contact with the party undertaking research. This approach allows for as complete as possible database on on-going research.

6.3 Technical recommendation

1. GIS environment is suggested as a common platform for data integration and communication.
2. Appropriate input formats, scales, and accuracy of individual task should be considered carefully.
3. A collaborative relationship among the participating parties is set as the ideal.

Hardware and software equipment of the Krkonose Mountains National Park Administration and sources of grants:

- ARC/INFO, UNIX, + INDI workstation (GEF - Biodiversity Program - World Bank),
- PC ARC/INFO (Ministry of Environment CR),
- ArcView 2.1. — two installations (Dutch foundation FACE + ME CR),
- GIS SPANS, SPANS MAP, OS/2 (Environment Canada),
- GRASS (via Internet),
- PC computers, digitiser GTCO5, IBM Lexmark Color Jetprinter PS 4079 (FACE foundation) and
- HP A0 jet printer.

6.4 Publishing of results

- Informal exchange of information, conferences, workshops, the Internet.
- Publications published by the Krkonose National Park Administration:
  - Opera Corcontica – Yearbook of Scientific Papers from Krkonose National Park,
  - The Yearbook of the Krkonose National Park Administration and
  - a popular monthly "Krkonose".

References

DRDA. 1995. (Sources of SO_2 and their adverse effect on the quality of atmosphere in Krkonose in view of destruction of forest ecosystems). Krkonose National Park Administration. Internal report in Czech. Prague, Vrchlabi, Czech Republic. 1-62 p.

Schwarz, O.,Vacek, S., Andìl, P., Hošek, J., Kaufman, R. 1996. Ecological Relations of Spruce Damage in the Krkonoše Mts.. In Conf. Proc. "Monitoring and Management of Ecosystems in the Krkonoše National Park", Opoèno Czech Republic. In print.

Schwenckfelt, K. 1601. Stirpiumet fossilium Silesiae Catalogus etc. Lipsiae (The Catalogue of Silesian plants and fossils). 407 p.

Sima, M. 1993. Assessing Forest Cover Change-Over-Time in the Krkonose National Park Using Satellite Data. Conf. Proc. Mountain National Parks and Biosphere Reserves: Monitoring and Management 1993. Spindleruv Mlyn, Czech Republic. p. 101-106.

Sternberg, C. 1818. Aufstellung drei neuer Pflanzen-Arten. Denkschr.d.Kgl. baierischen Bot. Ges. Regensburg 2: 55–63.

UNEP. 1995. Forest Damage in Central European Mountains – Final Report of a Large Area Experiment for Forest Damage Monitoring in Europe Using Satellite Remote Sensing. UNEP, Geneva, Switzerland. p 101–106.

Biogenic VOC emissions and photochemistry in the boreal regions of Europe

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Introduction

Our understanding of the role of biogenic emissions, their importance in relation to anthropogenic emissions, and their atmospheric fate in the European boreal regions is poor due to the lack of studies conducted in this area. Uncertainties in the emission estimates are large (Simpson, et al. 1995). In summer, obsevations show that a major part of the reactive mass of VOCs are from biogenic species even in the most northern part of the region (Laurila and Hakola 1996). To unravel the emissions of biogenic species and their role in photochemistry a new integrated project Biogenic VOC emissions and photochemistry in the boreal regions of Europe (BIPHOREP) has been initiated under the financial support by the Environment and Climate Research Programme of the European Commission. The project is built upon answering the following key questions:

- To make measurements of emission factors of biogenic VOCs from coniferous and deciduous trees, lichens, and ground flora.
- To test the dependence of these emission factors on environmental factors.
- To measure biogenic VOC emissions using micrometeorological methods.
- To make a boreal forest characterization and to develop a canopy model for the calculation of biogenic VOC emissions.
- To make measurements of concentrations of the most important biogenic VOCs in ambient air for understanding the seasonal cycle of concentrations and for using them as initial and validation data for the modeling excercise.
- To develop and test photochemical models to estimate biogenic emissions and the importance of biogenic emissions on the photochemical processes and ozone formation.

The project has started in 1996 and this presentation will present the research methodologies and the study areas.

2 The study area

The boreal forest is one of the world's major vegetation regions, forming a continuous belt around the whole northern hemisphere. Boreal coniferous woodlands are characterized by trees such as Norway spruce, Scots pine and downy and silver birch. Boreal forests are rich in mosses and lichens but poor in vascular plants.

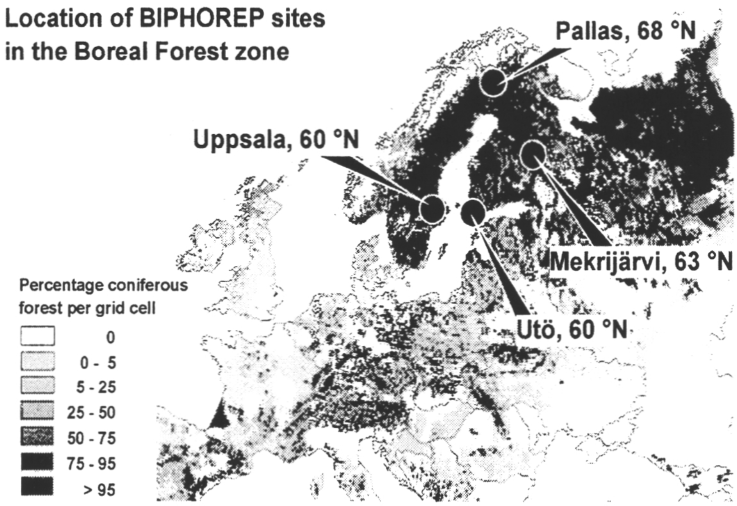

Figure 1. More than half of the world's 12 million km2 of boreal forests are situated in Scandinavia and the Russian Federation (Map from: Posch et al., Calculation and mapping of critical thresholds in Europe, RIVM Report No. 259101004, 1995)

The European boreal forest area and the study sites are depicted in Fig. 1 which shows the percentage of coniferous forest in a landuse map produced by RIVM (Posch et al., 1995). The ambient air samples at the site of Pallas are taken on the top of a fjäll, roughly 250 m above the surroundings to get VOC concentrations representative for the boundary layer average. The micrometeorological campaign in July 1996 was in a mixed birch, Norway spruce, Scots pine forest. At Mekrijärvi, the micrometeorological campaign in 1997 will be in a Scots pine forest which is more typical for this area. The ambient air samples have been collected on a hill top in the same area. Close to Uppsala is the IGBP/NOPEX site where biogenic emissions of typical coniferous trees and ground flora are studied.

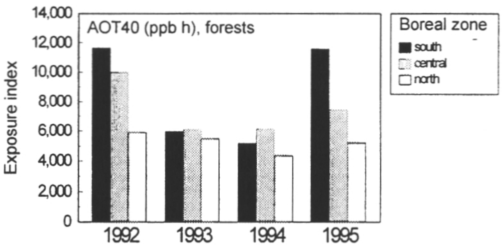

Figure 2. In the northern parts of the boreal zone, the growing season is shorter, and the climate more severe than in the south. The accumulated temperature for T>5°C is calculated for May-September, 1996.

In the boreal area cold winters and relatively short summers are typical. Forest growth depends mainly on the length and temperature of the growing season. In the northern boreal zone growing season is in June-August but in the southern zone it extends to May-September (Fig. 2). Low accumulated temperatures above 5 °C and harsh winter conditions restrict forest growth in the northern zone. Thus, in the southern zone forests are active for longer periods as sources of biogenic VOC species and effective sinks of ozone.

Forests are more impacted by ozone in the southern zone indicated by the AOT40 ozone exposure index (Fig. 3) which accumulates ozone concentrations above 40 ppb in April-September. The north-south gradient is due to anthropogenic emissions in continental Europe and also due to higher human activities and emissions in the southern boreal zone (Laurila and Lättilä 1994).

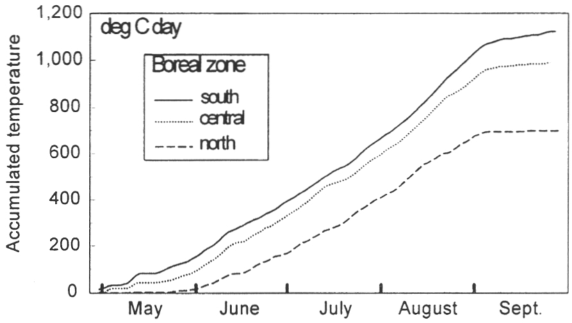

Figure 3. The forests in the southern parts of the boreal zone are more affected by anthropogenic ozone than the northern parts, mainly due to the high precursor emissions from continental Europe. The exposure index values for the years 1992–1995 are calculated according to the definitions by the UN-ECE Critical Levels Workshop in Kuopio, 1996, using background ozone monitoring data.

3 Methodology

The project methodologies include measurements of biogenic emissions from individual plants using a cuvette and/or teflon bags (Kesselmeier et al., 1996, Janson 1993). These emission factors are studied in relation to environmental parameters like light intensity and temperature and plant physiological parameters like net photosynthesis, leaf conductance, and transpiration. To get integrated emissions at the canopy scale micrometeorological flux measurement of light hydrocarbons and terpenes are part of the field campaign activities. Forest modelling (Kellomäki and Väisänen 1995) and extensive use of forest inventories (Tomppo 1996) are essential parts of the up-scaling of the emission measurements to all boreal forest zones. Ambient air concentration mesurements of biogenic VOCs and oxygenated compounds at two representative sites during an extended summer period will be used to study the seasonal composition and emission pattern of VOCs. Emission and photochemical modelling and measured ambient air concentrations will be used to make a preliminary study of the effect of biogenic VOCs on the photochemical processes (Lindfors et al. 1996).

Acknowledge

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References

Janson R. W. 1993. Monoterpene emissions from Scots Pine and Norwegian Spruce, J. Geophys. Res. 98: 2839–2850.

Kellomäki S. & Väisänen H. 1995. Model computations on the impact of changing climate on natural regeneration of Scots in Finland. Canadian Journal of Forest Research, 25: 929–942.

Kesselmeier J., Schäfer L., Ciccioli P., Brancaleoni E., Cecinato A., Frattoni M., Foster P., Jacob V., Denis J., Fugit J. L., Dutaur L. & Torres L. 1996. Emission of monoterpenes and isoprene from a Mediterranean oak species *Quercus ilex* L. measured within the BEMA project. Atmos. Environ. 30: 1841–1850.

Laurila T. & Lättilä H. 1994. Surface ozone exposures measured in Finland. Atmos. Environ.: 28, 103–114.

Laurila, T. & Hakola H. 1996. Seasonal cycle of C2–C5 hydrocarbons over the Baltic Sea and Northern Finland. Atmos. Environ. 30: 1597–1596.

Lindfors V., Hakola H. & Laurila T. 1996. Boundary layer photochemistry of light hydrocarbons in Finland; measurements and model studies. In: EUROTRAC Symposium '96, Garmisch-Partenkirchen. Zerhoch-Schmidt, Garmisch-Partenkirchen, in press.

Posch M., de Smet P. A. M, Hettelingh J.-P. & Downing R. J. (eds.) 1995. Calculation and mapping of critical thresholds in Europe. CCE Status Report 1995, RIVM Report No. 259101004, National Institute of Public Health and the Environment, Bilthoven, the Netherlands.

Simpson D., Guenther A., Hewitt C. N. & Steinbrecher R. 1995. Biogenic emissions in Europe Part I: Estimates and uncertainties. J. Geophys. Res. 100(D11), 22, 875–22, 890.

Tomppo, E. 1996. Multi-source National Forest Inventory of Finland. New Thrusts in Forest Inventory. Proceedings of the Subject Group S4.02-00 'Forest Resource Inventory and Monitoring' and Subject Group S4.12-00 'Remote Sensing Technology'. Volume I. IUFRO XX World Congress 6–12 August 1995, Tampere, Finland. EFI Proceedings, 7. 15 p. European Forest Research Institute.

BIPHOREP home page: http://www.pub.fmi.fi/~biphorep/

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Repeated red belts at Lusmavaara, western Lapland

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Introduction

Red belts are a particular type of winter frost damage injuring trees in certain topographic localities. The result is reddening of the foliage of conifers to the extent that the reddening is spectacular in late winter or early spring. Typically, red belts appear as more or less well defined horizontal stripes or broader bands at specific elevations in valleys and along mountain sides, but less commonly in forests in valley bottoms (Venn 1993).

The oldest written records on red belts in Fennoscandia go back over 100 years (Evenstad 1881, Hørbye 1882). Red belts have a long history not only in Fennoscandia (Skurdal 1908, Schøyen 1909, Langlet 1929, Venn 1962, Jalkanen 1992a), but also in the Rocky Mountains of North America (Melrose 1919, Henson 1952, MacHattie 1963, Robins and Susut 1974, Schmid et al. 1991).

This brief communiqué describes the red belts of 1986, 1991 and 1996 in the proximity of the Pallas-Ounastunturi National Park in Lusmavaara, western Lapland.

2 Material and methods

A systematic line survey was carried out in 1991 and 1996 to study the damaged forest area at Lusmavaara. In accordance with the results of the 1991 survey, the boundaries of the 1986 red belt were estimated based on the visible branch injuries on Scots pine (*Pinus sylvestris* L.). The dating of the oldest red belt in Lusmavaara was based on branch analysis (see Kaitera and Jalkanen 1992). An altimeter was used to locate the red belts of 1991 and 1986 in relation to the contour lines. Some damage-intensity parameters were determined from sample trees.

The stand on the hill side under decline is dominated by Scots pine, age ca. 120 years. Some parts of the forest have been thinned more strongly, giving rise in places to new growth. Seed-tree felling was carried out in 1990 in the northern part of the damaged area and in 1994 in the southern part.

3 Results

The first red belt symptom, discoloration of needles, was noticed on Scots pine in March 1991 and 1996 by local forest workers of the Pallasjärvi research area. However, there are no records of the 1986 red belt before the 1991 survey.

The areas covered by the three red belts of 1986, 1991 and 1996 over-lapped and were located along the same slope of the Lusmavaara ridge, facing southeast to north, mainly east–northeast (Fig. 1). The oldest and tiniest red belt of 1986, about 20 ha in size, lay within the other two on the east-facing slope. Most of the damaged living trees were located near the contour line of 260 m a.s.l. adjacent to Lusmavuoma, an aapa mire with a few scattered pines.

The 1991 red belt, 105 ha in size, had a more northerly location in relation to Lusmavaara, but its southern part entirely over-lapped the 1986 red belt (Fig. 1). In fact, the most severely damaged core area of the 1991 red belt, 23 ha in size, was located just like the 1986 area. The 1991 red belt was situated between the contour lines of 260–285 m a.s.l., its horizontal width being 200–500 m and altitudinal height 7 m at its minimum and 25 m at its maximum. Again, the most distinct damage began from the boundary between the aapa mire and the forest, at 260 m a.s.l.

In 1996, the main red belt was more southerly in occurrence, covering about 140 ha. For the first time, severe damage was noticed as far as on both sides of the Kivijärvi–Pallasjärvi forest road (Fig. 1). Slight, but visible needle damage was observed also far into the pine bog west of the road and north of Kivijärvi. The 1996 belt was mainly located between the contour lines of 260–280 m a.s.l., but trees at 305 m showed some needle injuries in the SE corner of Lusmavaara. The 1986 red belt was located in the northern part of the 1996 area, and this red belt, too, over-lapped the two earlier ones.

The most severely damaged trees in each of the red belts, like the trees within the 23 ha area in 1991, were found to occur in the middle of the damaged area. Less damaged trees were found along the edges of the area, except along the edge adjacent to the aapa mire. In 1991, the trees nearest to the mire showed top damage, with the lower parts of the canopy remaining healthy (green). However, especially in 1996, heavily damaged solitary trees were found scattered on the mire. Some trees were damaged evenly on all sides of their canopy. A minority of trees (especially conifers) showed heavier needle and shoot injuries generally on the downslope side of the tree. The compass directions of the most severe damage within canopy were east, east and north-east in 1986, 1991 and 1996, respectively.

Lusmavaara is dominated by naturally established Scots pines of varying ages. Therefore, the damage was concentrated on pine, but nevertheless, all tree species and their above-snow parts in winter were injured. The lower branches and seedlings were protected by snow. Typically, pine lost most or all of its overwintering needles and most of its buds. In more severe cases, only the buds in the topmost leader and branch shoots stayed alive, and these buds burst in the following summer. These trees have stayed alive, and they have extended their canopy area from year to year. In slighter damage cases, the needles, buds, and therefore branches, died on one (eastern) side, but remained alive on the other side. Dead pine needles stayed intact more than a year from the appearance of damage, whereas Norway spruce (*Picea abies* (L.) H. Karst.) lost its needles sometime in the spring of injury.

A typical symptom of severe damage on broadleaved trees was that the trees flushed only in a few places along the thickest parts, such as along the stem and along older branches, where adventitious buds were viable. All the fine shoots seemed to be dead and did not flush the following season. Like the pines that lost

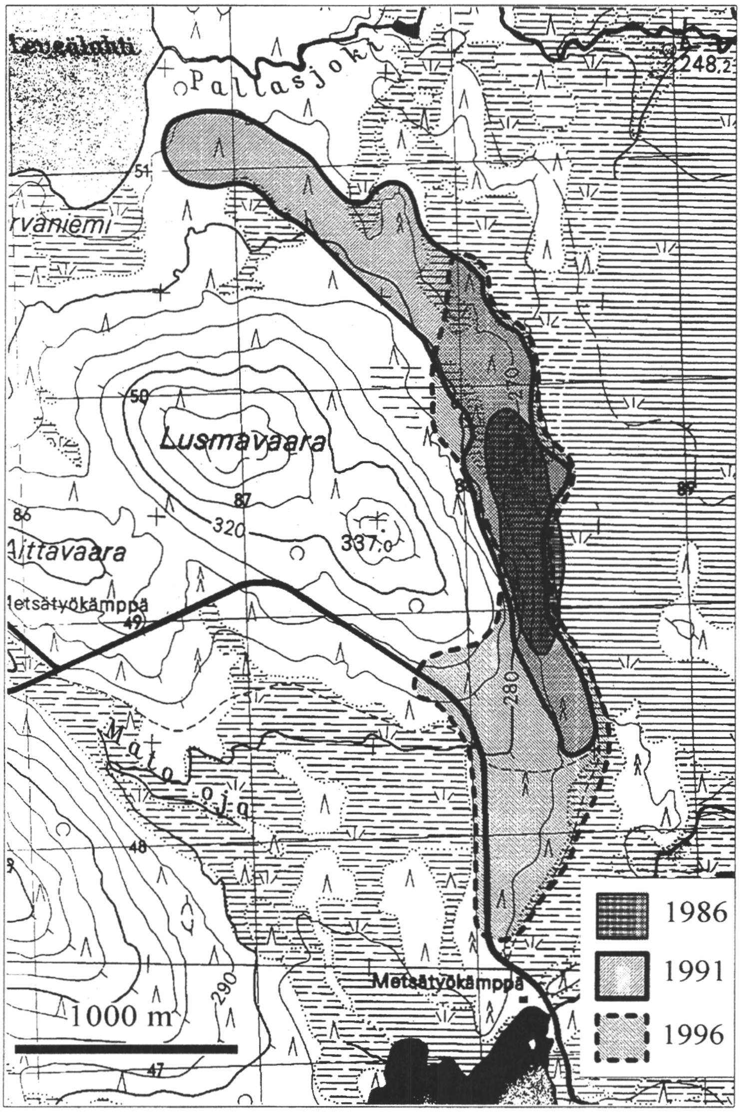

Figure 1. The location of the 1986, 1991 and 1996 red belts on Lusmavaara ridge near Pallas-Ounastunturi National Park, western Lapland.

all their needles, broadleaved trees with a few living points in 1991 were still alive five years later. In this respect, birches (*Betula pendula* Roth, *B. pubescens* Ehrh.), aspen (*Populus tremula* L.), willow (*Salix caprea* L.), and alder (*Alnus incana* (L.) Moench) behaved in a similar manner.

4 Discussion

The eastern slope of the Lusmavaara hill seems to be very prone to conditions favouring the occurrence of a red belt. Although this is the first time that it has reported for over-lapping red belts to have been repeated from the same slope, it can occur elsewhere, too. In fact, there was repeated damage in 1996 in at least two other areas of the 1991 red belts (Jalkanen 1992b), namely at Levi and Ylläsunturi (Jalkanen, unpubl.). Ylläsunturi had its red belt phenomenon already in 1986 (Jalkanen 1986). Repetition is possible because most trees within a red belt survive (Bella and Navratil 1987, Schmid et al. 1991), and it is mainly growth loss (Blyth 1953, Venn 1962, Bella and Navratil 1987) and sometimes bark beetle attacks (Klein 1990, Jalkanen and Närhi 1993) that follow.

Why, then, is the eastern slope of Lusmavaara exceptionally prone to conditions leading to red belt type damage? According to Langlet's (1929) hypothesis, temperature inversion, typical for the boreal zone in winter, and rapid temperature fluctuations are the main contributing factors in the occurrence of a red belt. Cold air in the valley bottom, or in another place enabling cold air to accumulate, moves towards the warmer upper slope causing rapid freezing of plant cells and tissue death. In temperature inversion, it is always coldest in the valley bottoms, but when the temperature is slowly decreasing, accumulating cold air in the valley bottom cannot markedly harm the trees. Locally, the temperature can drop extremely low if there are no objects (trees, stones etc.) to prevent heat radiation. All this needs is a clear sky with no wind. Places with maximal out-radiation include lakes and larger clear-felling areas. At Lusmavaara, highly heat out-radiating areas are Lusmavuoma aapa mire, which begins from the hill slope, and the nearby Lake Pallasjärvi. At Lusmavaara, cold air has blown from over the Lusmavuoma aapa mire. This is supported by the findings that trees were more damaged on the downslope (windward) side and less on the leeward side. The last red belt was largest due to the fellings in 1994, which opened the way for cold air to stream further than earlier.

References

Bella, I.E. & Navratil, S. 1987. Growth losses from winter drying (red belt damage) in lodgepole pine stands on the east slopes of the Rockies in Alberta. Can. J. For. Res. 17: 1289–1292.

Blyth, A.W. 1953. Reduction of growth in conifers caused by red belt in the subalpine region of Alberta. Division of Forest Research, Forestry Branch, Department of Resources and Development. Silvicultural leaflet 79. 3 p.

Evenstad, O. 1881. Et Særsyn af Tørke paa Furuen. Den Norske Forstförenings Aarbog 1: 127–128.

Henson, W.R. 1952. Chinook winds and red belt injury to lodgepole pine in the Rocky mountain parks area of Canada. Forestry Chronicle 28: 62–64.

Hørbye, J. 1882. Om frostskader paa barskoven. Den Norske Forstföreningens Aarbog 2: 99–105.

Jalkanen, R. 1986. Metsätuhot Lapin metsissä talven jälkeen. Lapin Kansa 24.6.

— 1992a. Syntyykö Kittilän Leville vaakasuora pujottelurinne? Länsi-Lapin metsävauriovyöhykkeitä tutkitaan. Teollisuuden Metsäviesti 1/1992: 24–27.

— 1992b. Metsävauriot tunturien rinteillä. Ympäristökatsaus 1992(9): 9–10.

— & Närhi, P. 1993. Red belt phenomenon on the slopes of the Levi fell in Kittilä, western Lapland. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 55–60.

Kaitera, J. & Jalkanen, R. 1992. Disease history of *Gremmeniella abietina* in a *Pinus sylvestris* stand. European Journal of Forest Pathology 22(6–7): 371–378.

Klein, W. 1990. A survey of winter damage in the forests of Montana, 1989. USDA Forest Service, Northern Region. Timber, Cooperative Forestry and Pest Management. Report 90-6. 11 p.

Langlet, O. 1929. Några egendomliga frosthärjningar å tallskog jämte ett försök att klarlägga deras orsak. Zusammenfassung: Einige eigentümliche Schädigungen an Kiefernwald nebst einem Versuch, ihre Entstehung zu erklären. Svenska Skogsvårdsföreningens Tidskrift 27: 423–461.

MacHattie, L.B. 1963. Winter injury of lodgepole pine foliage. Forest Research Branch Contributions 536. 4 p.

Melrose, G.P. 1919. Red-belt injury in British Columbia. Canadian Forestry Journal 14: 164.

Robins, J.K. & Susut, J.P. 1974. Red belt in Alberta. Information Report NOR-X-99. Northern Forest Research Centre, Edmonton, Alberta. 6 p.

Schøyen, W.M. 1909. Om frostskade paa furuskog. Tidsskrift for Skogbruk 17: 25–27.

Schmid, J.M., Mata, S.A. & Lynch, A.M. 1991. Red belt in lodgepole pine in the Front range of Colorado. Research Note RM-503. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 2 p.

Skurdal, O. 1908. Frostskade paa furuen i Tolgen. Tidsskrift for Skogbruk 16: 375–377.

Venn, K. 1962. Frostbelter, en sjelden frostskade i Krødsherad. Norsk Skogbruk 18: 591–594.

— 1993. Red belts in boreal forests. In: Jalkanen, R., Aalto, T. & Lahti, M-L. (eds.). Forest pathological research in northern forests with a special reference to abiotic stress factors. Extended SNS meeting in forest pathology in Lapland, Finland, 3–7 August, 1992. Metsäntutkimuslaitoksen tiedonantoja 451: 50–54.

Development of a plant-phenological observation network in Finland

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Introduction

Phenological research examining the rhythm of biological phenomena and the effect that various factors have on them is a branch of science of long standing in Finland. The Finnish Society of Science launched a nationwide system of phenological monitoring way back in 1846, and this continued, with a few breaks in between, up to the 1960s (Johansson 1945, Lappalainen 1992). At present, there is no systematic plant-phenological monitoring network fulfilling scientific criteria in Finland. However, the University of Helsinki's Museum of Natural Sciences has, during the recent years, collected data on various natural phenomena by way of questionnaires aimed at the public. On a smaller scale, plant-phenological research has been conducted in recent years by at least the following institutions: the Finnish Meteorological Institute, the University of Oulu, the University of Turku, the Agricultural Research Centre, and the Finnish Forest Research Institute (e.g. Aniszewski 1988, Hari and Häkkinen 1991, Lappalainen and Heikinheimo 1992, Lappalainen 1994, Heino 1995). There are also three gardens in Finland belonging to the network of European Phenological Gardens (IPG) maintained by the German Meteorological Institute with the purpose of monitoring the phenology of genetically identical species of trees and shrubs (Polte-Rudolf 1993).

The Finnish Forest Research Institute (Metla) has initiated a study with the aim of establishing a plant-phenological monitoring network. Such a network is considered necessary for reasons such as studying the effects that temperature changes taking place in the atmosphere have on forest ecosystems. In 1995, Metla and various universities, Finland's Environment Centre and the Agricultural Research Centre conducted a joint preliminary study during which phenological phenomena were monitored in different parts of the country with respect to a few plant species. In 1996, this monitoring work was primarily at various Metla research premises. This was accompanied by an expansion of the preliminary study to cover the forecast system of berry and mushroom yield and observations related to the seed crops and the growth rhythm of forest trees. The purpose is to make the said monitoring work a continuing process once the various elements have been fused to form a working, contiguous whole.

Climate change and particularly variations in air temperature have significant impacts on the growth rhythm of plants when these occur at the limits of their natural distribution range, especially at northern latitudes. The effect that long-term changes in air temperature, for example, have on the rhythm of phenological phenomena is most readily obtained in these extreme conditions. In the case of

Metla's monitoring contribution, the institute's northernmost observation points, at Pallasjärvi and Kilpisjärvi, and the University of Turku's Kevo Research Station, are especially valuable.

2 Material and Methods

In 1995, various phenological phenomena were monitored at a total of sixty-eight monitoring points in different parts of Finland (Fig. 1). These monitoring points were research stations of universities and research institutions and field research stations, whose staff were also responsible for making the observations. In 1996, the observation network comprised just twenty-three monitoring points all of which (with the exception of Kevo, the University of Turku's research station) were located in areas under the administration of Metla.

In the years 1995 and 1996, plant-phenological monitoring included four broadleaved tree species, i.e. downy birch (*Betula pubescens* Ehrr.), silver birch (*Betula verrucosa* Ehrr.), bird cherry (*Prunus padus* L.), rowan (*Sorbus aucuparia* L.), and two dwarf-shrub species, namely bilberry (*Vaccinium myrtillus* L.) and cowberry (*Vaccinium vitis-idaea* L.). Silver birch and downy birch were monitored regarding the timing of the following phenomena: leaf-emergence, bursting into leaf, reaching of full leaf size, yellowing of leaves, and shedding of leaves. Bird cherry and rowan were monitored only as to their flowering time. Bilberry and cowberry were monitored for their flowering and ripening of berries. In 1996, monitoring also included height increment of pine and the occurrence of frost damage in spruce. The observations were recorded on monitoring forms 2–3 times a week.

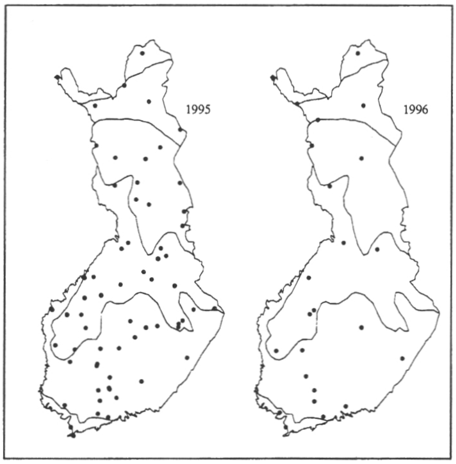

Figure 1. Plant-phenological observation points of the monitoring period 1995 and 1996 in relation to the plant-geographical division of Finland (Kalliola 1973).

Kalliola's (1973) plant-geographical division of Finland was used as an aid in depicting the results. The average times of occurrence were computed for each phenological phenomenon monitored and these were then used in outputting a series of maps for each of them. This series of maps depicts the progress of individual phenomena at intervals of one week from that point in time onwards when the phenomenon is perceived for the first time.

3 Results and discussion

The following are examples of observations made in the course of plant-phenological monitoring of the bursting into leaf, leaf growth, yellowing, and shedding of leaves by downy birch (*Betula pubescens*) in 1995 and 1996. Even observations made of a single plant clearly reveal the dependence of the various phenomena on weather factors, above all on air temperature. The leaves of downy birch emerge when an adequate effective temperature sum has accumulated. In addition to temperature, other factors also affect the bursting into leaf; e.g. the amount of light (number of daylight hours), genetic factors, soil factors, etc. The leaves of downy birch in southern Finland came forth on the 20th of May (Fig. 2) in both of the monitoring years. The effective temperature sum required for leaf emergence and for bursting into leaf is delayed the more northerly the location. In northernmost Lapland, the leaves of downy birch emerged about a month later than they did in southern Finland in 1995 and 1996.

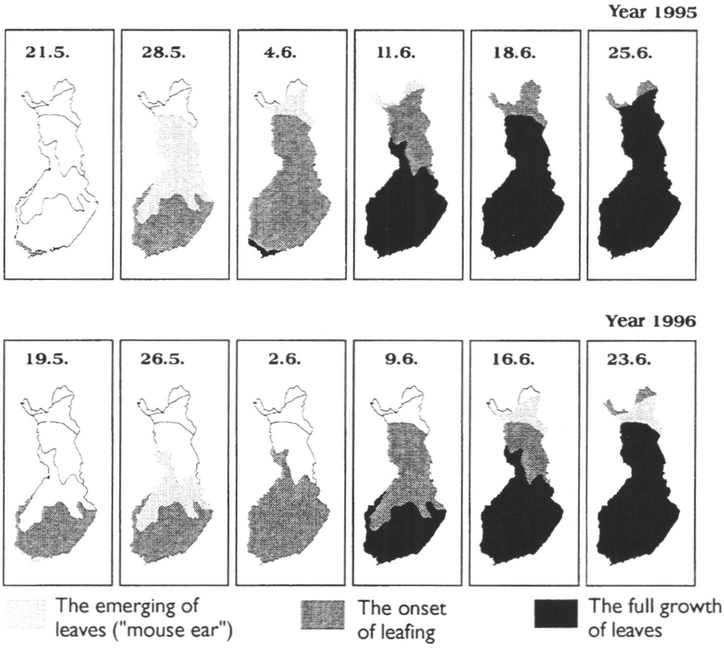

Figure 2. Emergence of leaves, bursting into leaf, and attaining of full leaf by downy birch (Betula pubescens). Pictures are based on phytogeographieregions of Finland. Date is the last day of the week.

The time of the bursting into leaf of downy birch varies every year and is dependent on the weather conditions in spring and early summer. In southern Finland, the mean temperatures in May in 1995 and 1996 were almost the same and so downy birch's leaf growth (emergence, bursting into leaf, and attaining full-size) took place almost at the same time in both years, towards the end of May. When compared to the situation in 1995, the mean temperature in May 1996 was so much the lower the more northerly the location monitored. Whereas June in 1996 was cooler than average throughout Finland, the emergence of the leaves of downy birch and their growth to full size took place approximately a week later than in 1995; this was especially the case in northernmost Lapland. The variation in the timing of bursting into leaf is at its maximum in the fringe areas of the distribution range of birch. At Kevo, for instance, where phenological observations have been made on various plant species since 1980, the leaves of mountain birch (*Betula pubescens* ssp. *tortuosa*) have emerged at their earliest on 23.5. (1984) and at their latest on 24.6. (1993) (Heino 1995).

Results on the yellowing of leaves of and shedding of the leaves by downy birch are available only for the autumn of 1995 (Fig. 3). The yellowing of leaves and the onset of autumn colouring are connected to plants preparing themselves for winter dormancy. The series of events leading up to the yellowing of the leaves is launched mainly by the length of the night. In 1995, the leaves of birches in northernmost Lapland began to turn yellow already at the beginning of September, which more or less corresponds to the long-term average yellowing time of leaves in the said region (Heino 1995). Almost throughout Lapland, downy birch shed its leaves that year by the end of September. The yellowing and shedding of leaves proceeded towards the south with downy birch in southern Finland turning yellow and shedding its leaves about 2–3 weeks later than in Lapland.

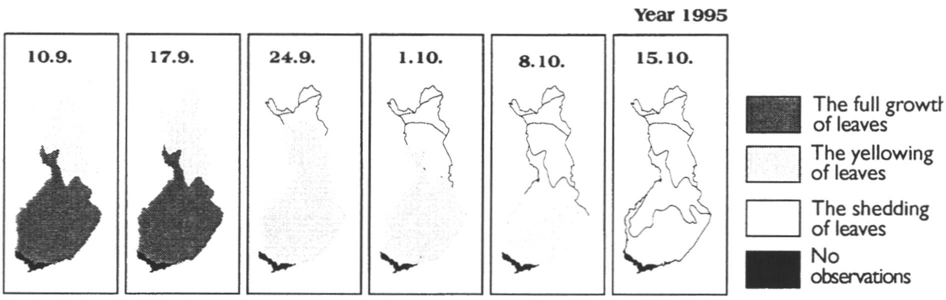

Figure 3. Yellowing and shedding of leaves of downy birch in 1995.

The above results are based merely on the information received from observation points. In future, the purpose is to use climate data and suitable models and interpolation in obtaining more detailed maps on phenological phenomena. When modelling, attention will be paid to the effect of altitude above sea level, and the proximity of seas and great lakes. The quality and number of the climate data used in the modelling depend on the particular phenological phenomenon. In the matter of growth-related phenological phenomena the practice will be to mainly use the effective temperature sum (Lappalainen 1994), even though the use of the effective temperature sum is not without its problems (Lappalainen 1992, Lappalainen and Heikinheimo 1994). In modelling phenomena related to plants' transition to the dormant stage, use will be made of the number of daylight hours in addition to temperature data. One reason for doing is that the yellowing of leaves is tied up with the length of the day (number of daylight hours). Microclimatic factors, soil factors, and other factors affecting the growth of plants, can also cause deviations from results obtained through interpolation. The accuracy of recordings made at observation points is also an important factor affecting the results.

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References

Aniszewski, T. 1988. Puiden, pensaiden ja viljeltävän turvemaan fenologinen tutkimus. Summary: Phenological sudy on the trees, bushes and arable peat land. Maatalouden tutkimuskeskus. Tiedote 2/88. 120 p.

Hari, P. & Häkkinen, R. 1991. The utilization of old phenological time series of budburst to compare models describing annual cycles of plants. Tree Physiology 8: 281–287.

Heino, S. 1995. Lehteentulon ja ruskaantumisen vuotuinen vaihtelu pohjoisella metsänrajalla. Julkaisussa: Poikolainen, J. & Väärä, T. (toim.). Metsäntutkimuspäivä Kuusamossa 1994. Metsäntutkimuslaitoksen tiedonantoja 552: 62–68.

Johansson, O.V. 1945. Det fenologiska observationsmaterialet i Finland och provstudier av samma. Bidrag kännedom Finlands nat. folk 88(8): 5–118.

Kalliola, R. 1973. Suomen kasvimaantiede. 308 s. WSOY. Porvoo.

Lappalainen, H. 1992. Kasvifenologiatutkimuksesta. Luonnon Tutkija 96: 120–125.

— 1994. Examples of plant phenological events in Finland and their relation to temperature. Memoranda Society Fauna Flora Fennica 70: 105–121.

— & Heikinheimo, M. 1992. Relations between climate and plant phenology. 1. Survey of plant phenological observations in Finland from 1986–1965. Meteorologisia julkaisuja 20. 74 p.

Polte-Rudolf, Ch. 1993. Die IPG-Datenbank im Deutschen Wetterdienst. Arboreta Phaenologica. Mitteilungen der Arbeitsgemeinschaft Internationaler Phaenologischer Gärten No 38: 5–27.

Ants and insect damages of mountain birch

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Introduction

Geometrid caterpillars defoliate mountain birches (*Betula pubescens* subsp. *czerepanovii* (Orlova) Hämet-Ahti) in NW Europe at about 10-year intervals (Tenow 1972). Usually trees survive well, but sometimes they suffer from high mortality. In the mid 1960's, vast areas of mountain-birch forest were killed by the autumnal moth (*Epirrita autumnata* (Brk.) in Inari Lapland (Kallio and Lehtonen 1973).

In the midst of destroyed fell slopes, there are undamaged green islands around wood ant (*Formica aquilonia* Yarr.) mounds. Their origin has been explained by predation (Laine[1] and Niemelä 1980, Niemelä and Laine 1986) and soil amelioration (White 1985) by ants.

2 Research project

In our current research project we have conducted experiments to test predation and fertilization hypotheses. Further, we have made manipulative field trials to check how well our model applies to a local outbreak of the autumnal moth in white birch (*Betula pubescens* Ehrh.) forests in Pallas-Ounastunturi National Park in 1992–94.

3 Preliminary results

The percentage of undamaged birches declined during both outbreaks when the distance from the ant mound increased from 0 to 20 m, which is the average radius of green islands. The proportion of intact leaves decreased both in a normal year (Fig. 1) and during the latter outbreak. Similarly, the population size of caterpillars and their invertebrate predators (spiders) increased with distance.

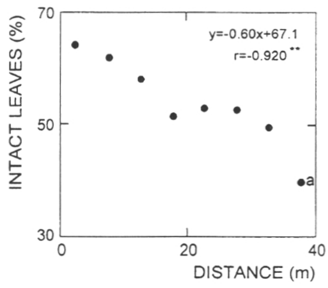

Figure 1. The percentage of intact leaves at different distances from the mound a in a normal year 1979 (Laine and Niemelä 1980).

[1]Presently K.J. Karhu.

Table 1. Nitrogen content (%) of birch leaves (31 July, 1985) (Niemelä and Laine 1986).

Area	Sample site	Foliar nitrogen content			
		mean	S.D.	n	t-value
Damaged	Nest periphery	1.87	0.25	4	0.775 N.S
	25m from nest	1.75	0.25	8	
Healthy	Nest periphery	2.00	0.08	4	0.052 N.S
	25m from nest	2.00	0.21	8	

No clear trends in concentrations of nitrogenous nutrients in the soil were evident. However, the nitrogen content of birch leaves was higher in mound-located trees (Table 1). They maintained better growth of autumnal-moth larvae both in field and laboratory experiments. This suggests that wood ants may indeed fertilize soil (at a range of 2–6 m) by collecting nest material and food into their nests.

In field experiments where half of the trees were inaccessible to ants (a glue ring around the trunk), higher survival rate of test larvae in a normal year and more naturally occurring larvae during an outbreak were found in trees without ants. Moreover, the difference between glued and unglued trees was more pronounced in the vicinity of ant mouds. This suggests that wood ants prey upon the caterpillars, when they collect honeydew excreted by an aphid (*Symydobius oblongus* Heyd.) in birch foliage. The radius of the predatory activity of ants was found to be about 20 m in a predator exclusion experiment.

4 Discussion

In conclusion, our study shows that there is significant small-scale spatial heterogeneity in interactions between wood ants, mountain birches, ant-attended aphids, autumnal moths and their natural enemies. It is important to measure their relative strengths and spatio-temporal variation before we properly understand outbreak dynamics of forest pests.

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References

Kallio, P. & Lehtonen, J. 1973. Birch forest damage caused by Oporinia autumnata (Bkh.) in 1965-66 in Utsjoki, N Finland. Reports from the Kevo Subarctic Research Station 10: 55–69.

Laine, K.J. & Niemelä, P. 1980. The influence of ants on the survival of mountain birches during an Oporinia autumnata (Lep., Geometridae) outbreak. Oecologia 47: 39–42.

Niemelä, P. & Laine, K.J. 1986. Green islands – predation not nutrition. Oecologia 68: 476–478.

Tenow, O. 1972. The outbreaks of Oporinia autumnata (Bkh.) and Operophthera spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862–1968. Zoologiska Bidrag från Uppsala Universitet, Supplementum 2: 1–107.

White, T.C.R. 1985. Green islands – nutrition not predation – an alternative hypothesis. Oecologia 67: 455–456.

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