Research and management of the northern timberline region

Proceedings of the Gustaf Sirén symposium in Wilderness Center Inari, September 4.–5.1997

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The Finnish Forest Research Institute
Kolari Research Station

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Cover photo: Heavy snow-load on pine and spruce crowns near the timberline in Kolari. It is one of the factors influencing the location of timberline in certain areas of Finland. Photo: Tapani Tasanen 1996.

Gummerus Kirjapaino Oy
Saarijärvi 1998

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Preface

The supposed warming of the atmosphere has aroused a common interest in timberline issues. Timberlines and treelines are among the most reliable of biological indicators of global climate change. People living north of the Arctic Circle expect increasing amounts of CO_2 to have positive effects besides the threats commonly feared. During the latest 70 years, the northern timberline has been observed to be slowly moving northwards and upwards on the slopes of Lapland´s fells. This has been seen as positive development, because the frightening lowering of the timberline at the beginning of this century is still remembered. However, global changes are very complicated phenomenoms. We should not draw biased conclusions of their advantages or disadvantages. A lot of questions concerning the change in the timberline ecosystems are waiting answers from researchers. This symposium represents a modest effort to present a survey of the present timberline research and management of northernmost areas in Finland. In addition to researchers, also those who are responsible for planning and making decisions of land use in timberline regions are represented among the writers of this publication.

Professor Gustaf Sirén, to whom this symposium and publication is dedicated, started his research work at the northern timberline of *Pinus sylvestris* nearly fifty years ago. In the late 1940´s timberline research started mainly from silvicultural needs. Making forest regeneration more effective was an important objective for Sirén´s employer, the Finnish Forest and Park Service. The young researcher presented practical instructions for site preparation, sowing, planting and tending of pine stands. Together with his fellow-researchers he prepared instructions for management of the Protection Forest Zone of northern Lapland.

Sirén continued his research work at the timberline while working as a professor of silviculture at Helsinki University, The Royal College of Forestry in Sweden and the Finnish Forest Reasearch Institute. His approach to timberline problems developed in a more ecological direction. Nevertheless, his main interest was still the regeneration of Scots pine, especially the flowering and seed maturation processes. In 1990´s, besides continuing his former researches, Sirén localized the exact position of the present northern pine treeline. The significance of his work has increased because of its connection to the global climate change. For example, the World Resources Institute has recently invited professor Sirén to give presentations at its annual conferences. Although Sirén is now bringing his field studies to an end, a big task is still ahead. He has started to write a synthesis of the results of his research work at the northern tree- and timberline. His article in this publication is a synopsis of that extensive work.

Tapani Tasanen

Figure 1. Professor Sirén presenting his experiments in Muotka to the participants of the symposium.

Results and conclusions of pine advance in subarctic Finland in the 20th century

Gustaf Sirén

1 Introduction

The discovery of an unexpected occurrence of a large one-year old pine (*Pinus sylvestris*) seedling area in northernmost Finland (N Lat 69° 20') in August 1951 raised the question of the survival of the pine germlings. Five old pine seed trees per ha had efficiently produced a dense population of small pine seedlings under a sparse five-six meters tall mountain birch (*Betula pubescens ssp. czerepanovii*) stand four km north of pine timberline. An immediate clearcut saved the pine seedlings from a deadly covering of autumn litterfall. Thus, today a 47-year long research task was initiated. A hypothesis of pine northward advance was formulated in 1957. The main aim of this presentation is to inform about the most significant features of this work. I shall concentrate on

- the process of pine advance and its causes
- local conditions, seed year occurrence and successional changes
- stemwood production capacity
- potential of CO_2 sequestration
- evaluation of results

Definitions of pine advance related concepts are illustrated in Fig. 1.

2 General procedure

In the beginning the main components of the project dealt with improvement of pine seed germination, seedling survival, development in various mountain birch stand conditions and ecological adjustment of ageing pine stands. In 1957 additional sample plots were established for comparative studies of pine stand production in some representative pine seedling thickets. Later on the study focused on improvement of flowering, seed production and seed maturation as well as seed dispersal, age of sexual maturation and details of the spontaneous northward advance. The new pine thickets and tree-lines further north of the previous timberline gave a chance to study the process of increasing stem number caused by repeated seed years. Soon it became possible to study the reversed process of decreasing stem number caused by ageing of the stands. In the final stages the project concentrated on quantifying stemwood production, bioenergy resources and CO_2 sequestration. Some complementary field work is still going on. Therefore, this report is of preliminary nature. The main report is planned to be available in two years time.

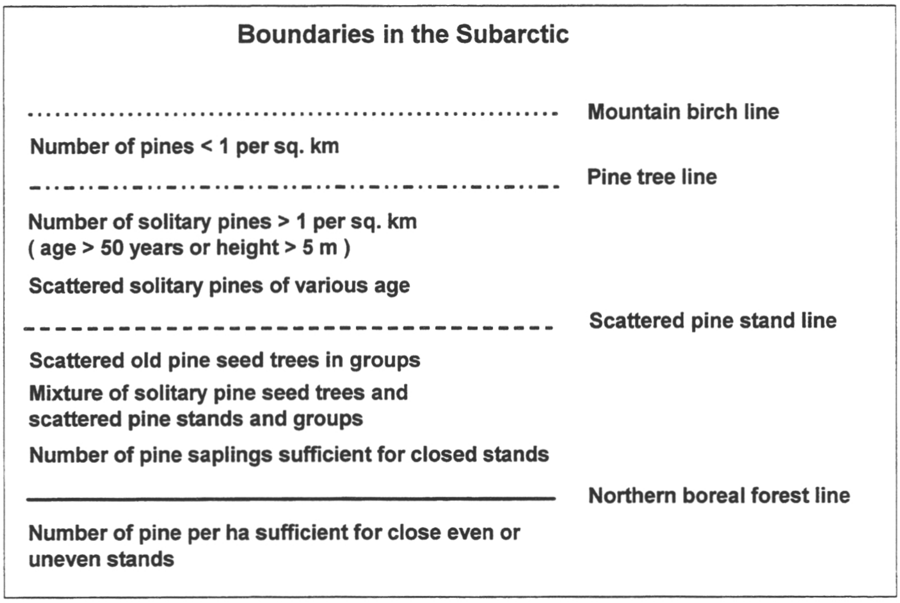

Figure 1. Definitions of timberline and tree-line concepts used in this article.

3 Methods

As early as in 1948 Hustich assumed the pine advance in the Pallas mountain area to be caused by warming climate (Hustich 1948). It seemed rational to test whether this hypothesis was applicable also in the Muotka area 150 km further north. For the time period of 1908-1996 we have used basic climate data from meteorological stations at distances of 40-100 kilometres. Information about climate trends of previous centuries was obtained from two different tree-ring studies for the period 1300-1960 (Sirén 1961) and 1300-1995 (Timonen 1998) respectively. Survival inventories were carried out in existing germling plots as well as in later designed sowing experiments. Because of the value of exact dating of previous seed years careful measurement of the age was of crucial importance. The most exact method available in the fieldwork was to count nodes and tree-rings of seedlings from young and old sample trees. An inventory was carried out in order to quantify and date the ongoing advance of pine seed-trees and seedlings into the mountain birch-dominated transition zone between the timberline and treeline. In the regeneration studies two different methods were used, cluster network method and a conventional trajectory inventory method applied between the clusters. Transparent and perforated plastic bags were periodically used as miniature greenhouses to promote female flowering and seed maturation.

GPS-method was used to locate the present position of the pine treeline (map and description of the method, see Forest 1998). For CO_2 sequestration the roots of representative sample trees were excavated. In two cases single tree roots were carefully dug up. In two other cases 20 regularly located 30x30 cm wide plots were excavated in 10 cm thick sample layers from which the roots were carefully extracted by sieves. Extracting the pine roots from the humus layer was extremely time-consuming. Conventional forest research methods were used for site classification and annual stemwood production measurements.

4 Main results

The main results so far obtained will be presented of general stand development. Since the seed year of 1939 forest-lines have advanced from the former timberline (determined by Hiilivirta in 1935, see: Metsähallitus 1944 - 1956) 2 - 12 kilometres northward in 58 years time. The wide variation of advance is mainly due to the uneven occurrence of pine seed trees and the degree of blockading effect of mountain birch stands as well as location of large swamp lands. Among factors contributing to the advance, the following deserve to be mentioned:

Rich pine reproduction years have so far occured six times during the 20th century and a seventh seed year is expected in 1998. Each one of the flowering years has taken place after but in some concordance with maximum activities of the sunspot cycle lasting for three or four years since 1919. Pine seed years recurred when the annual temperature sum of the growing season exceeded 800 d.d with a few minor exceptions (Fig. 2).

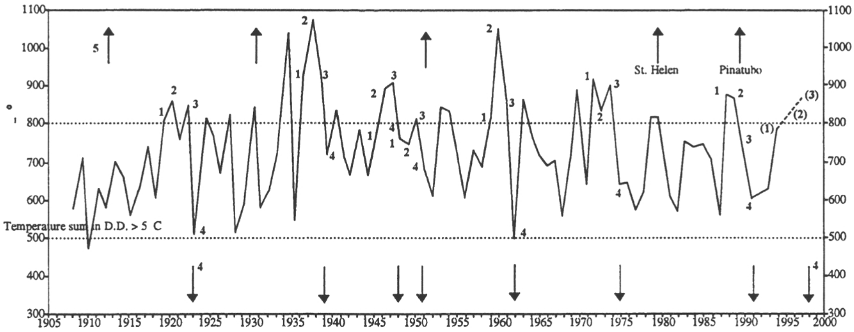

Figure 2. Variation of growing season temperature sum ($\sum T \geq 5°C$) at Ivalo meteorological station during the period 1908 - 1995. (the d.d. values of 1996 - 1998 are based on local measurements in the research area). Pine reproduction periods covering at least three warm successive summers are indicated by thick lines (d.d. sum > 800). The numbers 1, 2 and 3 correspond to the following processes: 1. Conversion of vegetative buds into generative ones is going on. 2. Flowering and pollination takes place, conelets are formed. 3. Conception and thereafter cone development and seed maturation. 4. If seed has matured dispersal starts gradually in early spring.
Arrows at the bottom indicate seed dispersal years. The uppermost vertical arrows represent years of volcanic eruptions. The dotted lines indicate temperature sum levels of 500 and 800 d.d., respectively.

The seed year correspondence with the sunspot cycles seems rather pronounced during a few of the previous centuries (Fig. 3; see also Timonen 1998). Details of the impact of the late summer climate variation upon the entire process of seed development remain to be studied in detail.

Basic research work valuable for this study has been successfully carried out by a seed research group at Oulu University (Tillman-Sutela and Kauppi 1995) and the forestry faculty of the Swedish University of Agricultural Sciences in Umeå (Sahlén and Bergsten 1993, Sahlén and Abbing 1995).

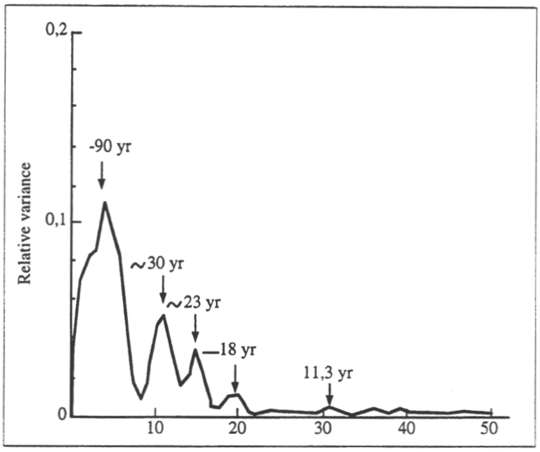

Figure 3. The power spectrum of a Lapland tree-ring series for the period 1463 to 1960. This series which is considered to provide an indication of temperatures during the high summer in northern Finland, shows the most marked periodicities at 90, 30 and 23 years. (From Lamb 1972; compare with Burroughs 1994, p. 69).

It is generally assumed that the first warm summer of a three year long seed production period causes conversion of vegetative buds into generative ones. Flowering, pollination and small-cone formation follow the second summer. Fertilization, cone development and seed maturation are completed the third summer. The results of the promotion experiments of pine female flowering can be seen in table 1. In some cases the seed maturation experiments need to be repeated.

Table 1. Average number of female flowers per twig in field experiments 1994 - 95.

	Forced trees		Comparison trees	
Forcing period	Free top	Forced crown	Free top	Free crown
June	0.92	1.97	0.74	1.46
July	0.58	0.65	0.54	0.69
August	0.48	0.52	0.78	0.65
September	1.64	1.78	0.82	1.19
1.6. - 30.9.	1.03	0.40	0.71	1.25

Seed dispersal takes place in late spring and early summer the fourth year, which often in the past has been rather cool. Apparently it was too cool in 1962 for seed germination. In this connection it must be emphasized that delayed germination is commonplace in the subarctic.

Wind-dependent dispersal distance sometimes exceeds 50 metres. Apparently, gusts of wind, running animals and daily variable riverlet melt-water can occasionally transport fully matured seed more than two kilometres. In late spring weather-driven seed is easily carried over snowcrust-covered treeless mires. Evidence of this type of migration can be seen along the tongues of land at the northern shores of large mires where uneven-aged pine individuals occur.

The first reliable large-scale evidence of a northward advance was obtained in 1957 when an inventory of mainly seven year old seedlings was carried out north of the timberline. For partly unknown reasons the lasting benefit of this advance has been locally heavily disturbed (snowblight?).

Germination conditions vary with soil type. The mountain slopes are mostly dominated by moraine and the lowlands by sand. In the north soil moisture is seldom a minimum factor. Ground vegetation is an obstacle to pine seed germination especially on fresh sites dominated by *Empetrum nigrum* and/or *Vaccinium myrtillus.* Mountain birch forms another type of obstacle by covering the ground with heavy litterfall in the autumn. To get a better understanding of the impact of natural germination obstacles, field experiments on a variety of ground conditions were established with a strip-sowing method as control.

Generally speaking, soil conditions in the north seem critical mainly on fresh birch-dominated soils. Fortunately, there are remedies. The impact of large catastrophes on the soil has been considerable in the transition zone between the timberline and treeline. Uprooting storms, wildfires and biological ravages have improved germination conditions. In most cases they positively promote the successional development of vegetation in favour of pine. When there are too few pine seed trees the effect may be delayed. Establishment and survival of pine seedlings is reduced particularly in birch-dominated succession stages. Successful attacks of autumn moth (*Epirrita autumnata*) improve the odds for pine, with the exception of compact thick raw humus sites which prevent survival of germinating seed. On these sites only wild-fires or the use of controlled burning can initiate a new successful succession.

The duration of storms and wildfires has usually been a day or a few days only. The disaster areas they have caused sometimes exceed 30 000 ha. Numerous separate *Epirrita*-attacks have destroyed mountain birch stands more than 400 000 hectares in a few years time. The recovery of the destroyed areas requires time. Prerequisites for rapid recovery are availability of viable seed, favourable climate and germination conditions, resistance to insects and especially to pathogenes, low competition etc. Thus, destructive catastrophes alternate with a constructive series of events, which may be called *anastrophes* - using a concept originally suggested by Baltscheffsky (1997) in a biochemical, evolutionary context.

Sexual maturation of female-dominated young pine trees in the subarctic takes about 40±10 years time. Thanks to generally abundant pollen clouds even solitary female pine trees produce large amounts of cones. The cone number of 50-70 years old solitary trees sometimes exceeds 300, which may mean that ten seed trees per hectare produce >60 000 seeds. Vigorous old seed trees often carry more than a thousand cones. In the 20th century, this type of fertility has been one of the main prerequisites of the rapid advancement of pine in the transition zone between pine timberline and treeline.

Thanks to careful age measurement of trees, the timetable of advance is fairly easy to model. As for speed, early sexual maturation and regeneration of solitary pines in all directions in the transition zone contributes more efficiently to the total advance than the timberline with its unidirectional frontline advance.

Within the new pine forest-line stemwood volume of a 45 a year old stand was found to be 65 m^3 in average. The running annual growth totals 2.90 m^3/ha/yr during the years 1991 - 1995 which have been comparatively cold.

The dry weight of all separate parts of the sample trees above the soil surface were measured, both dead and alive, to increase understanding of the CO_2 sink. In four stands of different age considerable root quantities (kg/m^3) have been excavated. The results obtained reveal the impact of the cold soil. Pine trees in the transition zone have large and flat root systems. Because of the physiological function of the roots, their wood density is low and their volume in most cases a fraction of the tree above the ground. There is a periodic renewal of the fine roots.

Speed of advance has been studied in different ways. Two of them will be mentioned. The standard cluster method was used in four inventory areas >10 km^2 at increasing distance from the pine forest line of year 1935. If efficiency of regeneration had reached a number exceeding 800 dominant trees per ha aged ≥50 years, a new section of the forest-line (1995) was established. The average distance between the two forest lines was about six km. Time used for this advance was found to be about 60 years. The average advance of the forest line was found to be one km per decade, which seems due to the seeding efficiency of scattered solitary pine seed trees.

The border of the northernmost area of this inventory was identical with the new pine tree-line. Low number of solitary seed trees and seedlings per hectare or cluster indicated decreasing speed of advance.

The second method used was tracking the new pine tree-line of solitary trees along a border between areas with less than one and more than one tree per km^2. From this line the distance was estimated to the closest visible seed tree in SE - SW direction. The running average of the distance between ten pines in succession should not exceed one km. Selected tree-line pines had to be at least 50 years old or have a height of five metres. The purpose of this tree-line is to facilitate a follow-up of future changes of the advance or retreat from this established northernmost pine tree-line.

5 Conclusions

The climate of the 20th century has been favourable for pine in the far North of Finland. Six good seed years have promoted a return of pine stands to areas earlier covered by pine forests which have been ridden by catastrophes. In the last decades, the advance of the timberline has been rapid.

However, a word of warning. The failure of the seed year in the beginning of the 1980's will undoubtedly somewhat delay a further advance. The future of the continuation of the northward advance of pine will mainly depend on the temperature sum of the present growing season and the years after the millennium shift. Whether the next sunspot activity will recur simultaneously with warm summers remains to be seen. In case high sunspot activity normally initiates successful flowering of pine, there will be good reason to expect a rich seed year in the first decade of the third millennium. Seed tree groups can be established over large areas using small seed quantities.

Under prevailing warming conditions, the main long-term consequence of this process may imply that the productive forest area of Finland will increase with 0.2 - 0.3 million hectares during the next century. Standing stock as well as capacity of the CO_2 sequestration will increase accordingly. Ageing of pine stands creates CO_2-sinks which can last for hundreds of years.

Sustainability of this presumably new Nature reserve forest area will be most interesting beacause of the longevity of pine. On the other hand, the risk of storms and wildfires cannot be totally excluded.

From an international point of view, the observed advancement over decades of the pine forest-line in northernmost Finland appears to be a concrete argument supporting the message of the IPCC (Intergovernmental Panel On Climate Change) on global warming. However, the facts available about the advance of the pine forest-line in northernmost Finland indicate that the climate change so far seems slower than that prognosticated in the international models. The measured change of temperature in the period 1930 - 1990 was only 0.2 degrees Celsius (measured in Ivalo).

6 Some proposals

Regarding activities in the circumpolar subarctic, promotion of conifer seed year seems recommendable especially in case the need of efficient CO_2 sequestration increases dramatically. Experimentation with long-living genetically tested conifer species should be intensified in suitable circumpolar and high altitude regions.

To improve future observation reliability of the advance of subarctic tree species, semi-permanent circumpolar and altitudinal tree-lines have to be established where possible, at earliest possible date.

Previously protected forest areas within the former timberline can gradually be included within the region of normal ecologically skilful and sustainable forestry. Logging waste and mountain birch should be used in local cogeneration plants instead of fossil fuels, where other energy resources are too distant, more expensive or environmentally disastrous.

Creation of a new forest resource means not only establishment of new seedling stands and new CO_2 sinks. Sustainable use of new biomass reserves also means a formerly neglected potential of diversified employment possibilities for local people. The costs of the creation of this type of natural resources seem bearable, provided that implemention is carried out with methods especially promoting efficient seed production for natural regeneration.

The methods outlined above are by no means the only unique possibility of creating both CO_2 sinks and energy resources. Everywhere around the globe Man has injudiciously destroyed forest resources. Now is the moment of efficient and careful restoration. Forests are creeping upwards the mountains in many parts of the world. There the biomass output per altitudinal metre will be substantially higher than in the circumpolar forest-tundra. However, the alpine areas available are small compared to the millions of hectares in the subacrctic of our globe, especially in Russia, Siberia and North America.

This study has concentrated on the advance of pine in the Subarctic of Finland. However, there are other species that also deserve attention. The mountain birch has in many places developed in a way similar to the stand development of pubescent birch (*Betula pubescens*). A few spontaneous 20 - 30 years old silverbirches (*Betula pendula*) do already exist at a latitude of 69° N lat. These would be interesting objects of study for the research group on mountain birch at the Kevo subarctic research station administered by the University of Turku.

Finally, to all seed researchers of our time I would like to express my admiration and gratitude. Seed is the key to the future, and hopefully a long lasting anastrophe.

References

Baltscheffsky, H. 1997. Major "anastrophes" in the origin and early evolution of biological energy conversion. J. theor. Biol. 1977(187): 495 - 501.

Burroughs, W. J. 1994. Weather cycles. Real or imaginary? Cambridge University Press.

Forest, P. 1998. GPS traversing the Scots pine treeline of northern Finland - research and related survey problems. In this publication, pages 89 - 94.

Hustich, I. 1948. The Scots pine in northernmost Finland and its dependence on the climate in the last decades. Acta Botanica Fennica 42: 1 - 75.

Metsähallitus 1944 - 1956. Utsjoen hoitoalue. Yleinen kertomus, taloussuunnitelma ja yleiskartta.

Sahlén, K. and Abbing, K. 1995. Effect of artificial environmental conditions on anatomical and physiological ripening of *Pinus sylvestris* L. seeds. New Forests 9: 205-224.

Sahlén, K. and Bergsten, U. 1993. Artificial ripening of early collected Scots pine cones attached to branches. In Edwards, D.G.W. (ed.) Dormancy and barriers to germination. Proc. Internat. Sympos. IUFRO Project Group P2.04-00 (Seed Problems). Victoria, B.C., Canada, Pacific Forestry Centre, Victoria, B.C. 113-120.

Sirén, G. 1961. Skogsgränstallen som indikator för klimatfluktuationerna i norra Fennoskandien under historisk tid. Communicationes Instituti Forestalis Fenniae 54.2: 1 - 66.

Tillman-Sutela, E. and Kauppi, A. 1995. The morphological background to imbibition in seeds of *Pinus sylvestris* L. of different provenances. Trees 9: 123 - 133.

Timonen, M. 1998. Dendrochronological analysis at pine timberline. In this publication, pages 37 - 42.

Timberline, insect pests, and minimum winter temperatures; applications of GIS

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1 Introduction

Insect pests commonly attack trees in northern Fennoscandia and they have an important role in the dynamics of timberlines. Large-scale defoliations caused by geometrid larvae (*Epirrita autumnata*, and *Operophtera* spp.) are typical in the mountain birch forests (Tenow 1972, Haukioja et al. 1988) and they may occasionally kill trees over hundreds of square kilometers (Kallio and Lehtonen 1973). The gregarious sawfly *Neodiprion sertifer* is an important pest of Scots pine in southern Finland but in northern Finland it attacks only some stands at the timber line at high elevations (Virtanen et al. 1996).

The most important defoliators of both birch and Scots pine share similar life cycles in the respect that they overwinter as eggs. Furthermore, the critical temperature for the survival of eggs of these species is about -36 °C. This, together with the geographical and topographical distribution of minimum winter temperatures causes clear patterns in the distribution of damage during outbreaks; defoliation is more common in the upper parts of slopes while forests in the valley bottoms are protected by 'cold air lakes' (Kallio and Lehtonen 1973; Tenow 1975; Niemelä et al. 1987).

In this paper we review studies that have applied geographical information systems (GIS) to study patterns of minimum winter temperatures in relation to egg mortality and/or outbreaks of forest insects.

2 Mountain birch and the autumnal moth

Mountain birch (*Betula pubescens* ssp. *czerepanovii*) forms the timberline in north-western Europe and it is here that the autumnal moth (*E. autumnata*) periodically defoliates vast areas of forests. Normally the birches can recover from 1-2 years of defoliation but sometimes forests can be killed over large areas, e.g. in Finnish Lapland in 1965-1966 (Kallio and Lehtonen 1973).

We studied the relationship between *E. autumnata* egg mortality, minimum temperatures, and topography in the surroundings of Kevo Subarctic Research Station (69°45'N, 27°00'E) during three winters 1993-1996 (in more detail in Virtanen et al. 1997). The topography of the area has low rolling hills dissected by river valleys and smaller streams. The study sites were selected to be representative of areas with different topography. Egg mortality was measured by placing 30-40 eggs (in plastic vials) per site in mountain birch canopies 1.5 m above ground level in autumn; egg mortality was recorded the following spring. Temperatures were recorded at the same sites. The data was imported to a geographic information system (ARC/INFO^{TM}) together with a digital elevation database.

A statistical model that predicted egg mortality as a direct function of topography was reasonably accurate; in a comparison of observed vs. predicted mortality, only 4 of 43 cases were misclassified. However, this approach is not feasible for wider applications since the actual model varies from year to year and estimating parameter values would require field observations for each winter.

One way to achieve wider applicability is to model egg mortality in two steps: 1) by modeling site specific minimum winter temperatures as a function of minimum temperatures in a nearby meteorological station and topographical parameters, and 2) applying a function (based on laboratory studies of Nilssen and Tenow 1990) describing egg mortality as a function of minimum temperature. The topographical parameters we used for each site were altitude above sea level, and a flow-accumulation function at higher altitudes (part of ARC/INFO's hydrological modelling tools based on topography and used in the present context to describe the flow of cold air along stream channels; see Tenow 1975). A regression model incorporating minimum temperature at Kevo meteorological station and these topographical parameters explained 81 % of the variation in site specific minimum temperatures in a set of observations not used in model construction. A comparison of egg mortality in field to the function based on laboratory determinations of supercooling points (Nilssen and Tenow 1990) showed a good fit especially in the lower part of the temperature range (Virtanen et al. 1997).

Using the models described above and accumulated data from Kevo Meteorological Station during a 30 year period 1961-1991 it was possible to estimate the frequency of years with *E. autumnata* egg mortality in different altitudinal classes. Estimates varied from 84 % at elevations below 100 m a.s.l. to less than 4 % at elevations above 250 m a.s.l. When we overlaid a GIS map of vegetation type, we obtained estimates of the frequency of egg mortality in different forest types. These ranged from 36 % in mixed birch and pine forest to 15 % in healthy mountain birch forests, and to 6 % in birch forests damaged by *Epirrita* (Virtanen et al. 1997).

When the density of moths in the previous season and the minimum winter temperatures (e.g. at meteorological stations) are known, the models discussed above can be used to forecaste where *E. autumnata* outbreaks will occur. More generally, we have shown that GIS is a valuable tool for modelling ecological processes and their dependence on climate and topography at various spatial scales.

3 Scots pine and the European pine sawfly

Presently, European pine sawfly outbreaks are rare or non-existent in northern and eastern Finland probably because cold winters kill the overwintering eggs in these areas (Virtanen et al. 1996). GIS was applied to analyse the distribution pattern of *N. sertifer* outbreaks in Finland during 1961-1990 at two spatial levels: forest board- and municipal levels. At the coarser spatial resolution (forest boards) the incidence of minimum temperatures below -36 °C explained one third of the variation in the frequency of outbreaks. At smaller spatial scale (municipalities) the incidence of cold winters as well as the proportion of coniferous forests on damage-susceptible soils (dry and infertile sites) explained a significant part of the variation in outbreak frequency in northern Finland (Virtanen et al. 1996).

A notable exception in the general geographical pattern of European pine sawfly outbreaks is an isolated but more or less chronic outbreak at

Saariselkä (Virtanen et al. 1996). On the slope of Mountain Kaunispää the pines at the summit (430 m a.s.l) and on the upper slope (380 m a.s.l) were heavily damaged while those at the foot of slope (280 m a.s.l.) were intact (Niemelä et al. 1987). This pattern can be explained by temperature inversions and, consequently, higher minimum winter temperatures on the upper slope and summit where temperatures were warm enough to permit survival of overwintering eggs.

The *N. sertifer* outbreak in Saariselkä also shows that this pest can survive the short summers and low temperatures of northern Finland although it requires two years for its life cycle compared to one year in southern and middle Finland. If warmer winters with less severe minimum temperatures are realized in the future, the risk of *N. sertifer* outbreaks may also increase at lower altitudes in northern Finland, as predicted by Virtanen et al. (1996). Furthermore, if warmer summer temperatures permit pines to grow at higher altitudes, the area susceptible to *N. sertifer* outbreaks may increase at the northern timberline.

Virtanen et al. (1996; Fig. 4) showed that *N. sertifer* outbreaks can occur if the incidence of winters with temperatures below -36°C is less than 35 %. During 1961-1991 the estimated frequency of winters so cold was 57 % in the pine forests surrounding Kevo and 36 % in mixed pine-birch forests (Virtanen et al. 1997); this means that cold winters protect pine forests around Kevo from *N. sertifer* outbreaks in the present day climate. However, according to scenarios of global warming, the situation may change in 50-100 years so that *N. sertifer* outbreaks become as common in northernmost Finland as they are today in southern Finland (Virtanen et al. 1996, 1997).

4 Conclusions

The preceding examples demonstrate practical applications of GIS to analyses of timberline, forest pests, and environmental factors. GIS is a tool that facilitates the linkage of large scale ecosystem processes (e.g., the dynamics of timberline) to various landscape features. In addition GIS can bridge the gap between the scales at which processes operate in nature and the scales used in general circulation models. However, to better understand the responses of vegetation to climatic change at the edge of forest distributions in the north we need more information about the interactions between trees and herbivores. In particular, we need to know what affects the population dynamics of herbivores themselves, whether biotic factors like natural enemies or abiotic factors such as summer temperature, precipitation, UV-radiation, and the concentrations

CO_2 and ozone (see e.g., Neuvonen et al. 1996, Saikkonen and Neuvonen 1993). This knowledge is crucial to understand the relationship between large-scale changes such as defoliations and vegetation change, hydrological, and climatic processes.

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References

Haukioja, E., Neuvonen, S., Hanhimäki, S. and Niemelä, P. (1988) The autumnal moth in Fennoscandia. Pp 163-178 in: Dynamics of Forest Insect Populations: Patterns, Causes, and Management Strategies (Ed. A. A. Berryman). Plenum Press.

Kallio, P. and 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.

Neuvonen, S., Virtanen, T., Nikula, A. and Varama, M. (1996) Climate change and the risks of forest insect outbreaks. In Roos, J. (ed) The Finnish Research Programme on Climate Change. Final Report. Publications of the Academy of Finland 4/96, 275-280.

Niemelä, P. Rousi, M. and Saarenmaa, H. (1987) Topographical delimitation of *Neodiprion sertifer* (Hym., Diprionidae) outbreaks on Scots pine in relation to needle quality. J. Appl. Entom. 103, 84-91.

Nilssen, A. and Tenow, O. (1990) Diapause, embryo growth and supercooling capacity of *Epirrita autumnata* eggs from northern Fennoscandia. Entomologia Experimentalis et Applicata, 57, 39-55.

Saikkonen, K. and Neuvonen, S. (1993) European pine sawfly and microbial interactions mediated by the host plant. Pp. 431-450 in M.R. Wagner and K.F. Raffa (Eds): Sawfly Lifehistory Adaptations to Woody Plants. Academic Press, San Diego.

Tenow, O. (1972) The outbreaks of *Oporinia autumnata* Bkh. and *Operophtera* spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862-1968. Zoologiska Bidrag från Uppsala, Supplement, 2, 107 pp.

Tenow, O. (1975) Topographical dependence of an outbreak of *Oporinia autumnata* Bkh. (Lep., Geometridae) in a mountain birch forest in Northern Sweden. Zoon, 3, 85-110.

Virtanen, T., Neuvonen, S., Nikula, A., Varama M. and Niemelä P. (1996) Climate change and the risks of *Neodiprion sertifer* outbreaks on Scots pine. Silva Fennica 30, 169-177.

Virtanen, T., Neuvonen, S. and Nikula, A. (1997) Modelling topoclimatic patterns of egg mortality of Epirrita autumnata (Lep.: Geometridae) with Geographical Information System: predictions in current climate and in scenarios with warmer climate. - submitted for Journal of Applied Ecology.

Physiological changes in needles of *Pinus sylvestris* during late winter under sub-arctic conditions

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1 Introduction

Late winters and early springs in the sub-arctic are characterized by freezing temperatures and high radiation levels. Thus, winter desiccation (Tranquillini 1982) and photoinhibition (Öquist 1986) are typical stress factors acting upon conifer needles during that time of the year. Yellow needles or needle tips are visual indications of this stress condition. This is clearly seen especially in conifer seedlings and saplings. The extent of yellow coloring show noticeable tree-to-tree variation. This brings up the question of whether yellowing is an indication of better adaptation to the harsh late winter conditions or whether it is merely the first stage in injury. Further, there is the question of the connection between the presence of yellow color, photosynthesis, freezing stress resistance, and the water relations of conifer needles.

2 Materials and methods

A naturally regenerated stand of Scots pine (*Pinus sylvestris* L.) saplings growing on a sandy soil was selected as the study site. Five saplings, the most green and most yellow ones, were chosen each time that needle samples were taken. The current year's needles were used as the study material. Study period was between May 27 and June 25 1996. Chlorophyll fluorescence was measured with a portable fluorometer (PEA, Hansatech Instruments LTD). The water content, chlorophyll content, and freezing-stress resistance (electrolyte leakage method, Sutinen et al. 1992) of the needles were measured in the laboratory within 24 hours of the sampling. For the ultrastructural studies the methods of Soikkeli (1980) and Sutinen *et al.* (1995) were used. ^{1}H NMR imaging was carried out using a Bruker AMX-400 spectrometer equipped with a micro-imaging accessory. Spin echo, single-slice pulse sequences were used. The qualitative distinction between free and bound water was achieved by using variable spin-echo times (TE from 5.76s to 8,32s). The water content (dielectric coefficient) of the soil, roots, and stem was measured using a time-domain reflectrometer (TDR, Tektronix 1502B, metallic cable tester). The temperatures were automatically recorded by Hamster (ELPRO-BUCHS AG).

3 Results and discussion

The yellow color of needles is an indication of a state of severe photo-inhibition. The chlorophyll *a* and *b* contents and F_v/F_m in the green needles were higher than in the yellow needles (Fig. 3). The recovery of F_v/F_m in yellow needles was accompanied by an increase in chlorophyll *a* and *b* and greenish color.

The yellow color do not truly reflect the water relations of needles. There were no differences in the water content between the green and yellow needles. Furthermore, the change in the water content was opposite to the change in chlorophyll content and appearance of green color in the originally yellow needles. The yellow needles recovered (chlorophyll and F_v/F_m) completely by the end of June. However, the water content in the needles was at its lowest level by that time. This was not due to lack of water in the soil, roots or stem (Fig. 1 and 2).

The ultrastructural studies showed that the size of chloroplasts and the starch content were higher and increased faster in the green needles when compared to yellow needles. The amount of grana thylakoids was low at the first sampling in the yellow needles and increased during the study period. However, the amount of grana thylakoids was constant in the green needles during all samplings (Fig. 4A-4B). These results suggest that the yellow needles stay longer in the winter condition.

The distribution of free and bound water differed between the needle groups (Fig. 5). In green needles the total amount of free and bound water was high in the mesophyll cells surrounding the stomata and resin ducts and in the xylem cells. In yellowish needles the water was located mainly in the transfusing tissue. The images with the short TE of 5.76 ms and with the long TR (a repetition time) of 5.0 s contained the signals from all water protons whereas the signals of the images obtained by using a longer TE of 8.32 ms arose from more free water. The signal intensities of the yellow needles at a TE of 8.32 ms are higher than those of the green needles, which indicates that water existed in a more mobile form in yellow needles (Fig. 5 B, D).

The yellow needles maintained a higher level of freezing-stress resistance when compared to the green needles (Fig. 3). These results suggest that trees with yellow needles are better prepared for possible cold spells in the spring, which are a fairly regular feature of the sub-arctic.

The efficiency of photosynthesis was lower in yellow needles during the study period. This could mean lower productivity and weaker competitiveness in the normal spring weather conditions, when there is no risk of late spring frost.

References

Öquist, G. 1986. Effects of winter stress on chlorophyll organization and function in Scots pine. J. Plant Physiol. 169-179.

Soikkeli, S. 1980. Ultrastructure of the mesophyll in Scots pine and Norway spruce: Seasonal variation and molarity of the fixative buffer. Protoplasma 103: 241–252.

Sutinen, M-L., Palta, J. P. and Reich, P. B. 1992. Seasonal differences in freezing stress resistance in the needles of *Pinus nigra* and *Pinus resinosa*: Evaluation of the electrolyte leakage method. Tree Physiol. 11: 241-254.

Tranquillini, W. 1982. Frost-drought and its ecological significance. In: Lange O. L., Nobel P. S., Osmond C. B. and Ziegler H. (eds.). Encyclopedia of plant physiology, vol. 12B. Springer, Berlin, pp. 379-400.

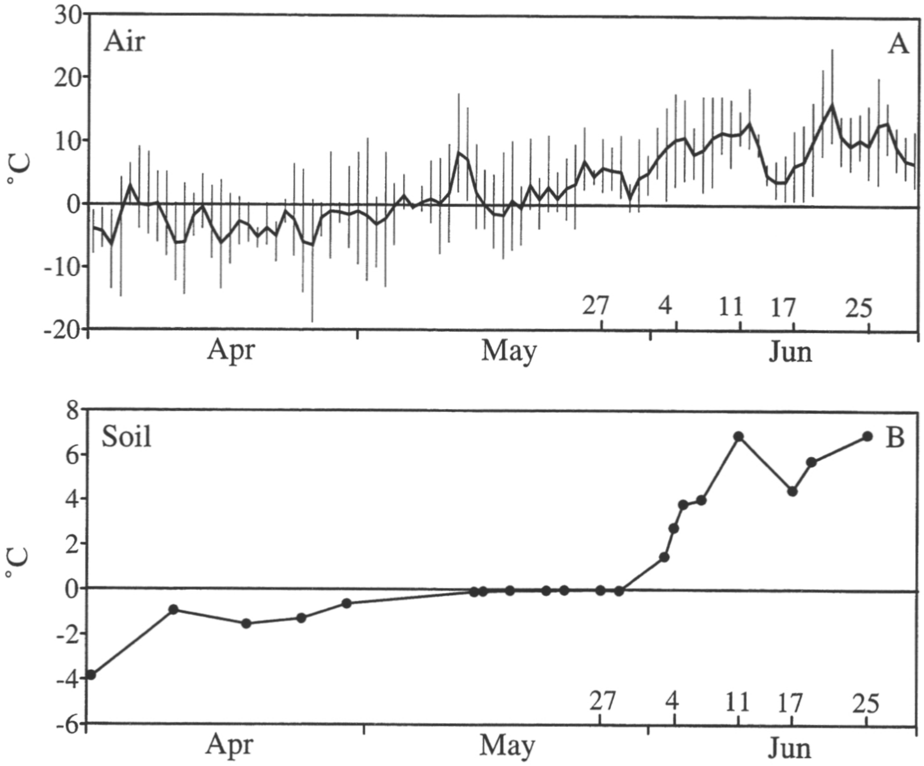


Figure 1. Seasonal changes in the daily minimum, maximum and mean air temperature (2 m above ground) and soil temperature (10 cm depth) from April to June 1996.

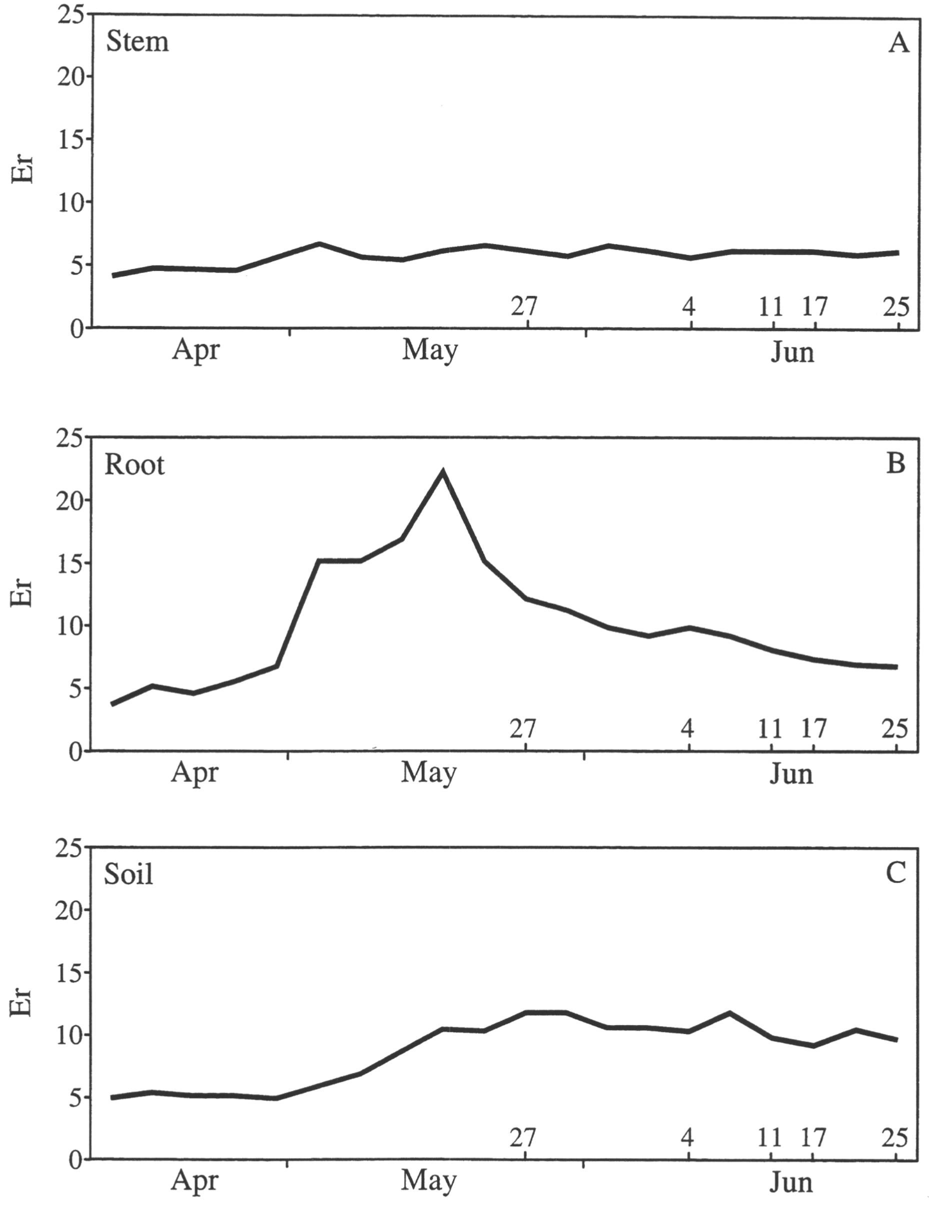


Figure 2. Seasonal changes in the water content (as dielectric coefficient) of Scots pine stem (A), root (B) and soil (10 cm depth) from March to June 1996.

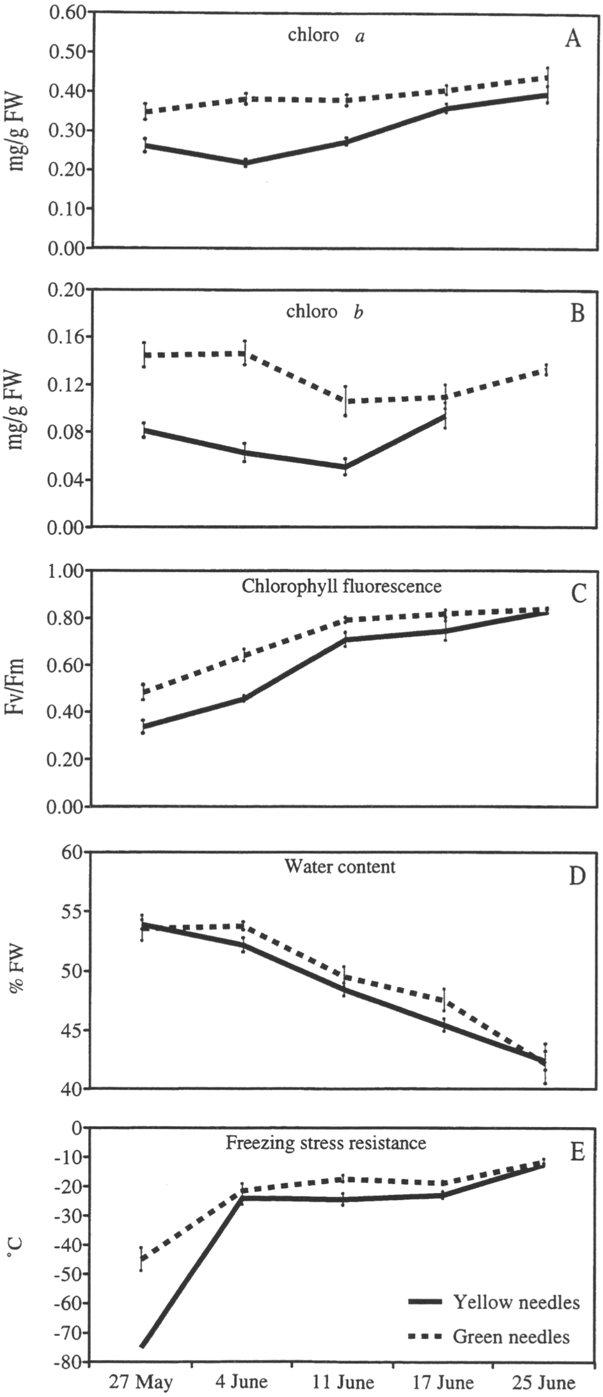


Figure 3. Seasonal changes in the chlorophyll *a* (A), chlorophyll *b* (B) content, in chlorophyll fluorescence (F_v/F_m , C), in water content (D) and in the freezing stress resistance of the green and yellow needles.

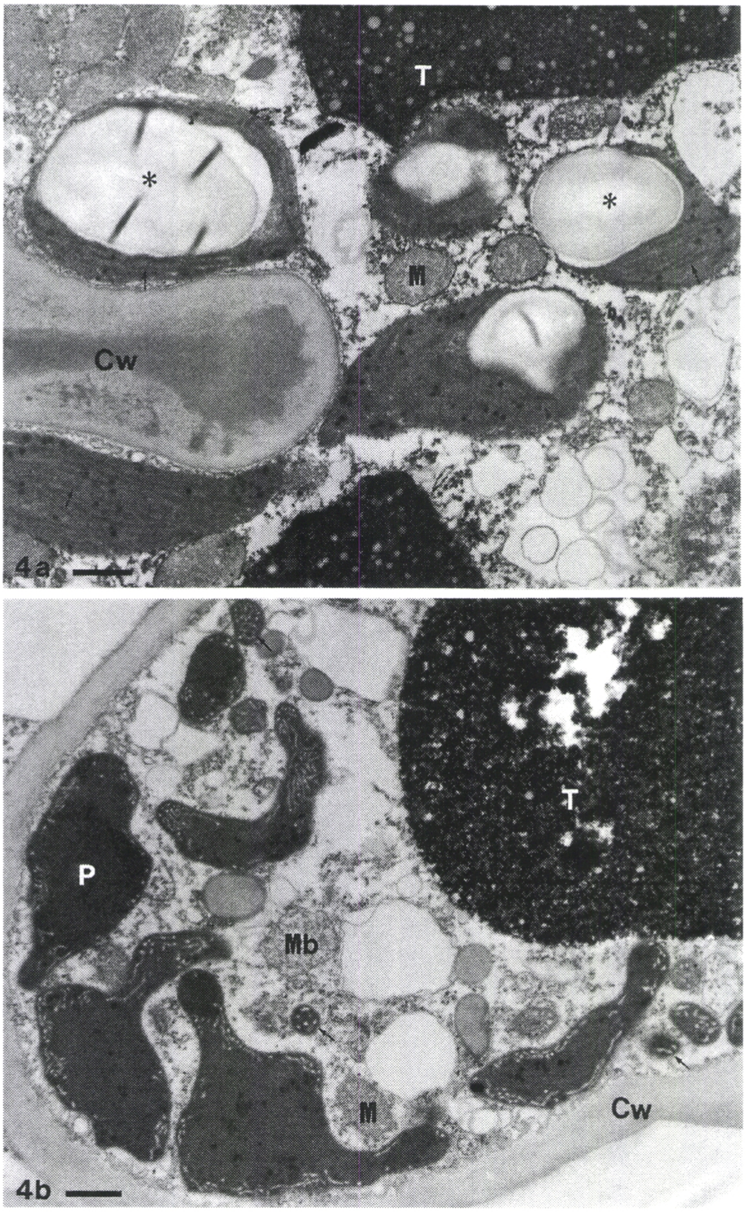
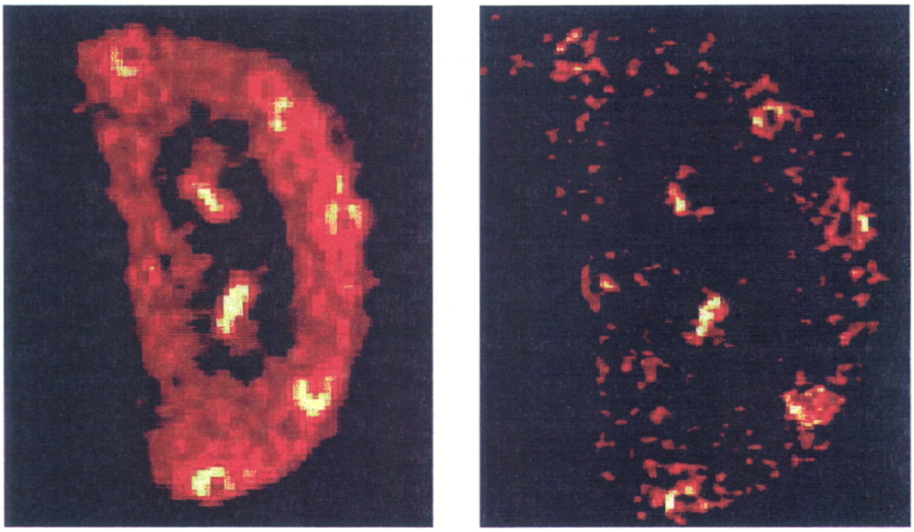
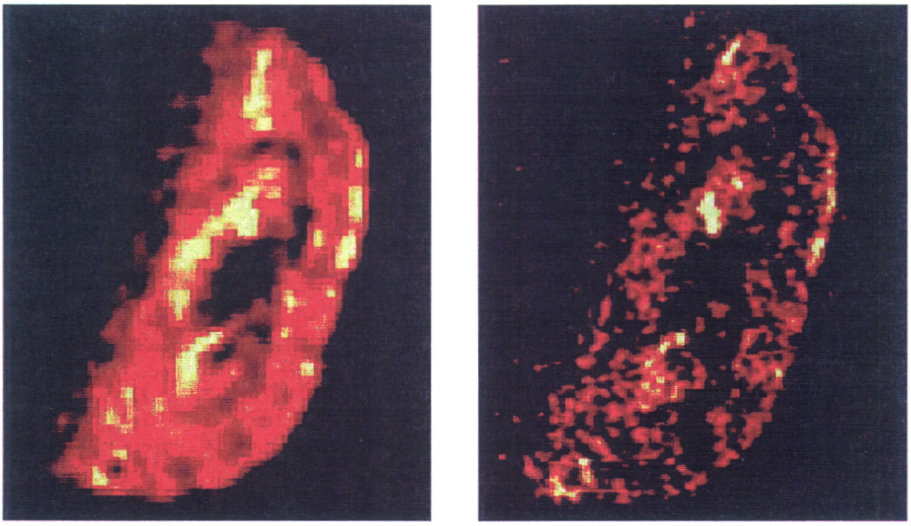


Figure 4. Electron micrographs of a transverse sections of mesophyll cells of the green needle (a) and yellow needle (b) sampled on 11 June 1996. The chloroplasts in the green needles have thylakoid systems with four or more thylakoids in a granum stack (arrow) and accumulated starch grains (stars). Cell wall (Cw), mitochondria (M) and tannin (T) can be seen in the central vacuole. In the yellow needles the chloroplasts do not have any thylakoids or starch grains but show an accumulation of plastoglobuli (P) and tubular structures in the electron-dense stroma. The chloroplasts have extensions, from which the small "satellites" seen in the cytoplasm may be originated. Cell wall (Cw), mitochondria (M), microbody (Mb) and tannin (T) can be seen in the central vacuole. Bars = 1 µm.



A. Green needle (Resol. 15.6, TE=5.76 ms) B. Green needle (Resol. 7.8, TE=8.32 ms)



C. Yellow needle (Resol. 15.6, TE=5.76 ms) D. Yellow needle (Resol. 7.8, TE=8.32 ms)

Figure 5. Transverse ^{1}H-NMR images of a green (A, B) and yellow needle (C, D). TE used were as follows: 5.76 ms (A and C) and 8.32 ms

(B and D). The brightness of the image correlates with different ^{1}H levels: yellow - high proton intensity; hot iron color - proton region; black - air or extremely strongly bound water.

Effect of disturbed photoperiod on the surface structures of ripening Scots pine (*Pinus sylvestris* L.) seeds

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1 Introduction

In northern areas fully ripened Scots pine (*Pinus sylvestris* L.) seeds are infrequent. As winter conditions also can make cone collecting difficult, the idea of employing artificial ripening for obtaining germinable seeds has been found interesting (Silen 1958, Simak 1966, Winston and Haddon 1981, Edwards and El-Kassaby 1988, Sahlén and Bergsten 1993). Most of the studies on seed ripening have emphazised the role of temperature and humidity of the environment during the ripening process. Not very much attention has been paid to the effect of light on the maturation of cones and seeds, even if developing Scots pine cones have been found to fix carbon dioxide in light until the late fall, i.e. as long as cones have stayed green (Linder and Troeng 1981). In their preliminary study Sahlén and Bergsten (1993) also concluded that ripening of Scots pine cones is influenced by light.

The artificial ripening has been more successful, more the anatomical and physiological maturity of seeds have been advanced at the time of collection (Winston and Haddon 1981). The structural basis of maturity have traditionally been evaluated by the development stage of embryo (Edwards 1980) often using the x-radiography classification developed by Simak (1980). Anatomical research of developing conifer seeds also has mainly focused on the embryo and the megagametophyte (Ferguson 1904, Håkansson 1956, Sarvas 1962), while the possible role of other parts in seed maturity has stayed unstudied. However, the tissues of maternal origin that surround the megagametophyte are known to restrict imbibition and germination of pine and spruce seeds (Tillman-Sutela and Kauppi 1995a, b). The aim of this study was to elucidate the role of these surface tissues in anatomical maturity of pine seeds and the effect of disturbed photoperiod on their structure.

2 Material and methods

Seeds of two Scots pine (*Pinus sylvestris* L.) trees at the Experimental Forest of Vindeln (64°N, 19°E, elevation 230 m) in northern Sweden were used. An extra light of twelve hours a day was given during the night (from 6 pm to 6 am) on the crown of one tree by two incandescent lamps. The other tree having natural photoperiod conditions was used as a control. The trial was started on July 25. The samples of 10 cones each were collected on August 14, September 4, 11, 18, 25, and October 9 and 30. The cones were opened manually and the seeds were extracted by hand. Colour of the seed coat was estimated visually. Ten seeds of each collection were sampled for structural studies.

The anatomical details of the seed coat, the nucellar layers and the megagametophyte (see the main parts of a mature seed in Fig. 1) of resin-embedded seeds were examined by light and fluorescence microscopy of about 1 000 stained or unstained sections of 4 µm thick.

Anatomical potential (Simak 1980) was calculated as percentage of seeds having structural prerequisites (megagametophyte size and embryo length) for germination. The germination tests were made on a Jacobsen apparatus at +20°C (±1 °C) and at constant light.

3 Results and discussion

The greatest anatomical changes during the observation period in the ripening seeds occurred in the outermost layer of the seed coat, the sarcotesta, and in the nucellar layers inside the seed coat. Maturation of the surface structures was essentially slowlier than could have been interpretated by the size of the embryo.

In mid-August, 21 days after starting of the trial, there were no visible macroscopic differences of the seed coat colour between the light-treated and the control seeds. The main structures of the seeds at both treatments were already well distinguished in the microscopic samples of the first collection, e.g. the tissues of the wing and the sclerotesta were mature with lignified cell walls, and the embryos appeared full-grown. However, the microscopy of the surface structures restraining passage of water in mature seeds revealed developmental differences between the treatments. While the sarcotesta and the nucellar tissue of the control seeds were still in cellular form bearing nuclei (Fig. 2A) and a notable amount of starch grains, the cells in the light-treated seeds were depleted or filled with brown granular phenolic compounds (Fig. 2B). Accumulation of phenolic substances and degeneration of cells advanced about a fortnight faster in the light-treated than in the control seeds up till the second half of September. But, from this period on colour changes in the light-treated seeds seemed to stagnate and also certain structural metabolism, e.g. cutinization of nucellar cap, was slowed by the light treatment. The colour of the untreated seeds continued to deepen and became dark brown at the end of September. Phenols causing the brown colour in the surface structures serve to protect seeds against fungal infections and improve germination by absorbing thermal radiation.

In addition to brown phenolic compounds, the effect of disturbed photoperiod appeared in accumulation of other substances, particularly at the chalazal region. The cells of the chalazal opening of the seed coat, the vascular connection between the tree and the developing seed, were already in mid-August filled with amber-yellow pigments of phenolic origin according to stainings. Accumulation of these pigments can be an indication of the defense mechanism against differing radiation. Conifers are known to be specially sensitive to excess light and protect indispensable structures, in this case the cells of the chalazal opening.

Nutrients and metabolic regulators from the mother tree to developing seeds flow through the vascular connection of the chalaza. On the other hand, Scots pine has a strong genetic control of bud set defined by the photoperiod. Consequently, generation of protective pigments can well be induced by the disturbed photoperiod registered by phytochroms in a branch or in green cones. Still, untimely increased amounts of phenolics may have a harmful effect on the metabolism of living cells. This opinion is supported by our results that the chalaza cells in the control seeds stayed alive about three weeks longer, up to early-September. However, it was first in the control seeds of late-September that the phenoliferous tissue of the chalazal opening was so compact that no single cell walls were found. Appearance of this phase in the light-treated seeds a fortnight later indicated that the altered photoperiod disturbed closing of the chalazal opening. We consider the closing of this vascular connection between the seed and the mother tree an essential criterion of the anatomical maturity of seeds.

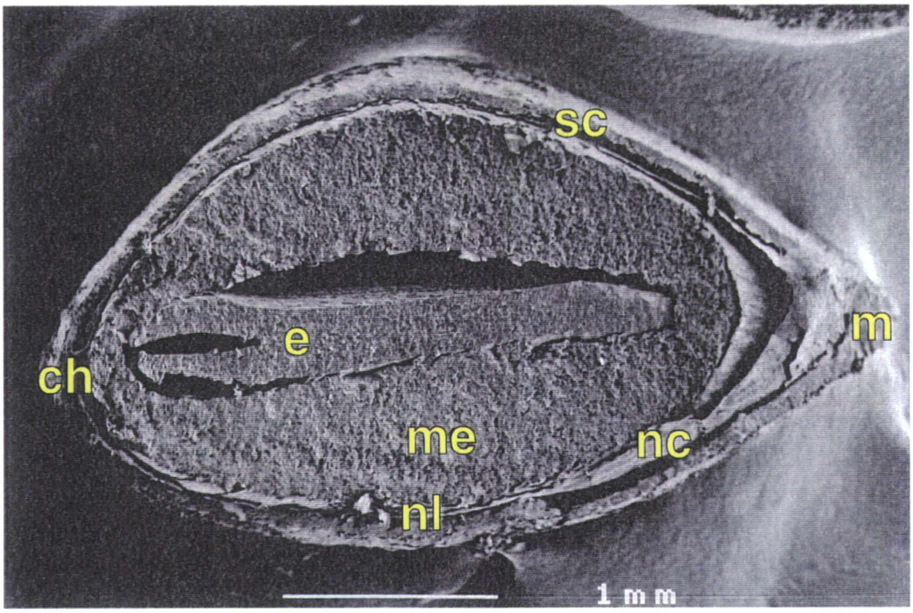

Figure 1. A SEM (Scanning Electron Microscopy) micrograph of a longitudinally cut mature pine seed showing the main structures: seed coat (sc), chalaza (ch), micropyle (m), nucellar layers (nl), nucellar cap (nc), megagametophyte (m), and embryo (e).

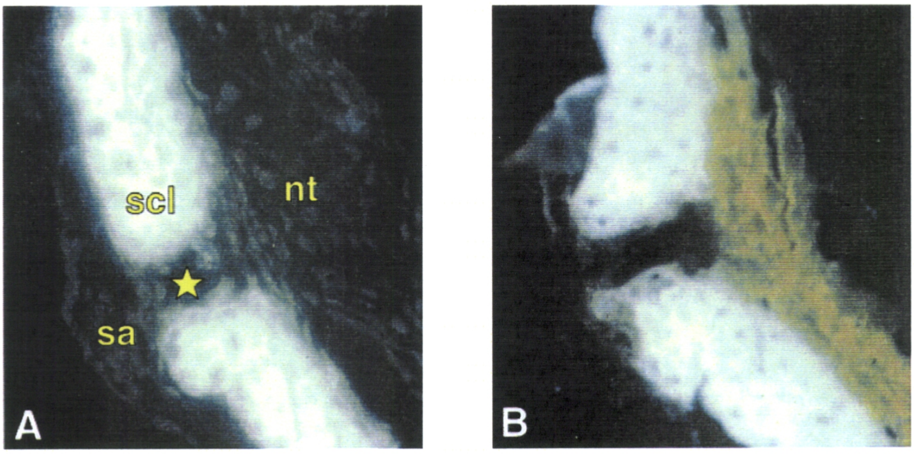

Figure 2. Unstained fluorescence microscope sections of the seeds collected in mid-August. A. Living cells of the nucellar tissue (nt) and the sarcotesta (sa) around the chalazal opening (star) of the lignified sclerotesta (scl) in the control seeds. B. Cells of the sarcotesta and the nucellus filled with brownish-yellow substance at the chalazal region of the light-treated seeds.

All together, altered photoperiod disturbed the structural development of seeds and indicated that photoperiod is important in the ripening process. The coincidental advancement of the anatomical potential examined by the X-ray method and the changes in germination supported the role of the surface structures on the anatomical maturity of pine seeds and the timing of cone collecting.

References

Edwards, D. G. W.1980. Maturity and quality of tree seeds - a state-of-the-art review. Seed Sci. & Technol. 8: 625-657

Edwards, D.G.W. and El-Kassaby, Y.A. 1988. Effect of flowering phenology, date of cone collection, cone-storage treatment and seed pretreatment on yield and germination of seeds from Douglas-fir seed orchard. Forest Ecology and Management 25: 17-29

Ferguson, M. 1904. Contributions to the life history of *Pinus*, with special reference to sporogenesis, the development of the gametophytes, and fertilization. Proc. Wash. Acad. Sci. 6: 1-202

Håkansson, A. 1956. Seed development of *Picea abies* and *Pinus silvestris*. Medd. Statens Skogsforskningsinst. 46: 1-23

Linder, S. and Troeng, E. 1981. The seasonal course of respiration and photosynthesis in strobili of Scots pine. Forest Sci. 2: 267-276

Sahlén, K. and Bergsten, U. 1993. Artificial ripening of early collected Scots pine cones and cones attached to branches. In Edwards, D.G.W. (ed.) Dormancy and barriers to germination. Proc. Internat. Sympos. IUFRO Project Group P2.04-00 (Seed Problems). Victoria, B.C., Canada, Pacific Forestry Centre, Victoria, B.C. 113-120

Sarvas, R. 1962. Investigations on the flowering and seed crop of *Pinus silvestris*. Comm. Inst. For. Fenn. 53: 1-198

Silen, R.R. 1958. Artificial ripening of Douglas-fir cones. J. For. 56: 410-413

Simak, M. 1966. Mognadsprocessen hos tallfrö. (The ripening process in Scots pine seeds). Sveriges Skogsvårdsförb. Tidskr. 64: 411-426

Simak, M. 1980. X-radiography in research and testing of forest tree seeds. SLU, Inst. för skogsskötsel. Rapport 3

Tillman-Sutela, E. and Kauppi, A. 1995. The morphological background to imbibition in seeds of *Pinus sylvestris* L. of different provenances. Trees 9: 123-133

Winston, D. A. and Haddon, B. D.1981. Effects of early cone collection and artificial ripening on white spruce and red pine germination. Can. J. For. Res. 4: 817-826.

Dendrochronological analysis at pine timberline

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1 Scots pine generations in Finnish Lapland

A typical timberline Scots pine (*Pinus sylvestris*) lives to an age of 200-300 years and the oldest ones encountered have been over 400 years old. The oldest Scots pine tree ever found in Lapland, age 810 years, was found by professor Gustaf Sirén in the 1950s. Dead pine trees can remain undecayed for over 1000 years on the ground; the oldest such individuals date back to the 8th century. Trees that have ended up submerged in ice-cold small ponds can remain stored in them for thousands of years (Fig.1.). In recent studies, we have found that it is possible to span the entire history of all the generations of Scots pine that have ever lived during the Holocene period (the past 10 000 years, starting from the end of the last Ice Age and including the present). Actually, this seems to be case throughout Finland, as well as Sweden, Norway and the Kola Peninsula (in NW Russia). The oldest found subfossilised pine trunks had commenced their growth over 7500 years ago. Some lakes have preserved tens of tree generations in their muddy bottom layers. Our basic experience is that it is possible to find lakes that contain most of the 16 - 80 tree generations ever lived on their banks during the Holocene period.

The first Scots pines spread out into Lapland about 8000-7500 years ago. Several studies have shown that the climate in Finland about 6 000 years ago was a couple of degrees warmer than it is today (Fig. 2). In those times, the growing season was significantly longer than it is today and the temperature sum may have risen on a specific site 150 - 200 d.d. higher than nowadays. This means that the ancient pine timberline was located along the present 350 - 400 d.d. zone (nowadays along about 550 d.d.) and at elevations 120 - 150 m higher than today, at an altitude of about 600 m (nowadays at about 450 m). During the warm period, there were extensive pine forests spread over tracts which nowadays are

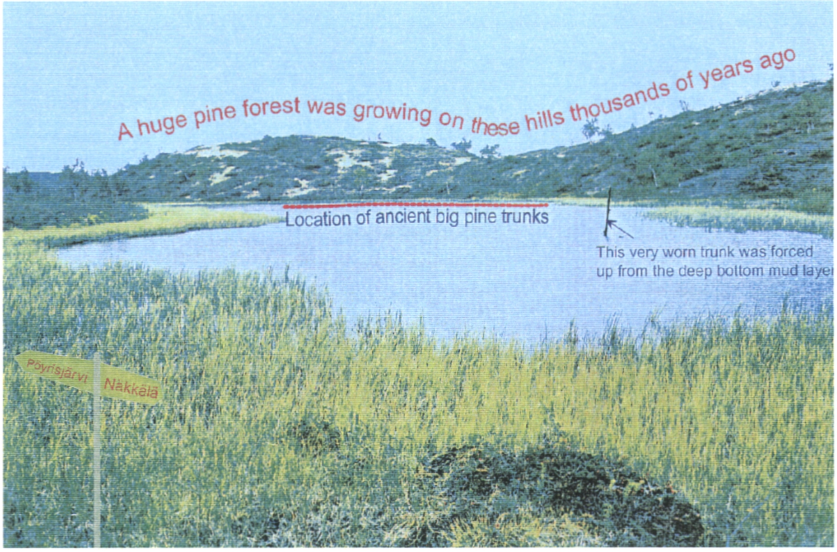

Figure 1. A small pond at the pine timberline in the Näkkälä area, is one of the places where subfossil sampling is being carried out. These kind of small lakes with their sinking swamp shores, muddy bottoms and spring-based waters are excellent sources of data that make it possible to study both the past, the present and the future climate and also the holocene period development of pine forests in Lapland. This lake is particularly intreresting because of the 1-1,5 m rise in ancient ground water level. The change caused all the shoreline pines to fall down to the water. These, in stump diameter over 50 cm thick trunks still lay well preserved in the shore hollow.

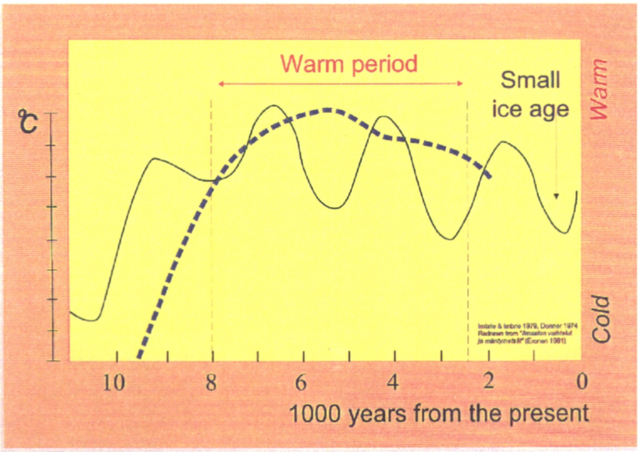

Figure 2. Global temperature development during the Holocene period (according to Imbrie & Imbrie, 1979; solid line) and development of temperature in southern Finland (Donner 1974; dashed line). Source: Eronen 1981: Jääkausien jäljillä).

only barren land or covered by bushy mountain birch. Proof of this is proved by numerous subfossil trunks found in lakes beyond the present timberline. The warm period ended about 4000 years ago. Since then, the timberline formed of Scots pine has gradually receded to its present-day range.

2 Why and how to study subfossil pines?

Firstly, it is important to know that the measured temperature records in Lapland span only about 90 years back in time. This relatively short time span does not enable one to make conclusions as to the causes of low-frequency oscillations in the climate. Longer temperature records can be generated from what is called proxy data, i.e. variables that indicate approximately the past climate. The timberline Scots pine has proved to be a good indicator as a thermometer: it is very sensitive to the temperatures of early summer months. The correlation coefficient between tree ring widths and the mean temperature in June-July may rise up to 0.80 in individual stands. This characteristic makes it possible to convert tree-ring widths to temperature records. Technically, this is carried out by dendrochronological methods.

In the endeavour to account for the present-day growth phenomena, it is necessary to know what kind of annual variations, fluctuations, growth trends, and other phenomena there existed in the times of ancient pine forests. Knowing climatic variations of throughout the Holocene period makes it possible to define natural limits for climate behaviour. These data is valuable for studying tree growth, climate change, and also environmental changes. Once we know exactly the long-term influence of climate on tree-rings, we are also in a better position to judge more reliably the effects of environmental changes, such as effects of nitrogen deposition. Long-term time scales also provide useful parameters for adjusting growth models to changing environments.

3 On-going pine subfossil studies

The first project involving study of past climate within the region that today is called Finland by accessing tree-rings was started in 1984 by professor Matti Eronen in connection with the SILMU project. The data were collected from the timberline zone formed by Scots pine. His subfossil tree-ring chronology covers a range of about 7500 years. Unfortunately, there is still a mysterious gap between 150 B.C. and 450 B.C.

That is why there are two subsets in his chronology: a contiguous part extending to 160 B.C. and a floating part from about 450 B.C. to 5500 B.C.

Another approach to constructing long chronologies was started at the Finnish Forest Research Institute (Metla) in 1994, under the leadership of the author. The study area covers all of northern Finland. The study material includes living pines, dead pines, and submerged wood. A contiguous chronology series covering 1911 years and including several floating parts were constructed on the basis of this material.

A joint Finnish endeavour to study past climate was started in 1996 under the auspices of an EU-project called ADVANCE-10K (*Analysis of Dendrochronological Variability and Associated Natural Climates in Eurasia - the last 10 000 years).* This project involving nine European countries is led by Dr. Keith Briffa of the University of East Anglia. The Finnish participants are Metla and the Universities of Helsinki and Joensuu. Professor Eronen is the Finnish signatory. The aim of the study is to build European-wide networks of pine and oak chronologies for the last 10 000 years and then use the data for investigating past and present climate change and related topics. The project is scheduled to be completed in 1999.

At the moment, over 2000 subfossil pine samples have been excavated from the bottoms and mud layers of lakes in Finnish Lapland. The demonstration point, a small pond in the Näkkälä area, is one of the places where subfossil sampling is being carried out.

4 Climatic variations and regeneration of Scots pine in Lapland during the last 1000 years

A low-frequency filtering using a scale of 200-400 years shows considerable variations in tree growth during the last 1000 years (Fig. 3). This 1000-year tree-ring calendar of a timberline Scots pine shows in its variation of tree growth a specific rhytm, which is closely related to temperature variations in June-July and to forest regeneration. A rule of thumb applicable in this connection is as follows: the warmer the weather in June-July, the better the growth of a timberline pine.

The tree-ring calendar shows that since 1961 the climate has been mainly unfavourable for the growth of pine. Some exceptional years (1973, 1979, 1982, 1983 ja 1989) have the effect of making the statistics less severe, and so the period cannot be considered to be more extreme than others during the millenium.

When viewed against a time scale of a thousand years, it becomes apparent that nearly a half a century (1915-1960) can be considered to be one of the warmest of the millenium. The previous period resembling it is to be found in the 1700s. This conclusion is supported by observations of young stands (age 35 - 75 years) that presently form geographically part of the northernmost (polar) and the highest (alpine) timberline.

During the present millenium, the living conditions for timberline pines were possibly severest during the latter half of the 1700s and the first half of the 1800s. During the coldest period in the 1830s, pines ceased to grow for several years. This was revealed by an analysis of missing rings. It is notable that (according to professor Sirén's studies) natural regeneration of significance of pine forests took place only once during the period 1781-1850.

The pine forests of the timberline have regenerated quite seldom, but (again according to Sirén) nevertheless frequently 3 - 4 times in a decade. Regeneration has always taken place during favourable growth periods. This is also demonstrated by the enclosed figure (fig. 3), in which Sirén's pine regeneration years and Metla's tree-ring indices for the period 1300-1990 are plotted one against the other.

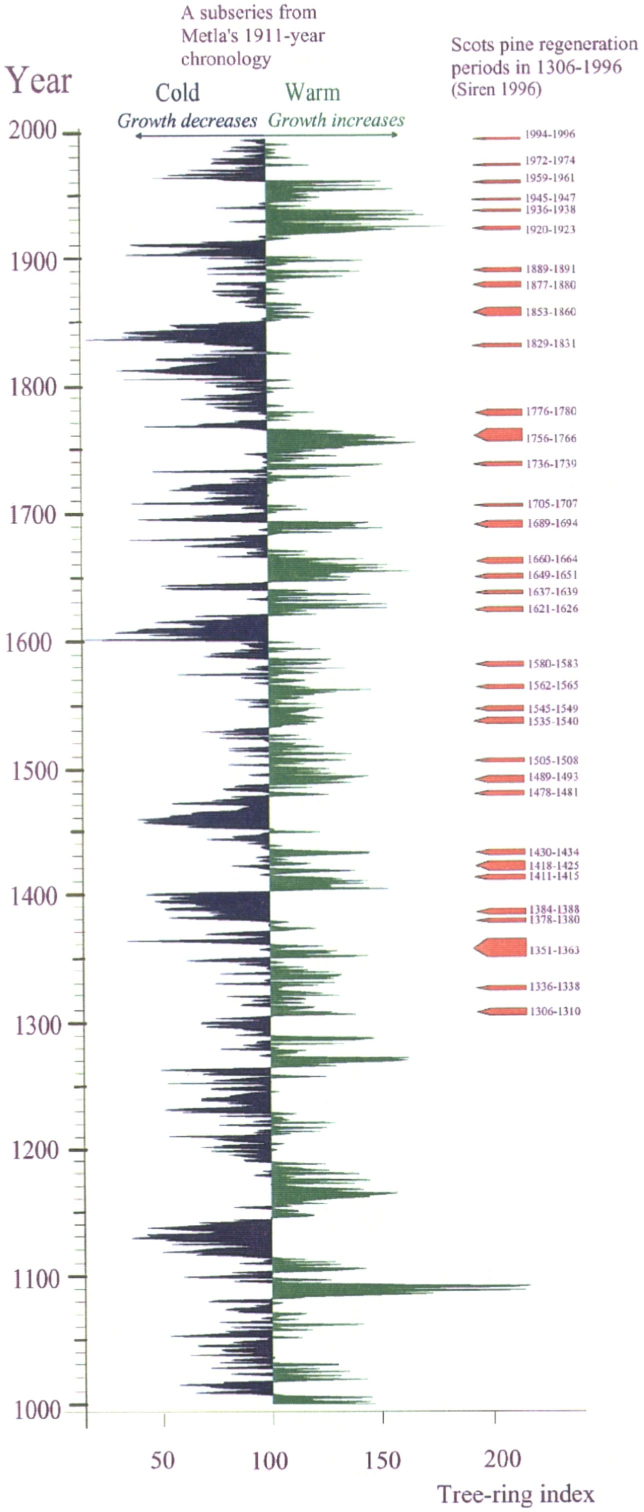

Figure 3. The cycles of growth in Metla's 1000-year tree-ring chronology and the regeneration periods of Scots pine found by Sirén show the connection between the climate and the trees.

Experiences of forest genetics under timberline conditions

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1 Introduction

The diversity of nature is too overwhelming to be condensed in a few generalizations. The same is also true of nature close to timberline although, on the surface, it appears rather monotonous compared to its southern counterparts. In principle, the northern and alpine timberlines are thermal limits, which are locally modified by snow, wind *etc* (Tuhkanen 1993, Wardle 1993). The northern treelines coincide approximately with the 10 °C isotherm of the mean temperature of the warmest month (Grace and James 1993, Wardle 1993). This shows that summer temperature is the most decisive factor. Local deviations to this rule are frequent *e.g.* in most maritime and continental climates.

The number of species extending to the northern timberline is not very high (less than 20, Kallio *et al.* 1986), but they belong to many different taxa and are not closely related to each others. The fact that no species has been able to reach considerably colder areas than other species has led to the hypothesis that there may be a fundamental physiological limit, beyond which the arboreal growth form is not a successful solution (Tuhkanen 1993). The timberline is by no means a stable limit, but responds to changes caused by climatic fluctuations. However, the longevity of the species forming the timberline, together with an ability to reproduce vegetatively, set some inertia on the timberline as regards environmental variation (Lloyd 1997).

Fluctuations in climate, including glaciations, mean that, from the geological and evolutional point of view, timberlines are young environments (Stern and Roche 1974). The timberline has usually not remained at the same place for as long a time as the more central habitats. Consequently there are no tree species which have specifically evolved under the present timberline conditions. Adaptative solutions are not necessarily the best possible strategy, but they do determine the limit up to which the arboreal growth form can spread. The lack of good adaptations is especially well demonstrated at the alpine timberline on small tropical and subtropical mountains, where the gene pool of the surrounding flora has not provided sufficient genetic material to conquer the climatically more demanding higher altitudes. For instance, the altitudinal timberline on a mountain in Brazil is located at the level where occasional night frosts occur during winter (Arno and Hammerly 1984), and is thus well below the potential timberline. Owing to geographical constraints of this type and the time lag in the spreading of hardy species, as well as natural catastrophes or human impact, the actual treelines and timberlines may lie in a more favourable climate than the potential limits (Ødum 1979, Tuhkanen 1993). The location of the potential timberline can be estimated by testing all the hardy tree species in the area in question.

One of the key factors in creating the diversity characteristic of nature is the genetic diversity of living organisms. The more diverse is the gene pool, the more variable is the biotic component of nature. The genetic diversity also has more fundamental effects than merely creating fascinating variation in nature. High genetic variation provides the organisms with a high potential of adapting to changing environmental conditions. Here I shall present some of the knowledge that has accumulated about the genetic variation of forest trees, and discuss its importance at timberline conditions. I will also include the effect of human impacts. The main emphasis is on Fennoscandian conditions, but the results from other timberlines are also frequently referred to. Very few forest genetic studies have been carried out on populations strictly at the timberline, but many conclusions can be drawn by extrapolating the results from slightly more southern forests.

2 Genetic variation

2.1 Level of genetic variation

Genetic variation is expressed at various levels. The highest level is the **species** level. Species can be treated as more or less coherent groups of individuals, within which gene transfer is possible at least in principle. Species are usually reproductively isolated from each other. Even different species have a considerable proportion of their genomes in common owing to their common ancestry, but there are sufficient crucial differences to make the species distinct from each other. The differences between species are often so self-evident that it is difficult to realize that the selection of species in forestry also has genetic implications. This can be more easily recognised when foreign species are introduced from other countries or continents.

The next level of genetic variation is the **population** level. It is difficult to define population precisely, because the variation within continuously distributed species is usually gradual (clinal). However, if populations are sampled from a large geographical area, it is possible to demonstrate differences in adaptational traits between them. In some cases the distribution of the species is disrupted at the margins especially. Thus in Lapland, for instance, Scots pine forms isolated stands or even large forests in favourable valleys to the north of its continuous distribution area.

Individuals form the third level of genetic variation. The genetic variation between individuals is most easily observed in certain special growth forms of trees, like narrow crowns, yellow needles *etc.* However, the greatest and the most important part of genetic variation is due to relatively small genetic effects, and it cannot therefore be observed directly in nature.

2.2 Affecting factors

Four different factors affecting the amount of genetic variation are usually distinguished (Table 1).

Table 1. Factors affecting genetic variation and the essential features of these factors at different observation levels.

	Affecting factor			
Level of variation	*Mutation*	*Migration*	*Selection*	*Random drift*
Species	—	Spreading to new areas, hybridization, (introduction by man)	Adaptation to climate, soil, (silviculture)	Extinction of rare species, colonisation after the Ice Age
Population	—	Long distance pollen transfer	Adaptation to climate	Extinction of local populations, founder effect
Individual	Point mutations, polyploidy	Pollen flight, seed dispersion	Adaptation to climate and other prevailing conditions	Random culling of individuals and loss of genes in small populations

Mutations occur at the individual level. They form the ultimate source of genetic variation, which is the raw material for other evolutionary forces. Most mutations are point mutations caused by small changes in the DNA code of the individual. A single mutation has usually only a small effect on the appearance and adaptiveness of the organism. Polyploidization means that the whole genome or parts of it are present in a number of extra copies. In plants, polyploidy is more common at northern latitudes, although this cannot be interpreted as an indication of its adaptational value (Heide 1985). Polyploidization has been - and still is - an important factor in the speciation of birches and willows (Stern and Roche 1974). Polyploid individuals occasionally emerge in other taxa, *e.g.* the clone of triploid aspen (*Populus tremula* f. *gigas*) found in Inari (Kallio and Mäkinen 1975). Mutation frequency is affected *e.g.* by certain chemicals and UV radiation, but there are no indications that it would be higher at northern timberline conditions than elsewhere.

The effect of **migration** depends on the level of observation. At the individual (within population) level, migration is a source of new variation as it transfers genes from one population to another. At the population level, migration can be said to decrease genetic variation, because by mixing gene pools of distant populations it tends to make them uniform. At the species level, migration can increase variation unless some strongly competing invading species is extirpating a local species or populations.

If the reproductive barriers between related species are not fully developed, gene flow can also occur between species. Examples of this are the birches in the northern circumpolar zone (Sulkinoja 1990) and the spruces of north-western North America (Stern and Roche 1974). The Fennoscandian mountain birch (*Betula pubescens* var. *czerepanovii*), with its many special features (*e.g.* vegetative propagation ability, polycormic growth habit, reddish autumn colour), has evolved through hybridization between *Betula pubescens* and *B. nana* (Kallio *et al.* 1983). It has been suggested that gene exchanges of this kind were important during the glaciation periods when related species and populations met in the southern refuges (Conkle 1992). At present, natural migration at the species level is limited (see, however, Tuhkanen 1993), but the more important is the effect of species introduced by man.

Because pollen is more mobile than seed in most trees, the importance of migration is greatly influenced by the **mating system** of the species. Most boreal forest tree species are cross-fertilized wind-pollinators, the pollen of which can disperse the genes over hundreds of kilometers (Koski 1970, Lindgren and Lindgren 1997). Migration is less effective on insect pollinating, self-fertilizing or vegetatively reproducing species. After the last Ice Age, strong southerly winds may have speeded up the spread of tree seed to invade the newly exposed soil released from under the melting ice masses (Robertson 1993).

Selection is the evolutionary force which is of decisive importance in creating adapted individuals, populations, species and finally ecosystems.

Selection operates through controlling the reproductive success of the individuals. The frequency of genes or gene combinations which increase the probability of producing progeny tends to increase in the long run.

In the boreal forests climate is the most decisive selecting factor up to the timberline, and adaptation to climate is therefore of great importance. Due to gradual changes in climatic factors and effective migration via wind-pollination, the variation between populations is clinal. Migration has also prevented the formation of distinct populations on different soil types, eventhough edaphic factors can change rather abruptly. On the other hand, adaptation at the species level to different soil types is possible, because reproductive isolation protects the genetic differences.

Man can also act as a selective force if certain species are favoured in silvicultural operations or, alternatively, removed in selective cuttings. Selective cuttings can also have genetic effects - usually detrimental - within species. Earlier other forms of human activity also influenced the composition of the forests. For instance, it has been estimated that the area of pine forests in northern Finnish Lapland decreased in earlier centuries, because the bast of trees was used as a substitute for flour in baking bread (Renvall 1919).

The stochastic events which influence the genetic constitution of a population are called **random drift**. As the name implies, this process causes some deviation between the expected and realized gene frequencies. It can be regarded as sampling error in the gene population when moving from one generation to the next. The effect of random drift is greatest in small populations, because in such situations the sampling errors are the greatest. Random drift can play an important role in small isolated populations at the timberline, where a high proportion of the population can be destroyed accidentally (*e.g.* by fire), which is a random event as regards the genetic background of the trees. When such a catastrophe occurs it is quite likely that some genes will be totally lost from the population, or at least their frequency is considerably altered. In larger population the effect of such a disaster would be negligible in genetic terms (Stern and Roche 1974).

Random sampling effects can be of crucial importance in the establishment phase of a population. This **founder effect** is clear if the number of population ancestors is small. A small number of individuals cannot convey all possible forms of genes (alleles) from the main population, and thus the new population deviates in genetic constitution from the original population. Random drift can cause the extinction of small populations or rare species and thus decrease genetic variation at a higher level. Also the recolonization of the northern areas after the last Ice Age is a process in which chance events may have had influence. Extinctions during the Ice Age, geographic obstacles *etc.*, together with ecological site factors, have shaped the species composition of the present boreal forests. Exotic tree species may also suffer from a narrow, skewed genetic base, because the introduction may have sampled only a small and unrepresentative number of individuals.

3 How to measure genetic variation?

The visible conformation, biochemical constitution, physiological reactions and, in fact, all the imaginable characteristics of living organisms are functions of both the genome and environment. This is often described by the following formula

$P = G + E$, where

P = observed phenotype, G = genotype (effect of genes), E = environmental effects.

Usually only the phenotype can be directly measured. Thus it is impossible to draw any definite conclusions either about the effect of genotype or environment merely by observing nature. The proportion of genetic variation out of total variation differs between characters. It is zero in characters controlled only by the environment and one in those under strict genetic control. This proportion, called **heritability**, is an important measure of the genetic variation in a population. It can be estimated using specifically designed experiments. In forest genetics a standard method is the so-called common garden test. In such a test the study objects (species, populations, progenies of individual trees) are grown in as similar conditions as possible. The better is the experimental lay-out, the purer is the estimate obtained of genetic variation.

The presented model is, of course, an oversimplification of the real situation. The expression of genetic effects is always dependent on the environment (genotype-by-environment interaction). If the genetic entries in the experiment represent widely differing adaptations, it is always debatable in which conditions the testing should be carried out. Measurements made in a natural population do not face this kind of problem, but they are unable to separate the genetic and environmental part of the variation. However, such measurements, when related to environmental factors, can provide an understanding of the adaptedness of the species-environment complex as a whole.

A crude example can elucidate the difference between phenotypic (total) and genetic variation. According to the National Forest Inventory, the mean annual volume increment of forests in southern Finland is four times higher than that in Lapland (Aarne 1995). However, one cannot deduce from this that southern trees are genetically so much superior to northern trees. In fact, according to the results of field tests, it has been estimated that genetically southern Finnish Scots pine and Norway spruce have only about 1.5 times higher growth rate than the corresponding species of Rovaniemi origin (Koski 1989). This fundamental difference between phenotype and genotype has been neglected in many studies on the adaptation of tree populations. For example, the different growth forms of trees at the timberline (spire type, flag type, elfinwood) cannot be regarded as genetic adaptations, unless the inheritance of the growth form is demonstrated by comparative cultivation tests.

The isoenzyme technique has been widely used during the last 30 years to estimate the amount of genetic variation in some polymorphic enzyme genes. Because these enzymes are protein molecules, they are direct products of the genes and thus closer to the gene level than morphological characters. Many enzymes are under such strong genetic control that the observed differences can be regarded as totally genetic (Weeden and Wendel 1989). Commonly used measures of genetic variation are the number of polymorphic genes (having more than one allele - form of the gene), number of alleles in a gene, and the proportion of heterozygous (having different alleles of the same gene) individuals.

Recent developments have also made it possible to measure the variation directly in the material carrying the genetic information - DNA. The DNA-markers used are distributed throughout the genome, including both the genes coding the polypeptides and the non-coding regions between them. Thus the observed DNA variation is not necessarily that which is expressed at the phenotypic level.

Different characters and techniques describe different kinds of genetic variation. Characters which are of adaptive significance to trees usually have variation that is parallel to a specific environmental factor. On the other hand, within a population such characters tend to have rather low inheritable genetic variation, because natural selection is directing the character towards an optimum value in the environment in question (Falconer 1981, Mousseau and Roff 1987). Most of the enzyme and DNA polymorphism is selectively neutral, so it can be used for purposes where natural selection would be a disturbing factor (*e.g.* measuring the amount of genetic diversity in neutral genes, tracing phylogenetic patterns of populations).

Serbian spruce (*Picea omorika*), a relict species with a natural distribution of less than 100 ha, is regarded as having little morphological variation in natural stands and plantations. However, more detailed studies have shown that it has a high level of enzyme polymorphism as well as variation in seedling traits (Kuittinen *et al.* 1991). This is again an example of the dangers of making genetic conclusions merely from observations or measurements in natural stands or plantations. DNA techniques have revealed a high level of variation in another endemic conifer, *Pinus torreyana*, although it has no enzyme polymorphism at all (Wagner 1992).

4 Amount of genetic variation in timberline conditions

4.1 Theories and observations on genetic variation

Theoretical considerations have led to the conclusion that at the timberline, as in marginal populations in general, the amount of genetic variation is less. Main factor contributing to this is supposed to be directional selection during many generations, which has ”squeezed” all the genetic variation out of a population at least in those characters related to adaptation. At the timberline there is usually strong selection pressure caused by the extreme environmental conditions. In addition, isolation and the small population size often decrease genetic variation through random drift and inbreeding (Stern and Roche 1974, Barrett and Husband 1989).

This view was strongly favoured some 30 years ago. Although the main evidence supporting this hypothesis was obtained from studies with other organisms, some support for it also came from studies with trees (*e.g.* Yeh and Layton 1979). In small isolated marginal tree populations genetic composition can deviate from the main population eventhough they contain quite high genetic variation (Nagasaka *et al.* 1997). This can be caused by the founder effect or some other random event. In the northern part of the distribution area of *Pinus contorta,* the number of alleles in isoenzyme genes is the lower, the later the species has arrived in the area (Cwynar and MacDonald 1987). This can be explained by the genetic drift during the colonization phase. However, even in this case the proportion of heterozygous individuals was at the same level in marginal and more central populations.

Sarvas (1970) presented a hypothesis concerning the generative adaptation of Scots pine, which also predicts the exhaustion of genetic variation at species margin and consequently a lack of adaptation in the marginal zone. According to measurements made in natural stands, there was no notable genetic variation in *e.g.* flowering time, amount of flowering and seed ripening north from the mean annual 950 d.d. temperature sum (+5°C threshold) isotherm. Some results also indicated the same for the survival of Scots pine (Sirén 1958, Etholén 1972). However, later research has shown that Scots pine also has considerable genetic variation north of the temperature sum limit proposed by Sarvas (1970).

Between or within population variation has been observed in Scots pine north from the 950 d.d. isotherm, *e.g.* in the amount and timing of flowering (Bhumibhamon 1978), seed maturation (Harju *et al.* 1996), length of growing period (Mikola 1982) and survival and height growth in field tests (Nikkanen 1982, Rousi 1983). In fact, even measurements in native stands revealed considerable variation between the populations in the timing of male flowering of Scots pine in northern Finland (Luomajoki 1993b). However, the studies have shown that the relative temperature sum at the time of male flowering in both Scots pine and Norway spruce drastically increases in northern Finland, whereas it is rather constant in more southern areas (Luomajoki 1993a, b). This indicates some sort of lack of adaptation as regards the annual temperature sum in the meaning proposed by Sarvas (1970), although there is still variation between the stands. The different reaction of northern stands can partly be explained by claiming that the temperature sum does not describe the relevant environmental factors in the correct way. The well known failure of seed ripening of Scots pine and Norway spruce in northern Finland in cold and even normal summers is a biological fact which can only be explained as an indication of the lack of adaptation (Kujala 1927, Henttonen *et al.* 1986).

In isoenzyme genes and at the DNA level the genetic variation of the northern Scots pine populations is of the same magnitude as in southern populations (Muona and Harju 1989, Karvonen and Savolainen 1993). Compared to southern populations, pines at the timber line seem to have more inbreeding and to be more self-fertile (Kärkkäinen 1994). However, selection against inbred individuals will maintain a high level of genetic variation. It has also been observed in other tree species that marginal populations contain as much variation as more central ones (Tigerstedt 1973, 1993, Neale and Adams 1985, Tremblay and Simon 1989).

At the timberline genetic flexibility in the long run is, in general, sacrificed for high survival (*e.g.* vegetative reproduction). In Japanese red cedar (*Cryptomeria japonica*) vegetative reproduction can lead to the situation where whole stands close to timber line consist of a single genotype (Taira *et al.* 1997). Species growing at the northern timberline are usually rich species complexes, which have large distribution areas extending far to the south of the timberline. This allows gene flow (even between species) mainly in the form of pollen flight from the south, which increases genetic variation. (Heide 1985, Lindgren 1993) The lack of endemic species at the northern timberline is evident considering the frequent glaciations during the pleistocene. On the other hand, small population sizes, inbreeding and changed selection pressures at the species margin can promote speciation through the breakdown of existing genetic relationships between characters, providing possibilities for new arrangements (Barrett and Husband 1989).

One crucial factor to which trees must adapt at the northern timberline is the shortness of the growing season, to which the active growing period must be adjusted (Lindgren 1993). At the timberline the main factor against which an individual must struggle is the adverse physical environment. In more favourable conditions, competition between individuals of the same and other species becomes more important. (Stern and Roche 1974, Heide 1985) Thus at the timberline trees must (and they can) sacrifice growth for hardiness. However, due to their longevity, tree populations can still maintain considerable variation in their gene pool in hardiness even, and "experiment" with less favourable genetic combinations in their progeny. In addition to the above-mentioned gene flow and longevity, there are several other factors contributing to the high genetic variation. Genetic variation can be hiding in dominant or other forms of non-additive gene action, and spatial and especially temporal variation in the environment can also promote the conservation of less favourable alleles. Because the northern environment is characterized by high annual variation in the climate (Stern and Roche 1974, Pohtila 1980), adaptations to local environments are improbable.

Theoretical calculations have shown that, if there is gene flow from the south and the environment is fluctuating, the mean hardiness of the population does not necessarily increase from generation to generation. In fact, gene flow is the main factor contributing to the maladaptation of the timberline populations. Due to problems of seed maturation in timberline conditions, regeneration usually occurs in warmer than average years. This also favours individuals which are adapted to more favourable climates (Lindgren 1993). Timberlines are young and unstable niches for trees. Evolutionary history during the pleistocene glaciations may have deprived genetic variation from the species. For instance, North American conifer populations from previously-glaciated northern areas are less variable than southern populations (Conkle 1992). Thus it can be claimed that timberline populations are not expressing the best possible adaptation to northern conditions, but "the best that a species can do with what was left over after evolution to past environment" (Strauss *et al.* 1992). Heide (1985) has stated "... it cannot be taken for granted, that plants which are inhabiting high-latitude areas are particularly well adapted to those environments in a broad sense, but merely that they are adapted in the sense, that they are surviving". Thus, although the premises of Sarvas's hypothesis do not hold, the conclusion of insufficient adaptation at marginal zone is valid to some degree. On the other hand, it can be expected that species which have survived recurrent glaciation cycles will have accumulated wide climatic adaptation (Conkle 1992).

Factors other than the length of the growing season can be important for adaptation. In the northern populations of lodgepole pine (*Pinus contorta* var. *latifolia*), trees from lower elevations are more hardy than trees from higher elevations, although the last-mentioned are adapted to a shorter growing season (Lindgren 1985). This can be an adaptation to frosts during the growing season or to the very low winter temperatures which occur at low elevations. Adaptation to disease resistance can also cause deviations from general climatic adaptation, although they are usually strongly interconnected (Björkman 1971, Uotila 1985).

4.2 Experiments with exotic species in northern Finland

Due to the east-west oriented mountain ranges and other geographic obstacles which have greatly hampered the movement of species during the glaciation-deglaciation cycles, the number of tree species in northern Europe is lower than that in other corresponding areas. Considering the random culling process during the glaciations, it can be assumed that North American and Siberian species will include ones which are better adapted to the extreme timberline conditions (Martinsson 1986, Lindgren 1993). Before the latest glaciation the arboreal flora of Lapland had species (*e.g.* larch) which no longer exist in the area today (Mäkinen 1982, Hirvas 1991). It must be noted that there may also have been differences between the climates of these two time periods. There may also be a more fundamental reason for the low number of species in the north. The low primary production of the northern ecosystems can lead to lower species diversity (Stern and Roche 1974).

An example of the survival and growth of exotic tree species at timberline conditions is given in figure 1. The results are taken from the oldest plantations in Tree Line Parks I and II in Utsjoki (latitude 69°45'N). Tree Line Park I (TLP I) is located in pine forest in a river valley (altitude 95 m asl) on dry sandy soil. TLP II is located a few kilometers from TLP I on a mesic mountain slope at the upper limit of the birch zone (altitude 280 m asl) (see Kallio *et al.* 1986 and Ruotsalainen and Neuvonen, 1995, for more details). In most cases there were originally 200 plants divided into three blocks. The experiment was measured 18 years after planting. Survival in both experiments was in general so high that it could be regarded as excellent even in a more favourable climate. Compared to local Scots pine (*Pinus sylvestris*), at TLP I the survival of Norway spruce (*Picea abies*), white spruce (*P. glauca*) and black spruce (*P. mariana*) was about the same (90 %), lodgepole pine (*Pinus contorta* var. *latifolia*) had a slightly lower survival, and Siberian larch (*Larix sibirica*) was worst with a survival of 70 %. At TLP II Scots pine had the lowest survival (40 %), followed by white spruce (50 %) and lodgepole pine (60 %). Norway spruce, black spruce and Siberian larch also had a high survival (80 to 90 %) at TLP II. Clear deviations from the general picture are the low survival of white spruce and local Scots pine in the harsh conditions at TLP II. It is also interesting to note that the survival of Siberian larch is higher at the climatically harsh, but mesic TLP II than at TLP I.

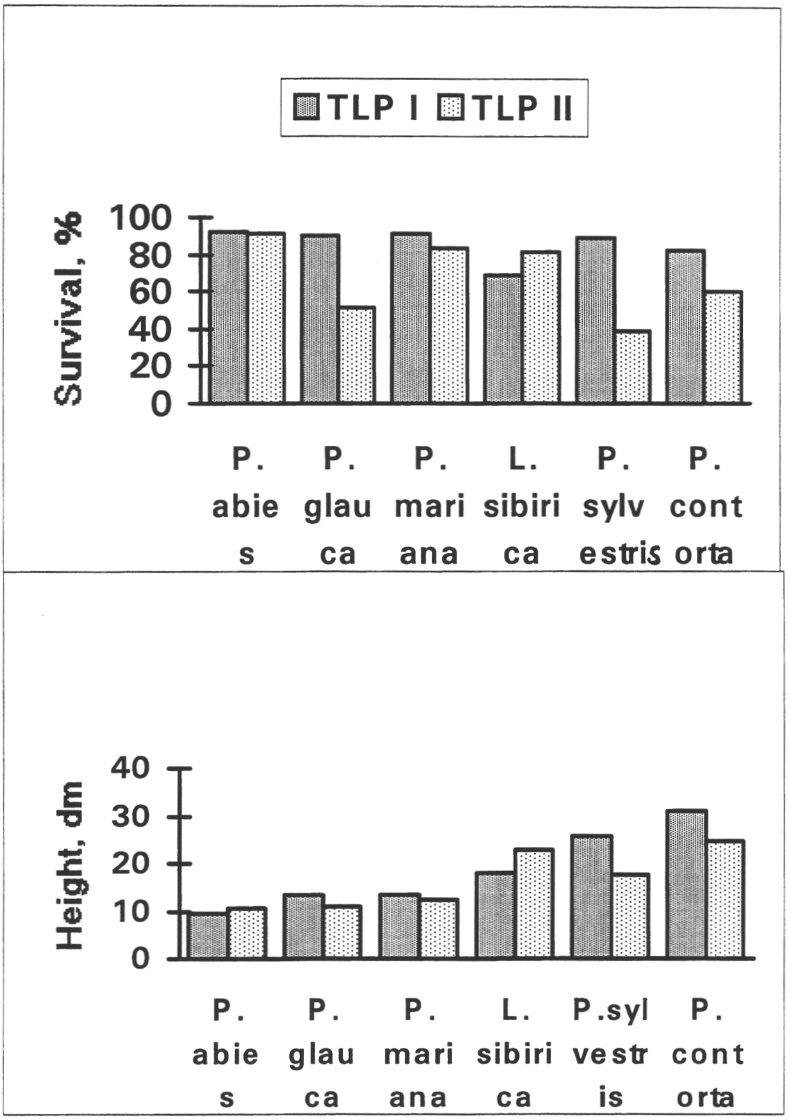

Figure 1. Survival and total height of six conifer species at Tree Line Parks I (experiment No. 940/1) and II (exp. No. 941/1) at the age of 18 years.

In height growth all three spruce species were about equal (approx. one meter) and clearly behind the other species on both sites. Lodgepole pine was the highest with a mean of 3 meters at TLP I and 2.5 meters at TLP II. Scots pine was second at TLP I (2.5 m) and third at TLP II (1.7 m). Siberian larch lost in height growth to Scots pine at TLP I, but won at TLP II. The favourable effect of the relatively fertile soil on the growth of Siberian larch is seen in the results - at TLP II it was higher than at the climatically more favourable TLP I.

Lodgepole pine in this experiment originates from the Yukon, which is the northern rim of the distribution area of the species. It can be regarded as the best possible provenance for the site (Ruotsalainen and Velling 1993), as well as the provenances of Siberian larch and Scots pine. The provenances of all spruce species are, however, slightly too southern for these conditions.The results concerning the good growth of lodgepole pine at the TLPs are in accordance with those obtained in more southern parts of Lapland (Ruotsalainen and Velling 1993). This is evidence that local species can be outperformed by exotic ones at the timberline conditions. This is by no means an unique situation. Ericsson (1993) has shown that, in northern Sweden, lodgepole pine thrives better than local Scots pine. This is attributed to the rapid winter acclimation capacity of lodgepole pine (Ericsson and Andersson 1997). It is interesting to note in this context that lodgepole pine is not a timberline species in its native distribution area. Extreme examples of cases where the actual timberline has not reached the potential timberline are offered by some isolated islands. The originally treeless Faroe Isles support well-growing forests of introduced species, which is not so strange concidering the mild climate of the islands (Ødum 1979). In Hawaii and New Zealand exotics have been successfully cultivated above the original timberline. In New Zealand, *Pinus contorta* is spreading naturally from plantations and establishing forests 150 meters above the natural timberline, and stunted individuals can even be found 400 meters higher (Arno and Hammerly 1984, Lindgren 1993, Wardle 1993).

4.3 Provenance variation in northern Finland

In climatically favourable areas (*e.g.* Central Europe), the results of provenance experiments with several species have shown that the use of seed from a slightly more favourable climate usually increases production compared to that of local seed source (adaptation lag, Matyas 1990). This rule holds true with Norway spruce up to southern Finland and Sweden, but in northern areas transfers from harsh to favourable conditions or the use of local provenance are recommended (Kalela 1937, Remröd 1976, Mononen 1987, Ruotsalainen 1987).

Table 2. Regression of survival at 10 years age on the average annual (1961-90) temperature sum of origin in four Scots pine provenance tests close to the timber line. Regression model is y = a + bx, where y = predicted survival and x = mean annual temperature sum of origin.

Test No	Location	Temperature sum of test site, d.d.	Coefficients for the model			
			a	b	R^2	F
936/1	Kilpisjärvi	460	101.8	-0.051	0.48	12.97^{**}
936/2	Muotkatakka	470	122.1	-0.077	0.72	36.54^{***}
936/4	Pallasjärvi	680	91.7	-0.068	0.56	18.97^{***}
936/5	Laanila	650	86.9	-0.085	0.79	57.06^{***}

At the beginning of the 1980's a large network of experiments with extremely northern provenances of Scots pine were established in areas on both sides of the Scots pine timber line. The results from some typical experiments are presented in Figure 2 and Table 2. These experiments were planted in 1982 with one-year-old containerized seedlings using a randomized block design (six blocks and 49 plants in a plot). In all the experiments survival was the lower, the warmer was the climate of the origin of the provenance. The effect of a decrease in survival for a 100 d.d. increase in the temperature sum of origin was about the same (5 to 8 %-units) in all the experiments (Table 2). The results are in accordance with those from more southern parts of Lapland (Mononen 1987).

It is interesting to note that the two experiments (Kilpisjärvi, Muotkatakka) which were established in the coldest climate north of the Scots pine treeline had a higher survival than the experiments in the warmer climate in the pine forest zone (Fig. 2). Etholén (1972) also observed that survival in commercial plantations of Scots pine was higher in northern Lapland than in more southern areas. These results can partly be explained by the young age of the plantations and the slower height growth in the northern experiments. The plants in the northern experiments are still protected by the snow cover, whereas the better growth in the more favourable climate has already exposed the plants to the harsh winter climate. The plantations to the north of the natural distribution of Scots pine (No.'s 936/1 and /2) may also benefit from the lack of biotic damaging agents. It was in fact observed that the plants in the experiments outside the natural distribution of Scots pine were not attacked by snow blight (*Phacidium infestans*) during the 10-year period, whereas at the same time this disease was recorded several times in the southernmost experiment at Pallasjärvi. The absence of natural pests and diseases can also explain the success of some exotic species in their new environments.

The results from provenance experiments with Scots pine show that the clinal adaptation to shorter growing season continues up to the timberline. This is in clear discrepancy with the hypothesis of Sarvas (1970), according to which genetic variation is missing north from the 950 d.d limit.

Exotic tree species exhibit provenance variation in their new environments. Therefore it is essential to test the genetic variation within species when new introductions are planned. The utility of a species having a distribution area extending over thousands of kilometres cannot be decided only by testing one or a few provenances.

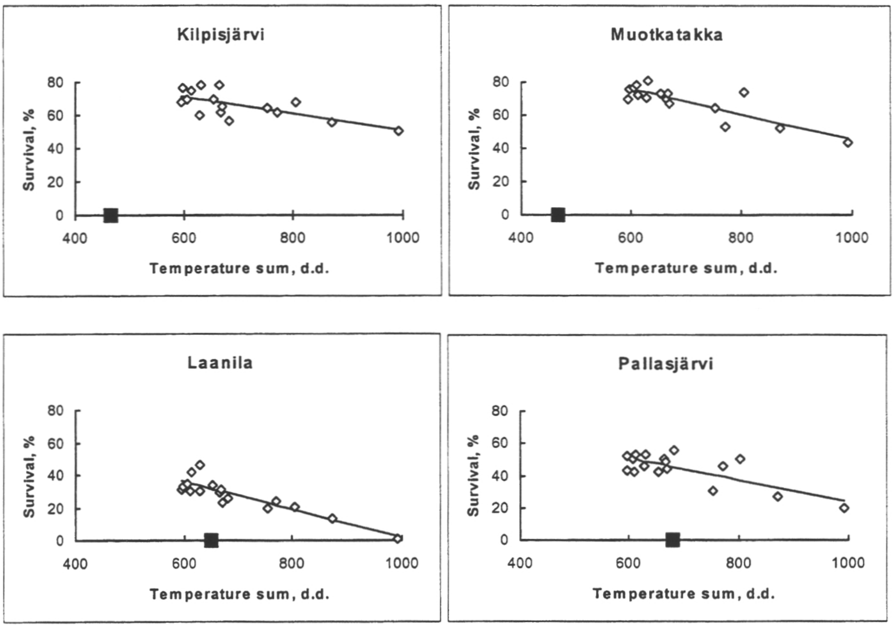

Figure 2. Regression of the survival of 10-year-old Scots pines on the average annual temperature sum of origin (years 1961-90, +5° C threshold) in four provenance experiments close to the timberline. Experiments at Kilpisjärvi and Muotkatakka are located north of the Scots pine tree line. (■ = temperature sum of test location)

4.4 Variation at the individual level

Variation at the individual level has been studied mainly in plus trees which have been selected for the purposes of tree breeding according to their good growth and quality. The plus trees cannot be expected to represent the original variation in selected characters of the species, but for other characters they can be approximately regarded as a random sample of the original population.

Variation between plus trees has been observed in many characters like the timing of seed fall of Norway spruce (Ruotsalainen 1990), seed maturity of Scots pine (Harju *et al.* 1996), survival and height growth (Nikkanen 1982, Rousi 1983, Mikola 1993) and freezing tolerance (Nilsson and Andersson 1987, Aho 1994). Survival and height growth have been extensively studied using field progeny tests established with seed from seed orchards located in central Finland. Because this material is provenance hybrid with northern mothers and central Finnish fathers, its hardiness is not good enough for practical use in northern Finland, but is well suited for progeny testing.

An example of the amount of genetic variation between plus tree progenies in survival and height growth is shown in Figure 3 and Table 3. The Scots pine plus trees in these tests originate from Inari, 50 to 100 km from the timberline. The lay-out in these experiments is also randomized blocks with six blocks and 25 plants per plot. The heritability values for survival were considerably higher than those for height growth, indicating greater genetic variation in hardiness (Table 3). The same observation can be made visually in Figure 3. The survival values within one site show large variation, whereas the differences in height growth are small. It is noteworthy that the survival values obtained at the different experimental sites are in rather good agreement. Height growth and survival seem to be rather independent. The plus trees having progenies with the highest (P550) and lowest (P641) survival in the experiment originate from the same river valley only three kilometers apart from each other. This indicates that considerable genetic differences in hardiness characters exist within geographically limited areas.

Table 3. The proportion of genetic variation (family heritability, %) for survival and height in three progeny tests of Scots pine plus trees from Inari. The age of the tests was 8 (792/1) or 10 (792/3, /4) years at the time of measurement.

Test No.	Location	Temperature sum of test site, d.d.	Family heritability, %	
			Survival	Height
792/1	Pello	820	85	0
792/3	Salla	750	78	-[1)]
792/4	Tervola	890	82	21

1) = survival too low for reliable height measurement

Attempts have been made to improve the hardiness of Scots pine in Sweden by selecting isolated trees growing north of the timberline. Preliminary results have shown that progenies from these trees better tolerate artificial freezing than progenies from the northernmost plus trees (Nilsson 1993). According to Andersson (1985), the survival of a local population growing at latitude 67 °N in Sweden could be improved from 30 % to 55 % by means of effective selection.

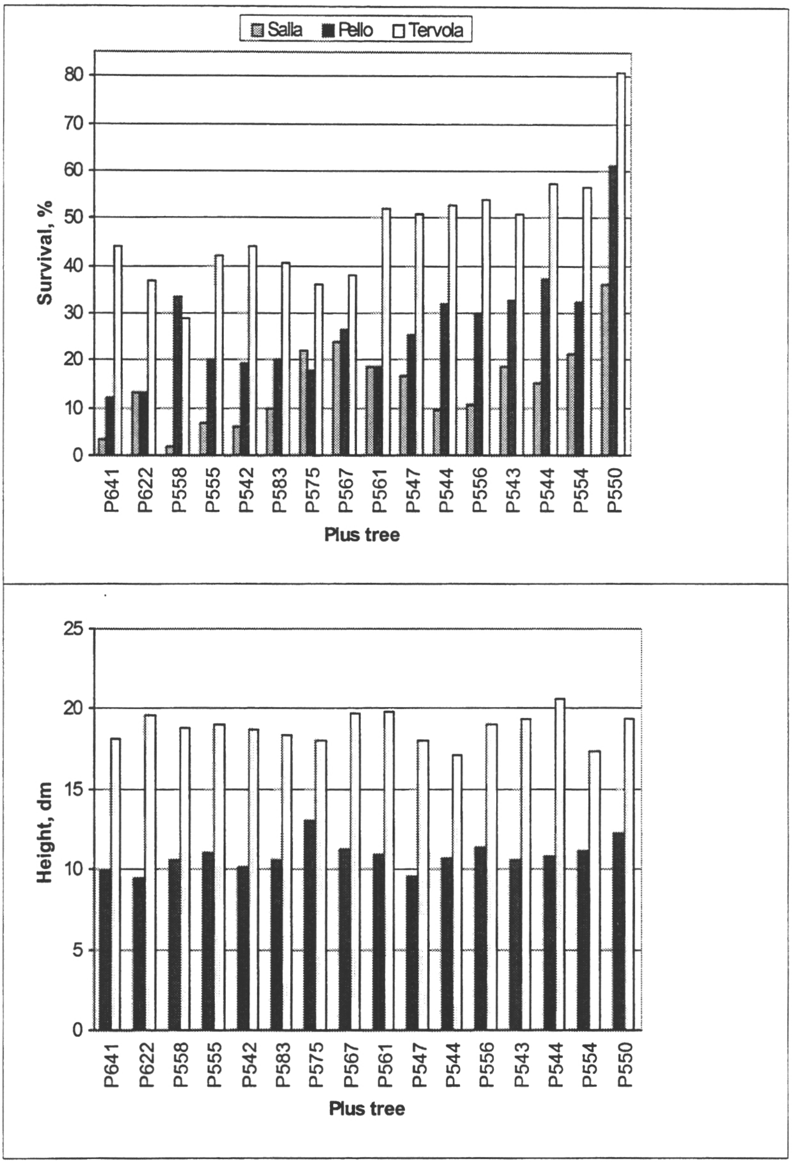

Figure 3. Variation in survival and height growth in progenies of plus trees from Inari in three progeny tests measured at 8 (test No. 792/1) or 10 (other tests) years age. Plus trees arranged according to increasing mean survival in the three progeny tests. Material in the tests was grown from seed collected from seed orchards in central Finland.

At first it may seem difficult to explain the high amount of observed genetic variation in survival close to the timberline, because hardiness has such a fundamental importance in the northern environment. One explanation could be the inefficiency of natural selection to counteract the effect of gene flow in an environment which is changing annually (Lindgren 1993). Also the conditions at the planting sites and requirements set on the planting material by man may be different to those in the natural state. Negative genetic correlation between survival and some other fitness component, *e.g.* fertility, could help to maintain genetic variation (Mousseau and Roff 1987). In fact, the hardiest plus tree in progeny test No. 792 (and also in the whole breeding zone), P550, has a low seed production. However, this kind of negative correlation was not found in a larger material (Anne Pakkanen, Foundation for Forest Tree Breeding, pers. comm.). According to theoretical models, a small population size during the evolutional history of a population can increase the genetic variation by reorganizing the existing genetic structures (Barrett and Husband 1989). Evidence from artificial selection experiments with organisms having a short generation interval, have shown that directional selection can continue over more than 70 generations without exhausting genetic variation (Falconer 1981). Thus, considering these several contributing factors, it is quite natural to find great genetic variation also close to the timberline.

5 Summary and conclusions

The genetic structure of the tree populations close to the timberline does not deviate drastically from that of more southern populations. Depending on the species, vegetative reproduction or selfing seem to be more abundant close to the timberline. However, the amount of genetic variation is also at a high level also in the timberline conditions if the distribution of the species is continuous. The earlier hypothesis of reduced genetic variation of Scots pine in the whole of northern Finland was based on preliminary observations on phenological events in natural stands. This conclusion does not hold as such, but some differences in the reaction to the temperature sum were observed in northern Finland compared to more southern populations.

The existing high genetic variation gives the populations a high buffering capacity against future changes in environmental conditions. There is also historical evidence of this. After the Ice Age trees migrated up to the timberline from their refuges in central and southern Europe, where the combination of climatic factors (especially temperature and light) was much different. Even in such southern populations there existed enough genetic flexibility to enable the trees to adapt to grow in the continuous day prevailing at high latitudes during the growing season! The special conditions at the timberline may even have been beneficial for the evolutionary speciation process.

Although the amount of genetic variation is high in timberline populations, they can suffer from some qualitative genetic maladaptations caused by their evolutionary history and migration through pollen flight. Thus the adaptation process can be promoted and directed by selecting the right species, population and individual to be used in forest regeneration. Special measures can be taken to decrease the harmful effects of pollen migration, and to identify the desired hardy material for cultivation purposes. Vegetative propagation would be an ideal technique for capturing the specific gene combination that gives the best final result. If there is the need and will, the stability and productivity of the timberline forests can be increased by improving their genetic constitution.

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References

Aarne, M. (ed.) 1995. Metsätilastollinen vuosikirja 1995. Statistical Yearbook of Forestry. The Finnish Forest Research Institute, Forest Statistics Information Service, Agriculture and forestry 1995:5.354 p.

Aho, M.-L. 1994. Autumn frost hardening of one-year-old Pinus sylvestris (L.) seedlings: effect of origin and parent trees. Scandinavian Journal of Forest Research 9: 17-24.

Andersson, B. 1985. Anläggning av tallplantager för kärva klimatlägen. Establishment of Scots pine seed orchards for areas with harsh climate. Institutionen för skoglig genetik och växtfysiologi. Sveriges Lantbruksuniversitet. Report 4: 75-83.

Arno, S.F. and Hammerly, R.P. 1984. Timberline: Mountain and arctic forest frontiers. The Mountaineers. Seattle. 304 p.

Barrett, S. C. H. and Husband, B. C. 1989. The genetics of plant migration and colonization. In: Brown, H. D., Cleg, M. T., Kahler, A. L. and Weir, B. S. (eds.), Plant population genetics, breeding and genetic resources. Sinauer Associates, Inc. p. 254-277.

Bhumibhamon, S. 1978. Studies on Scots pine seed orchards in Finland with special emphasis on the genetic composition of the seed. Communicationes Instituti Forestalis Fenniae 94(4). 118 p.

Björkman, E. 1971. Resistensprövning mot parasitsvampar hos skogsträd i Sverige. Summary: Resistance test against parasitic fungi in forest trees in Sweden. Sveriges Skogsvårdsförbunds Tidskrift 5: 499-510.

Conkle, M. T. 1992. Genetic diversity - seeing the forest through the trees. In: Adams, W. T., Strauss, S. H. Copes, D. L. and Griffin, A. R. (eds.) Population genetics of forest trees. Proceedings of the International Symposium on Population Genetics of Forest Trees. Corvallis, Oregon, USA, July 31-August 2, 1990, New Forests 6(1-4): 5-22.

Cwynar, L.C. and MacDonald, G.M. 1987. Geographical variation of lodgepole pine in relation to population history. The American Naturalist 129(3):463-469

Ericsson, T. 1993. Survival of Pinus contorta and Pinus sylvestris in northern Sweden. In: Lindgren, D. (ed.). Proceedings of ”Pinus contorta - from untamed forest to domesticated crop”. Meeting of IUFRO WP 2.02.06 and Frans Kempe Symposium, Umeå, August 24-28, 1992. Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Report 11: 326-333.

— and Andersson, B. 1997. Can field mortality of lodgepole pine (Pinus contorta var. latifolia) families be predicted based on early freezing test results? Forest Genetics 4(2): 61-67.

Etholén, K. 1972. Männyn viljelyn tulos Pohjois-Suomessa ja siemenen alkuperä. Summary: The success of artificial regeneration of Scots pine in northern Finland and origin of seed. Folia Forestalia 160. 27 p.

Falconer, D. S. 1981. Introduction to quantitative genetics. 2nd ed. Longman. London and New York.

Grace, J. and James, J. 1993. Physiology of trees at treeline. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p. 105-114.

Harju, A.M., Kärkkäinen, K. and Ruotsalainen, S. 1996. Phenotypic and genetic variation in the seed maturity of Scots pine. Silvae Genetica 45(4): 205-211.

Heide, O. M. 1985. Physiological aspects of climatic adaptation in plants with special reference to high-latitude environments. Julkaisussa: Kaurin, Å., Junttila, O. and Nilsen, J. (toim.). Plant Production in the north, Proceedings from "Plant adaption workshop", Tromsø, Norway, September 4-9, 1983. Norwegian University Press. Oslo. p. 1-22.

Henttonen, H., Kanninen, M. Nygren, M. and Ojansuu, R. 1986. The maturation of *Pinus sylvestris* seeds in relation to temperature climate in northern Finalnd. Scandinavian Journal of Forest Research 1:243-249.

Hirvas, H. 1991. Pleistocene stratigraphy of Finnish Lapland. Geological Survey of Finland, Bulletin 354. 123 + 4 p.

Kalela, A. 1937. Zur Synthese der experimentellen Untersuchungen über Klimarassen der Holzarten. Communicationes Instituti Forestalis Fenniae 26 (1). 445 p.

Kallio, P., Hurme, H., Eurola, S., Norokorpi, Y. and Sepponen, P. 1986. Research activities on the forest line in northern Finland. Arctic 39(1):52-58.

— and Mäkinen, Y. 1975. Vascular flora of Inari Lapland. 3. Salicaceae. Reports of Kevo Subarctic Research Station. 12:66-105.

—, Niemi, S., Sulkinoja, M. and Valanne,T. 1983. The Fennoscandian birch and its evolution in the marginal forest zone. *In*: Morisset, P. and Payette, S. (*eds.*) Tree-line ecology. Proceedings of the Northern Québec Tree-line Conference. Collection Nordicana No 47:101-110.

Kärkkäinen, K. 1994. Deleterious mutations and sexual allocation in the evolution of reproduction of Scots pine. Acta Universitatis Ouluensis. A. Scientiae Rerum Naturalium 259. 37 p + append.

Karvonen, P. and Savolainen, O. 1993. Variation and inheritance of ribosomal DNA in *Pinus sylvestris* L. (Scots pine). Heredity 71: 614-622.

Koski, V. 1970. A study of pollen dispersal as a mechanism of gene flow in conifers. Communicationes Instituti Forestalis Fenniae 70(4). 78 p.

— 1989. Siemensiirrot ja ilmastoon sopeutuminen. [Seed transfers and adaptation to climate] (only in Finnish). Metsäntutkimuslaitoksen tiedonantoja 328: 20-37.

Kuittinen, H., Muona, O., Kärkkäinen, K. and Borzan, Z. 1991. Serbian spruce, a narrow endemic, contains much genetic variation. Canadian Journal of Forest Research 21: 363:367.

Kujala, V. 1927. Untersuchungen über den Bau und die Keimfähigkeit von Kiefern- und Fichtensamen in Finnland. Communicationes ex Instituto Quaestionum Forestalium Finlandiae Editae 12[6]. 106 p. + 5 tables.

Lindgren, D. 1985. Contortatall - varifrån och vart? Lodgepole pine - where and from where? Institutionen för skoglig genetik och växtfysiologi. Sveriges Lantbruksuniversitet. Report 4: 159-168.

— 1993. Accelerating adaptation of trees at tree limits by selective breeding. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p. 299-320.

— and Lindgren, K. 1997.Long distance pollen transfer may make gene conservation difficult. *In*: Kurm, M. and Tamm, Ü. (Eds.), Conservation of Forest Genetic Resources. Nordic Group for Forest Genetics and Tree Breeding Meeting in Estonia June 3-7, 1996. Estonian Agricultural University, Tartu. ISBN 9985-830-11-3. Forestry studies 28:51-62.

Lloyd, A. H. 1997. Response of tree-line populations of foxtail pine (*Pinus balfourniana*) to climate variation over the last 1000 years. Canadian Journal of Forest Research 27: 936-942.

Luomajoki, A. 1993a. Climatic adaptation of Norway spruce (*Picea abies* (L.) Karsten) in Finland based on male flowering phenology. Acta Forestalia Fennica 242. 28 p.

— 1993b. Climatic adaptation of Scots pine (*Pinus sylvestris* L.) in Finland based on male flowering phenology. Acta Forestalia Fennica 237. 27 p.

Mäkinen, K. 1982. Tiedonanto Vuotson interglasiaalisesta lehtikuusen rungosta. Summary: Report on interglacial *Larix* trunk at Vuotso, Northern Finland. Geologi 34 (9-10): 183-185.

Martinsson, O. 1986. Historic background to the natural distribution of tree species in Scandinavia. Institutionen för skoglig genetik och växtfysiologi. Sveriges Lantbruksuniversitet. Report 6: 281-287.

Matyas, C. 1990. Adaptation lag: A general feature of natural populations. Joint Meeting of WFGA and IUFRO Working Parties S 2.02.5, 6, 12 and 14 Olympia, WA, USA - August 20-25 1990, 10 p.

Mikola, J. 1982. Bud-set phenology as an indicator of climatic adaptation of Scots pine in Finland. Silva Fennica 16(2): 178-184.

— 1993. Provenance and individual variation in climatic hardiness of Scots pine in northern Finland. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, I celand, June 18-23.1991. Plenum Press. New York and London. p. 333-342.

Mononen, S. 1987. Männynsiemenen siirrot Pohjois-Suomessa. [Transfers of Scots pine seed in northern Finland] (only in Finnish) Metsäntutkimuslaitoksen tiedonantoja 278: 80-91.

Mousseau, T. A. and Roff, D. A. 1987. Natural selection and the heritability of fitness components. Heredity 59: 181-197.

Muona, O. and Harju, A. 1989. Effective population sizes, genetic variability and mating system in natural stands and seed orchards of Pinus sylvestris. Silvae Genetica 38(5-6):221-228.

Nagasaka, K., Wang, Z. M. and Tanaka, K. 1997. Genetic variation among natural *Abies sachalinensis* populations in relation to environmental gradients in Hokkaido, Japan. Forest Genetics 4(1):43-50.

Neale, D. B. and Adams, W. T. 1985. Allozyme and mating-system variation in balsam fir (*Abies balsamea*) across a continuous elevational transect. Canadian Journal of Botany 63: 2448-2453.

Nikkanen, T. 1982. Pohjois-Suomen mäntyjen nuorissa siemenviljelyksissä syntyneen siemenen käyttömahdollisuuksista Oulun läänin alueella. Summary: Survival and height growth of North Finland x South Finland hybrid progenies of Scots pine in intermediate areas. Folia Forestalia 527. 31 p.

Nilsson, J.-E., 1993. Selection and breeding of Scots pine for northern Sweden. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p. 321-332.

— and Andersson, B. 1987. Performance in freezing tests and field experiments of full-sib families of *Pinus sylvestris* (L.). Canadian Journal of Forest Research 17: 1340-1347.

Ødum, S. 1979. Actual and potential tree-line in the North Atlantic region, especially in Greenland and the Faroes. Holarctic Ecology 2(4):222-227.

Pohtila, E. 1980. Climatic fluctutations and forestry in Lapland. Holarctic Ecology 3(2):91-98.

Remröd, J. 1976. Val av tallprovenienser i Norra Sverige — analys av överlevnad, tillväxt och kvalitet i 1951 års tallproveniensförsök. Summary: Choosing Scots pine (Pinus sylvestris L.) provenances in Nothern Sweden — analysis of survival, growth and quality in provenance experiments planted 1951. Institutionen för Skogsgenetik. Skogshögskolan. Rapporter och Uppsatser 19. 132 p.

Renvall, A. 1919. Suojametsäkysymyksestä I-VI. [On the question of shelter forest] (only in Finnish). Acta Forestalia Fenica 11. 671 p.

Robertson, A. 1993. Effects of wind on boreal forest. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p.203-225.

Rousi, M. 1983. Pohjois-Suomen siemenviljelysjälkeläistöjen menestymisestä Kittilässä. Summary: The thriving of the seed orchard progenies of northern Finland at Kittilä. Folia Forestalia 547. 14 p.

Ruotsalainen, S. 1987. Kuusen alkuperäsiirrot korkeilla mailla. [Provenance transfers of Norway spruce at high altitudes] (only in Finnish) Metsäntutkimuslaitoksen tiedonantoja 278: 66-79.

— 1990. Kuusen siemenen syysvariseminen. [Autumnal seed fall in Norway spruce] (only in Finnish) Metsäntutkimuslaitoksen tiedonantoja 362: 90-99.

— and Neuvonen, S. 1995. The role of tree line parks in studying adaptation of conifers in marginal areas. *In*: Tikkanen, E. and Mikkelä, H. (*eds.*). Kola Excursion through Finnish Lapland and Northeastern Norway to the Kola Peninsula. 12-19 August. Post-congress excursion guide 15. IUFRO XX World Congress, August 1995, Finland, p. 20-21

— and Velling, P. 1993. *Pinus contorta* provenances in northern Finland - first 20 years. *In*: Lindgren, D. (*ed.*). Proceedings of "*Pinus contorta* - from untamed forest to domesticated crop". Meeting of IUFRO WP 2.02.06 and Frans Kempe Symposium, Umeå, August 24-28, 1992. Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Report 11: 122-136.

Sarvas, R. 1970. Temperature sum as a restricting factor in the development of forest in the subarctic. *In*: Ecology and conservation. Ecology of the subarctic regions. Proceedings of the Helsinki Symposium 1966. Unesco. p. 79-82.

Sirén, G.1958. Eräitä havaintoja keskisuomalaisen ja paikallisen mäntyrodun biologisista ja teknillisistä ominaisuuksista Perä-Pohjolassa. Summary: Some observations on the biological and technical properties of the local and central-finnish pine provenances in North Finland. Silva Fennica 96 (1). 32 p.

Stern, K. and Roche, L. 1974. Genetics of forest ecosystems. Ecological Studies 6. Berlin. Springer Verlag. 330 p.

Strauss, S. H., Bousquet, J. Hipkins,. V. D: and Hong, Y.-P. 1992. Biochemical and molecular genetic markers in biosystematic studies of forest trees. *In*: Adams, W. T., Strauss, S. H. Copes, D. L. and Griffin, A. R. (*eds.*) Population genetics of forest trees. Proceedings of the International Symposium on Population Genetics of Forest Trees. Corvallis, Oregon, USA, July 31-August 2, 1990, New Forests 6(1-4):125-158.

Sulkinoja, M. 1990. Hybridization, introgression and taxonomy of the mountain birch in SW Greenland compared with related results from Iceland and Finnish Lapland. Meddelelser om Grønland, Bioscience 33: 21-29.

Taira, H., Tsumura, Y., Tomaru, N. and Ohba, K. 1997. Regeneration system and genetic diversity of *Cryptomeria japonica* growing at different altitudes. Canadian Journal of Forest Research 27: 447-452.

Tigerstedt, P. M. A. 1973. Studies on isozyme variation in marginal and central populations of *Picea abies*. Hereditas 75: 47-60.

— 1993, Genetic diversity of tree populations at their arctic limits. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p. 241-250.

Tremblay, M. and Simon, J.-P. 1989. Genetic structure of margianal populations of white spruce (*Picea glauca*) at its northern limit of distribution in Nouveau-Quebec. Canadian Journal of Forest Research 19:1371-1379.

Tuhkanen, S. 1993. Treeline in relation to climate, with special relation to oceanic areas. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p. 115-134.

Uotila, A. 1985. Siemenen siirron vaikutuksesta männyn versosyöpä- alttiuteen Etelä-ja Keski-Suomessa. Summary: On effect of seed transfer on the susceptibility of Scots pine to Ascocalyx abietina in Southern and Central Finland. Folia Forestalia 639. 12 p.

Wagner, D. 1992. Nuclear, chloroplast and mitochondrial DNA polymorphisms as biochemical markers in population genetic analyses of forest trees. *In*: Adams, W. T., Strauss, S. H. Copes, D. L. and Griffin, A. R. (*eds.*) Population genetics of forest trees. Proceedings of the International Symposium on Population Genetics of Forest Trees. Corvallis, Oregon, USA, July 31-August 2, 1990, New Forests 6(1-4): 373-390.

Wardle, P. 1993. Causes of alpine timberline: a review of the hypotheses. *In*: Alden, J., Mastrantonio, J. L. and Ødum, S. (*eds.*) Forest Development in Cold Climates. Proceedings of a NATO Advanced Research Workshop. Laugarvatn, Iceland, June 18-23.1991. Plenum Press. New York and London. p. 89-103.

Weeden, N. F. and Wendel, J. F. 1989. Genetics of plant isozymes. *In*: Soltis, D. E. and Soltis, P. S. (*eds.*) Isozymes in plant biology. Chapman and Hall, London, p. 46-72.

Yeh, F. C. and Layton, C. 1979. The organization of genetic variability in central and marginal populations of lodgepole pine *Pinus contorta* spp. *latifolia*. Canadian Journal of Cytology 21: 487-503.

The location of the coniferous timberline in the Pallas-Ounastunturi National Park

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1 Introduction

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. The national park, located at 67°55-68°20'N, 24°07'E, covers 50 000 hectares containing about 22 000 hectares of virgin timberline forests. That is why its location gives excellent chances for studying the dynamics of alpine timberline formations (Lovén and Kleinhenz 1996). The northern timberline of Norway spruce (*Picea abies* L.) runs through the middle of the park. Scots pine (*Pinus sylvestris* L.), Mountain birch (*Betula pubescens* ssp. *tortuosa* Lebed) and also spruce have their alpine timberlines in the park. The extensive timberline sites are a consequence of the long fell range through the park and the large gradient in elevation, i.e. more than a 500 m between the highest and lowest points. The highest peak is Taivaskero, 807 m above sea level.

Some studies have been made about timberline ecology in the Pallas-Ounastunturi National Park, but the exact location of the timberline has not been systematically researched. This kind of information is needed for many ecological studies and monitoring systems, such as climate change and its influence on the timberline.

The aim of this study was to determine the location of the alpine, coniferous timberline in the Pallas-Ounastunturi National Park and to investigate factors influencing on it. The study was based on a vegetation mapping made by Finnish Forest Research Institute.

The study is not yet completed and this paper concentrates on the altitude of the coniferous timberline in the Pallas-Ounastunturi National Park. The term ”timberline” in this paper means the limit above which coniferous trees can not form any more closed forests.

2 Material and methods

The vegetation mapping of the Pallas-Ounastunturi National Park was started 1987 by Rovaniemi Research Station of the Finnish Forest Research Institute. The vegetation mapping serves as a base for many research activities and park management. Besides the vegetation types, plenty of other information was stored, for example data on stand and site parameters (Eeronheimo et al. 1992). The data are stored in numerical form in a geographic information system.

The following variables of the vegetation database were used for the study: coordinates, altitude, exposition, gradient, site type group, vegetation types, dominant height of the trees, canopy cover percentage by tree species (pine, spruce, birch), windfalls, firescars and erosion. The data were collected on lines located at intervals of 500 metres. Three measurement spots were located on every line: the upper limit of the coniferous forest, the upper limit of the birch forest and lower limit of the treeless area.

In the vegetation mapping the minimum size of the compartment figure was 0,5 ha. The aim of the field work was to check the data taken from the vegetation map. The field study concentrated on places where the altitude of the timberline was located lower or higher than the average. The aim was also to find ecological factors influencing on the deviating location.

On the field the exact location of the checkpoint was determined with GPS-equipment and the altitude above sea level and the gradient of the slope were measured. The direction, macrotopography, moisture and stoniness of the ground were observed. The composition of tree species by number of stems and saplings (per ha) and mean height of trees were the stand parameters measured in this study.

3 Results and discussion

The mean altitude of the timberline in the Pallas-Ounastunturi National Park was 415 m a.s.l. The timberline was at its highest on the south-west slope and at its lowest on the north-east slopes. The difference was 110 m. On the south-west slopes the thermal conditions are most favourable than on the other sides.

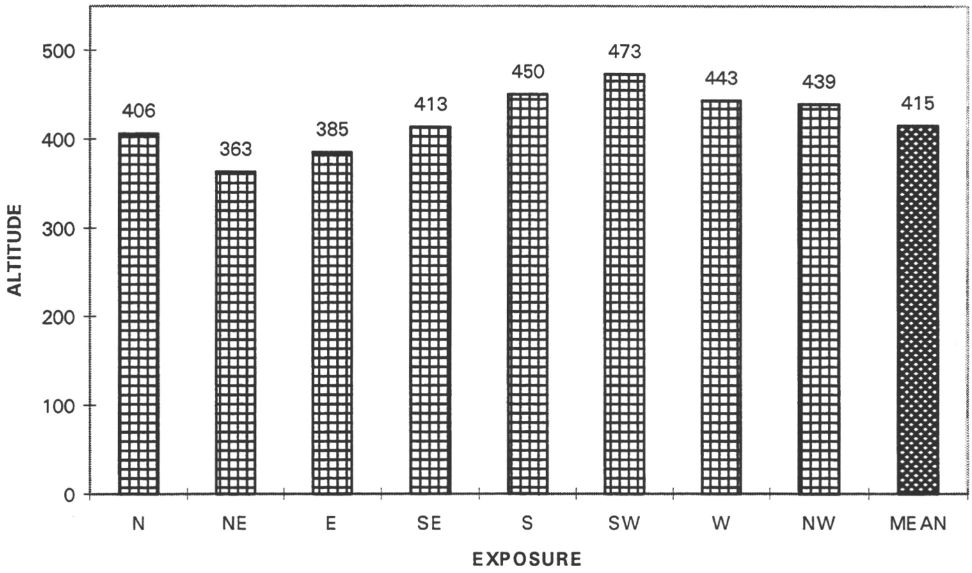

Figure 1. Altitude (m a.s.l.) of the alpine timberline in Pallas-Ounastunturi National Park with different exposures.

The ground is still cold after the night when the sun shines first to the east slopes in the morning. When the sun shines to the western side of the fell in the evening, the ground has warmed up during the day. Thus the same amount of radiation has more favourable effect on the tree growth and regeneration under higher temperatures on the west slopes compared to the east ones. Furthermore, the ground in the morning is moister and more radiation energy is needed for evaporation than in the evening when the ground is dryer and warmer. North-east exposures are even colder than east and north ones because the sun radiation is low and the sites have cooled during the night. The influence of different exposures have been found also in Kuusamo (66°N) where stand characteristics were greater on hill-sides facing south-west in comparison to those facing north-east. The differences were in the order of 20% for basal area and volume, and 10% for height characteristics (Norokorpi and Kärkkäinen 1985).

The results of the field measurements showed that the timberline is located little lower than it was determined by the vegetation mapping. The difference was about 30 m. The range was large and more field measurements are needed for more accurate determinations of the timberline location.

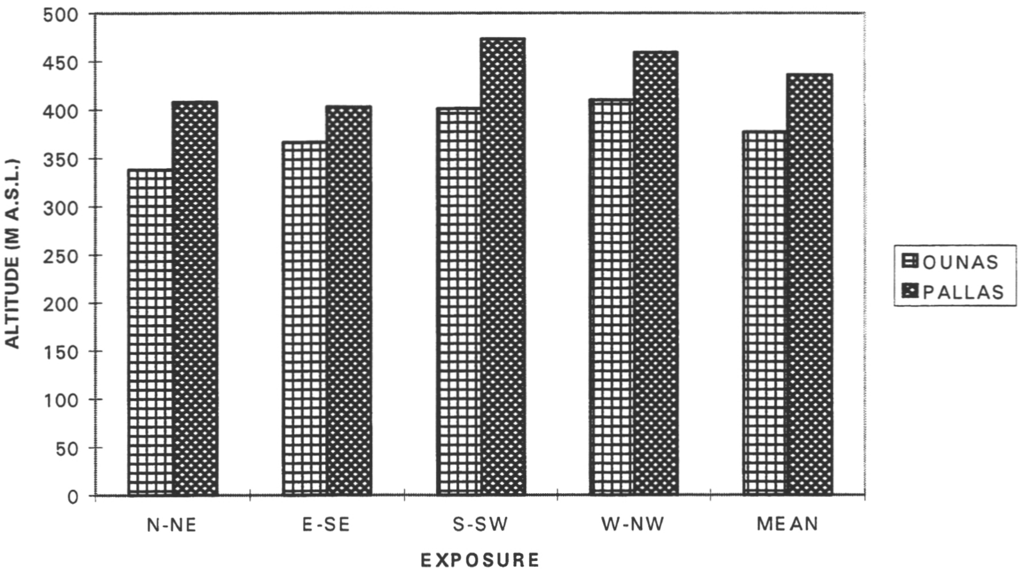

Figure 2. The altitude (m a.s.l.) of the timberline on the different exposures of the northern (Pallas) and southern (Ounas) fells.

The difference in the altitude of the timberline between the northern and southern fells was 60 m (Fig. 2). It is not only a consequence of the thermal conditions because the difference in the temperature sums is about 20 d.d. The other factors may involve in the quality of soils and sites. Norway spruce forms the timberline on the southern fells, Pallastunturit, Keimiö-, Sammal- and Lommoltunturi. On the northern fells, Ounastunturit, spruce is replaced by Scots pine. The polar timberline of the Norway spruce is located in the middle of the park. It is not controlled by the thermal conditions because Norway spruce can survive on the sites with the same or lower temperature sum than Scots pine

(Norokorpi 1994). The main reason for controlling the polar timberline of the spruce and the composition of the tree species is the dominance of the dry and barren mineral soil sites in the North (Heikinheimo 1921, Mäkitalo et al. 1994). That is also the situation in the Pallas-Ounastunturi National Park. In the Ounastunturi area the bedrock consists of quartzite and the soils are poor in nutrients. The spreading of the spruce on that kind of sites is slow and forest fires are very destructive.

The highest limit for the coniferous timberline in Finland is located at the latitude 67°30'N at the altitude of 500 m a.s.l. south of the protection forest zone. From that level it recedes southwards and can not be explained by the thermal conditions of the growing season. North of the above mentioned limit the timberline is located at the line where the average temperature sum (threshold value +5°C) is about 600 d.d. (Norokorpi 1994). The results of this study confirm this model. The average height of the timberline in the study area, 415 m a.s.l., is situated at the line which describes the altitude of the timberline at 68° N-parallel (Fig 3). The temperature conditions during the growing season determine the assimilation process of the trees. When there is not enough assimilation products for supporting the vital functions of the forest, the closed forest ends and only the hardiest individuals can survive up to the timberline. The coniferous treeline in located on the line of 550 d.d (Norokorpi 1994).

However, south of the latitude 67°30'N the timberline recedes and is dependent on the severity of snow damage. The closer the site is to the Gulf of Bothnia, the lower is the altitude of the so-called crown snow-load limit above which snow damage occurs repeatedly. The formation of the crown snow-load (i.e. accumulation of frost, ice and snow on tree crowns) is a repeated phenomenon above this limit. The coniferous forest line lies at about 150 metres above the crown snow-load limit. Above the forest line snow damage is so severe that it makes growth and regeneration impossible (Norokorpi 1981). In the area of the Pallas-Ounastunturi National Park the crown snow-load damage is not so remarkable because of the continentality but there occurs some crown snow-load influence in the southern parts of the national park.

This study will be continued by analysing ecological factors influencing on the location of the coniferous timberline at Pallas.

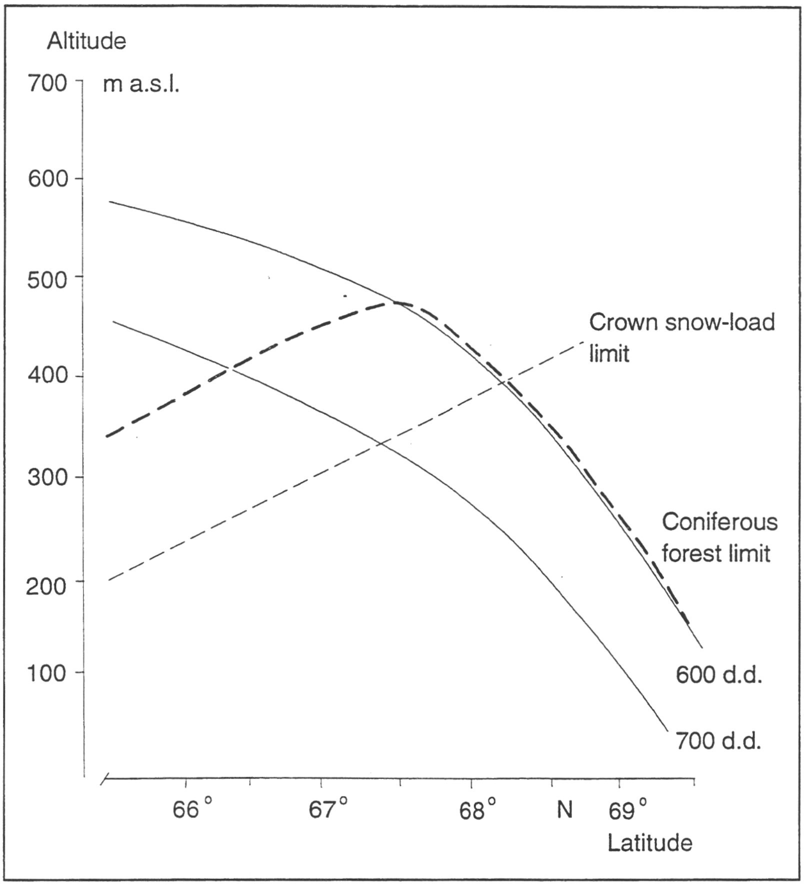

Figure 3. Coniferous forest limit (timberline), crown snow-load limit and the curves of the effective temperature sum on the 600 d.d. and 700 d.d. along the longitude on 27 °E (Norokorpi 1981).

References

Eeronheimo, H., Virtanen, R., Sippola, A., Sepponen, P., Salmela, S. and Pikkupeura, R. 1992. Pallas-Ounastunturin kansallispuiston kasvillisuus - Ounastunturin Pyhäkeron alue. Metsäntutkimuslaitoksen tiedonantoja 427. 119 p.

Heikinheimo, O. 1921. Suomen metsänrajametsät ja niiden vastainen käyttö. Referat: Die Waldgrenzwälder Finnlands und ihre kunftige Nutzung. Communicationes ex Instituto Quaestionum Forestalium Finlandiae Editae 4. 91 p.

Lovén, L. and Kleinhenz, B. 1996. National park as research area for monitoring environmental change. In: Lovén, L. and Salmela, S. (eds.). Pallas-symposium 1996. Metsäntutkimuslaitoksen tiedonantoja 623: 7-10.

Mäkitalo, K., Sutinen, R., Hyvönen, E., Pulkkinen, E., Pänttäjä, M. and Sutinen, M.-L. 1994. Määrääkö maaperä kuusen polaarisen metsänrajan Pohjois-Lapissa? In: Tasanen, T., Varmola, M. and Niemi, M. (eds.). Metsänraja tutkimuksen kohteena. Metsäntutkimuslaitoksen tiedonantoja 539: 35-48.

Norokorpi, Y. 1981. Lakimetsien rajaamisen perusteita. Metsäntutkimuslaitoksen tiedonantoja 24: 59-65.

Norokorpi, Y. 1994. Havumetsänrajan sijainnin määräytyminen Suomessa. In: Tasanen, T., Varmola M. and Niemi, M. (eds.). Metsänraja tutkimuksen kohteena. Metsäntutkimuslaitoksen tiedonantoja 539: 7-15.

Norokorpi, Y. and Kärkkäinen, S. 1985. Maaston korkeuden vaikutus puusto- ja kasvupaikkatunnuksiin sekä tykkytuhoihin Kuusamossa. Summary: The effect of altitude on stand and site characteristics and crown snow-load damage in Kuusamo in northern Finland. Folia Forestalia 632. 26 p.

Monitoring timberline dynamics in northern Lapland

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1 The aim and method of the project

This timberline monitoring project is carried out by the Finnish Forest Research Institute (Metla) and the northern experiment stations of the Universities of Helsinki, Oulu and Turku. The aim of the project is to follow the development of the arctic and alpine timberlines and treelines in Finnish Lapland (Kallio *et al.* 1985). The targets of monitoring are the growth, regeneration and survival rate of the dominant tree species, the changes in the position of timberlines and treelines, and the changes in the timberline ecotone. Permanent research plots were established in 1983 and 1984 in different parts of the Finnish timberline regions (Fig. 1). The study areas represent mainly alpine timberline, i.e. their location is highly dependent on the altitude. All the three dominant tree species of northern Lapland, Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies ssp. obovata*) and mountain birch (*Betula pubescens ssp. czerepanovii*) are represented in the study areas. Some preliminary results of the monitoring project are presented in this report.

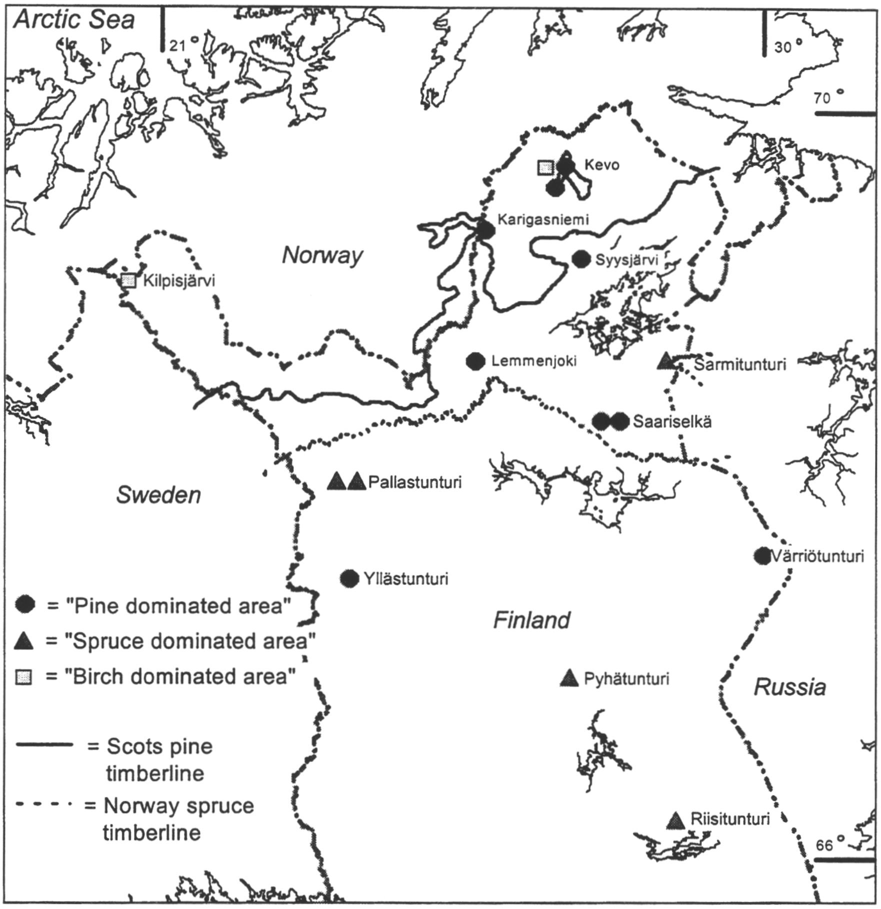

Figure 1. Location of the study areas.

The clusters consisting of three circular study plots are situated (Fig. 2):

- in a forest stand with a normally closed canopy under the timberline
- on the timberline (the edge of closed-canopy forest)
- on the treeline (the border, where the density of trees falls under one tree / square kilometer)
- in the treeless area beyond the treeline

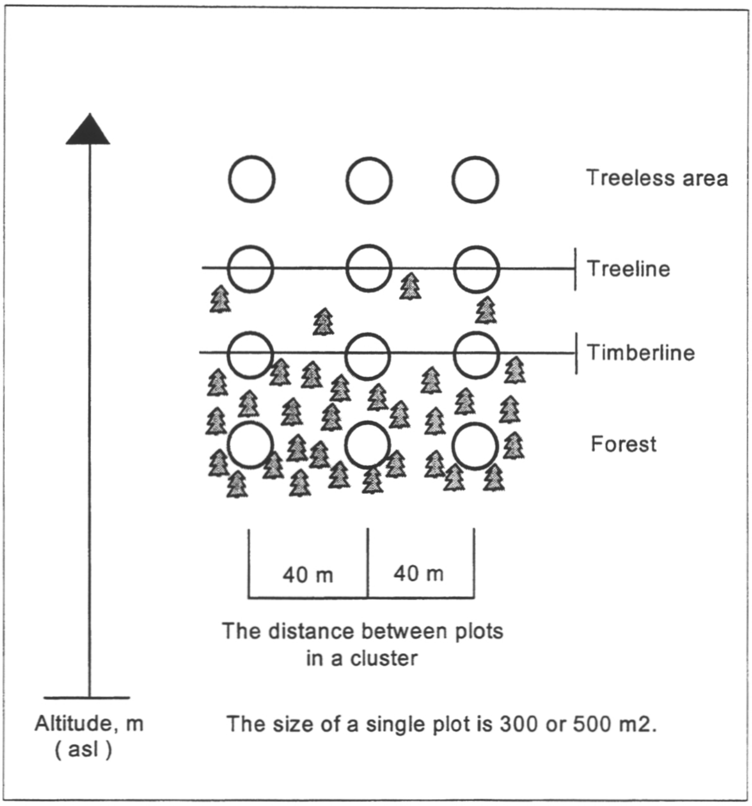

Figure 2. Location of the monitoring plots in a study area. The three parallel plots make together a cluster. The distances between the clusters vary from 100 m on fell slopes to several kilometers on even land.

The circular plots were established in 1983 and 1984. The measurements were repeated 11 years later, in 1994 and 1995. The most important parameters of the trees and seedlings were:

- stem number of different species
- height and diameter at breast height
- damage and diseases
- condition and vitality

The amount of seedlings less than 20 cm tall was tallied. Also the species compositon and coverage of the ground vegetation was measured in five study areas when establishing the study plots. That measurement will be repeated by longer, 20 - 30-year interval.

2 Results

2.1 The density and growth of the forests

The density of stands growing in the study areas was represented with two different parameters: basal area and stem number per hectare. Basal area is the cumulative area of the cross sections of the trees at breast height, counted per hectare. This charasteristic is useful for measuring the volume or volume growth of a forest stand. The basal area in the forest varied from 3 m^2/ha (Kilpisjärvi) to 20 m^2/ha (Pallastunturi). The change during the monitoring period was positive in most study areas indicating radial growth and/or increasing stem number (Fig. 3).

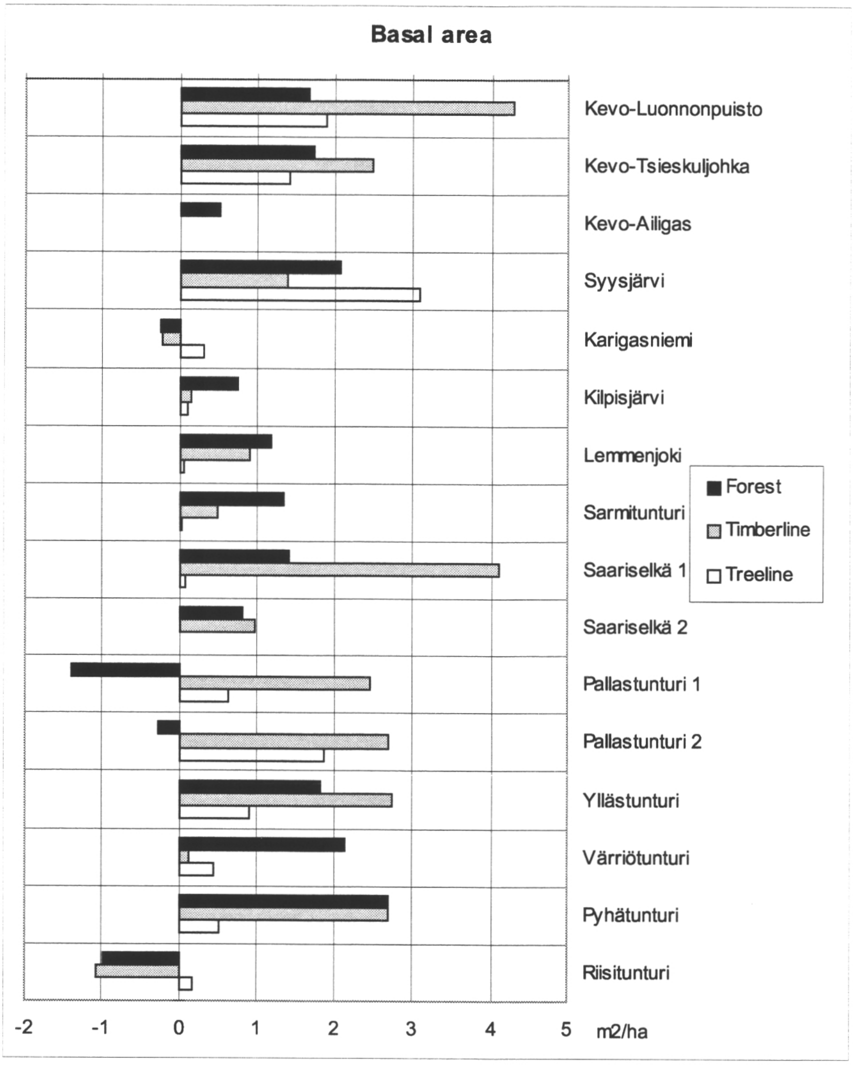

Figure 3. The change of the basal area (m^2/ha) during the monitoring period.

The number of trees per hectare increased almost in all the study areas. Only on some plots the stem number decreased. That was resulting from some damage: wind, snow, fungi etc. The damaged areas were usually quite small. The average increase was ca. 50 stems ha^{-1}, but the variation was wide, as can be seen of the bar graphs (Fig. 4).

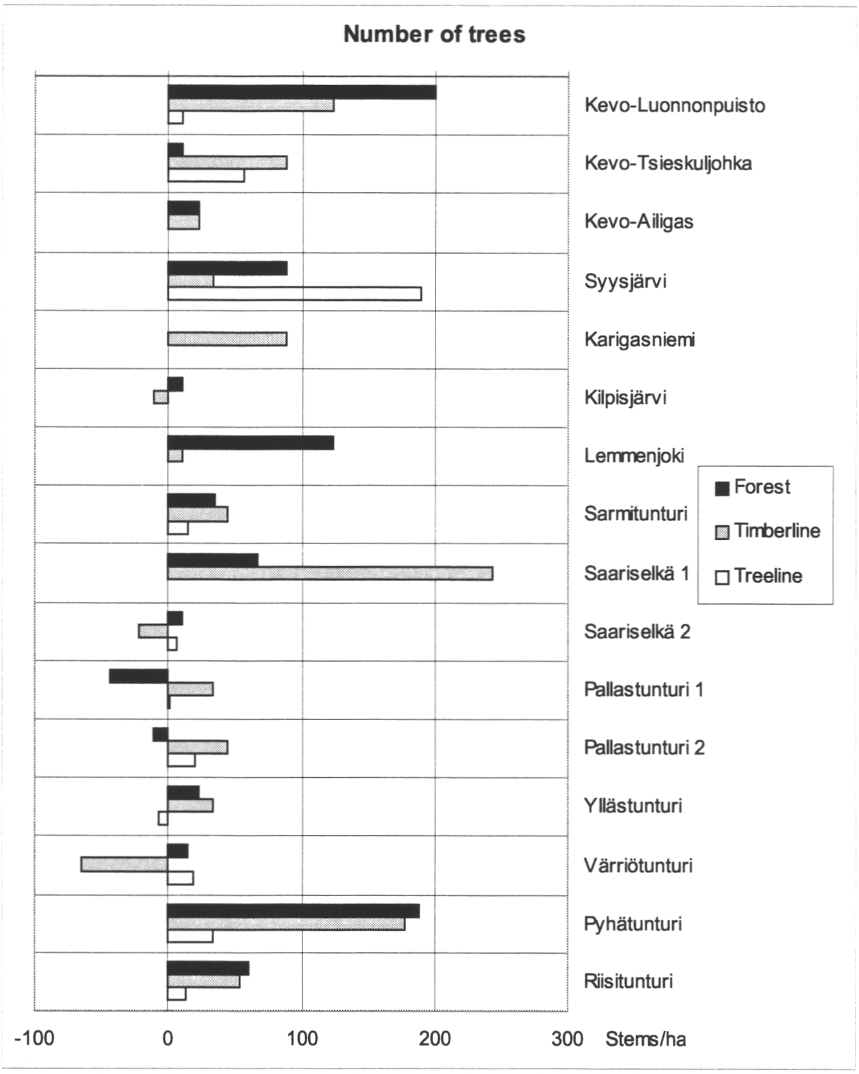

Figure 4. The change of the number of trees per hectare during the monitoring period.

The change of mean diameter of the trees was mainly positive, only a few exceptions occurred (Fig. 5). The average increment was about one centimetre during the 11-year monitoring period. There was a very wide variation within and between the clusters. Some stands were fairly even-aged and their diameter distribution was not very wide, but usually there were trees of different age and size classes in the stands. The smallest diameters of trees in the study areas were 2 cm at breast height and the biggest ones exceeded 40 cm. The results showed clear diameter increment in all the areas in the forest and timberline clusters, but the growth was obvious also on the treeline.

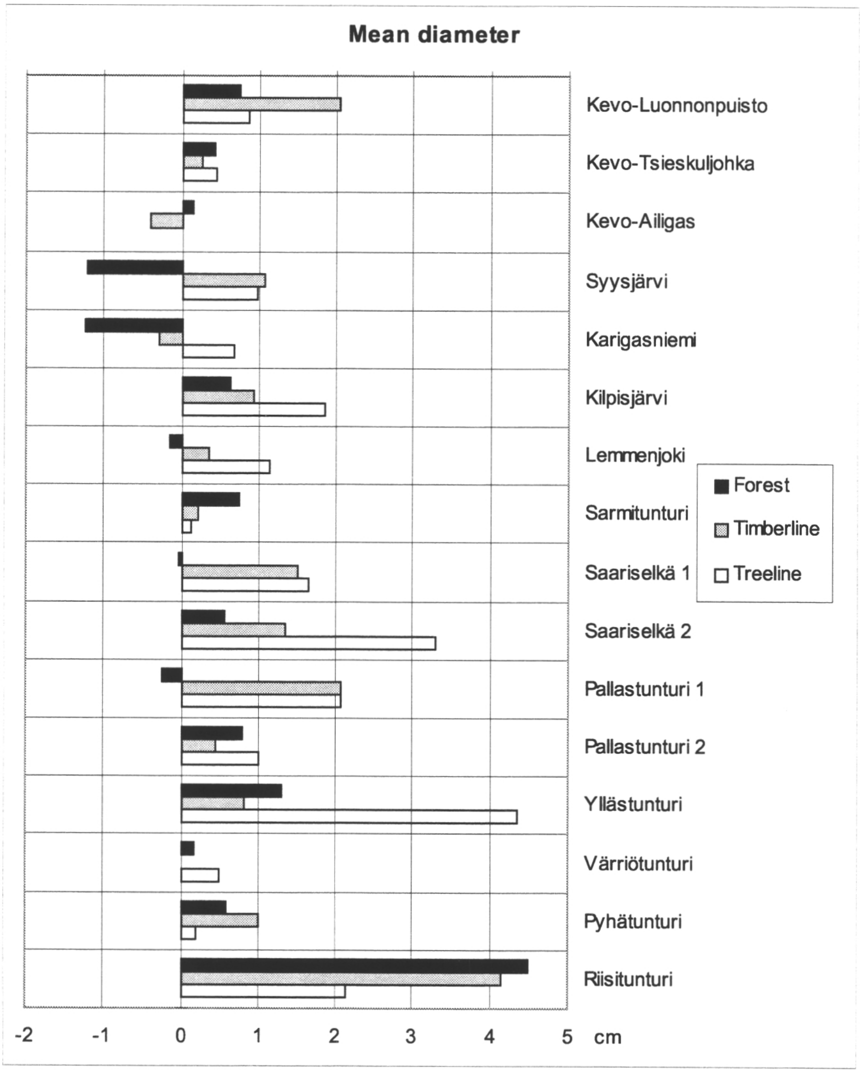

Figure 5. The change of the mean diameter (cm) durig the monitoring period.

The height development of the trees was very heterogeneous. There was a remarkable variation between the research areas and also between the clusters of some areas. The mean height decreased in one or two clusters of several areas and increased in the others (Fig. 6). A reliable explanation for this variation is not known so far, but more detailed information will be obtained by shortening the measurement intervals. One important factor influencing the height development is the heavy snow load that is gathering on the crowns of the trees and finally breaking the tops, especially on the fellsides. The mean height growth of the trees in all the areas was 0.3 m during the 11-year monitoring period. The heights of the trees varied from 2 to 15 m. The number of trees was very low in some clusters, and that is why, a couple of fallen trees or a transfer of one or two individuals from seedling class to tree class (the limit 2.0 m) had made a remarkable change on the bar chart.

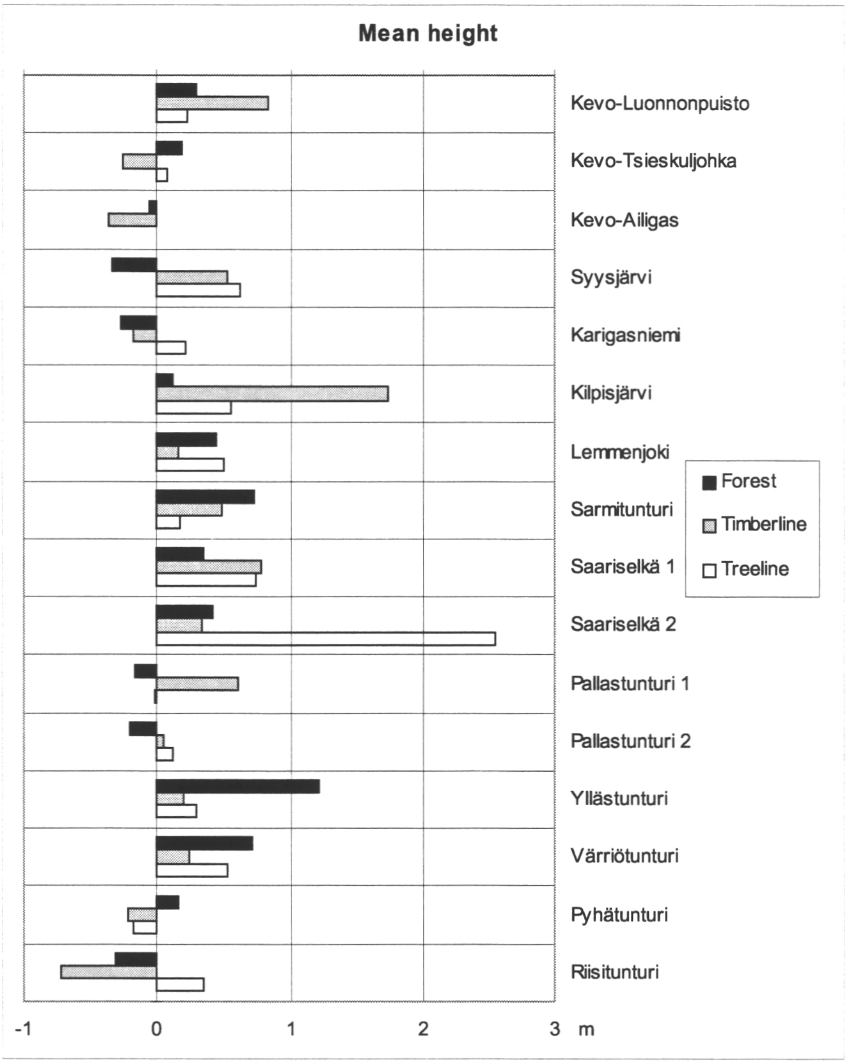

Figure 6. The change of the mean height (m) during the monitoring period.

2.2 Tall seedlings

The conifer seedlings more than 20 cm and the broad-leaved seedlings more than 50 cm tall were included in one class: tall seedlings. The upper limit of the class was 2.0 m. The change in the number of tall seedlings varied in large range (Fig. 7). The value was close to zero (0) in many areas which means a balance between the decrease and increase.

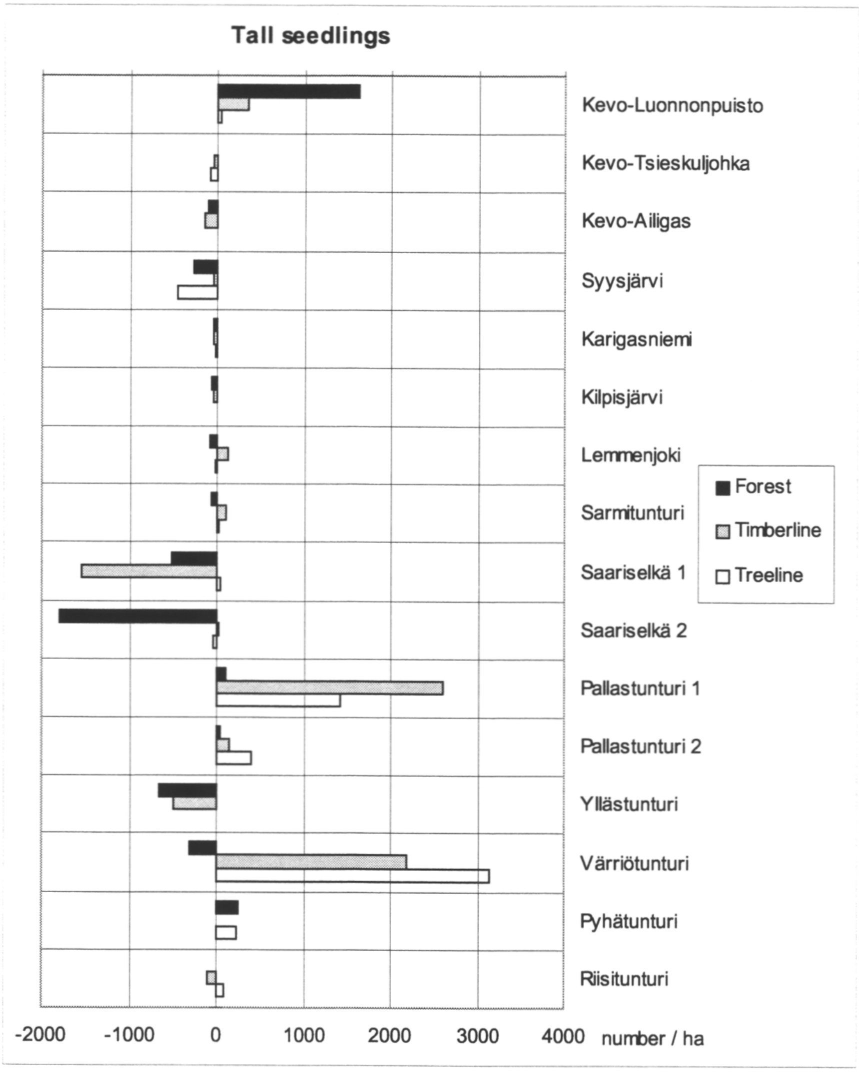

Figure 7. The change of the number of the seedlings over 20 cm tall during the monitoring period.

The number of tall seedlings changes rapidly for many reasons. In every growing season some seedlings exceed the 2-metre limit and belong then to the class of trees. At the same time, some small seedlings exceed the lower limit of the class of tall seedlings. The death rate is also remarkable in the harsh circumstances of the timberline region. The inventory of dead seedlings proved to be very difficult. The 10 - 11-year interval between inventories is too long. For example, the amount of seedlings eaten by reindeer or other mammals cannot be counted reliably. Because of these inventory problems, more intensive observation methods are developed at least for some of the study areas.

2.3 Small seedlings and the regeneration capacity of the trees

Good seed years occur irregularly in the timberline region, and the interval between them is usually several decades. There was a good pine and spruce seed year in 1972. Also the summers of 1973, 1974 and 1980 were so warm that the seed maturation of conifers was possible at least locally in favourable conditions (Numminen 1989, Sirén 1993, 1998). A major part of the colonizing seedlings found in the first inventory in 1983 - 84 originated from the early 1970's. Those good seed years were also followed by favourable germination conditions. A remarkable percentage of the seedlings established at that time had already died, but there were some hundreds per hectare of survived seedlings still alive. The variation between study areas and clusters was high indeed (Fig. 8). In the second inventory (1994 - 95) were found new seedlings which did not exist at the moment of the first inventory. A majority of them originated obviously from the seed that has maturated and germinated in the favourable years at the turn of 1990's. However, some natural regeneration has happened also in such years, that have not been very favourable in the whole of Lapland. Thus, small amounts of mature seed with a sufficient germination capacity has been produced almost every year in some of the research areas. Some delayed germination may have happened, too. The pine and spruce seed can maintain their germination capacity over some years. A shorter inventory interval and closer observations of the seed development are needed for clearing up which factors and what kind of conditions are crucial for successful seed maturation and germination.

The change in the number of small seedlings is clearly negative (Fig. 8). In addition to the high death rate, the decrease is due to the transfer of small seedlings to the next class (the height limit 20 cm for conifers and 50 cm for broad leaves). In the areas, where the number of small seedlings had increased remarkably, it was mainly question of mountain birch. Its regeneration can be both generative or vegetative.

On the clusters situated in the treeless areas behind the treeline, the number of small seedlings had decreased regurarly (not presented in the figures).

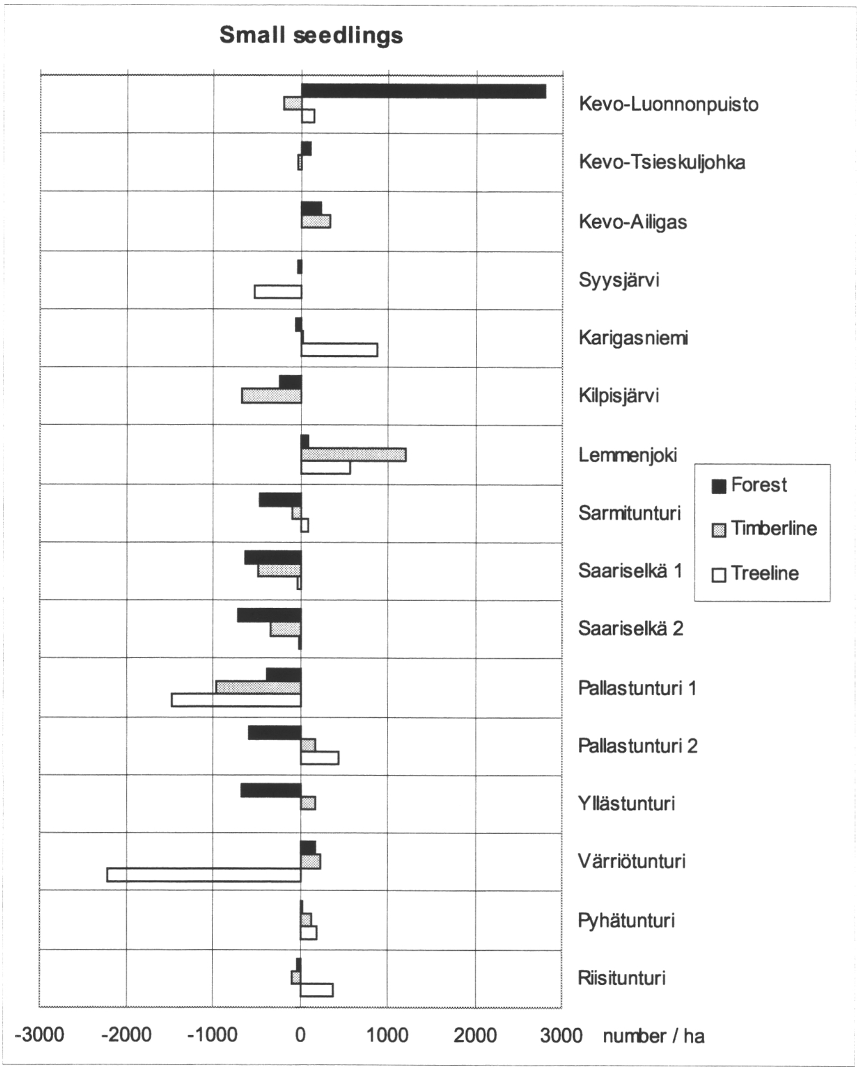

Figure 8. The change of the number of the small seedlings less than 20 cm (broad-leaved seedlings less than 50 cm) tall during the monitoring period.

3 Discussion

The results showed, that basal area, stem number, mean diameter and height increased on most study areas during the 11-year monitoring period. Thus there occurred noticeable growth in the forests and solitary trees of the timberline region. Especially the increasing density of the timberline forests had to be noticed. It was resulting from favorable conditions during the recent decades. Fungus diseases, damage by pests, frost, wind and other agents had been quite limited. A remarkable number of seedlings had reached the dimensions of trees.

Because the study plots had been measured only twice, it is not known yet, if there was happening any change in the growth rate. Anyway, it is obvious that the timberlines and treelines in the study areas are not declining at the moment. One can also conclude, that the fairly good vitality of the trees increase their regeneration capacity. According to some dendrochronological studies, the radial growth of trees at the timberlines and treelines of Fennoscandia has been stabile or to some extent decreased during the last 30 - 50 years (Kullman 1990, Timonen 1996 and 1998, Sirén 1998).

The results showed that a slow timberline advance may be happening, but according to the previous experience, it can be stopped again for a long time by some serious hazard: fungus disease, insect damage, summer frost, storm etc. (Hustich 1948, Holtmeier 1974, Eronen 1979, Seppälä and Rastas 1980, Sirén 1998, Veijola 1998). Different kinds of hazards have occurred approximately as often as good seed years in this century. Usually the hazards have been local by nature and destroyed the seedlings totally only in quite restricted areas.

Good seed years have occurred irregularly and their interval has usually been several decades in this century (Sirén 1961 and 1998, Holtmeier 1974, Veijola 1998). Any increase in their frequency is not probable. Although the timberlines and treelines are not declining, any rapid advance is not happening either. Some new theories and computer models forecast a rapid advance of timberline in the near future as a result of the global warming (Roos 1996, Kellomäki *et al.* 1997). Until now, there have not occurred any visible or measurable signs of such development in our study areas. However, it is obvious that the global change can sooner or later have some remarkable impact on the timberline ecosystems. That is why the inventories and measurements as well as formulating of models have to be continued. In addition to monitoring the development of trees and seedlings it is important to follow up the climatic, edafic and other changes at the timberline.

References

Eronen, M. 1979. The retreat of pine forest in Finnish Lapland since the Holocene climatic optimum: a general discussion with radiocarbon evidence from subfossil pines. Fennia 157:2, pp. 93 - 114.

Holtmeier, F-K. 1974. Geoökologische Beobachtungen und Studien an der subarktischen und alpinen Waldgrenzen in vergleichender Sicht. Franz Steiner Verlag GMBH, Wiesbaden. 130 pages.

Hustich, I. 1948. The Scots pine in northernmost Finland and its dependence on the climate in the last decades. Acta Botanica Fennica 42: 1 - 72.

Kallio, P., Hurme, H., Eurola, S., Norokorpi, Y. and Sepponen, P. 1985. Research Activities on the Forest Line in Northern Finland. Arctic vol. 39 (1): 52 - 58.

Kellomäki, S.; Väisänen, H. and Kolström, T. 1997. Model computations on the effects of elevating temperature and atmosphere CO_2 on the regeneration of Scots pine at the timber line in Finland. Climatic Change 37: 683 - 708.

Kullman, L. 1990. Dynamics of altitudinal tree-limits in Sweden: a review. Norsk geografisk Tidsskrift. Vol. 44: 103 - 116.

Numminen, E. 1989. Metsäpuiden siemensato ja tuleentuminen Suomessa. Summary: Seed crops of forest trees and ripening of seeds in North Finland. Acta Lapponia Fenniae No. 15: 87 - 94.

Roos, J. (ed.) 1996. The Finnish research programme on climate change: final report. Edita. 505 pages.

Seppälä, M. and Rastas, J. 1980. Vegetation map of northernmost Finland with special reference to subarctic forest limits and natural hazards. Fennia 158(1): 41 - 61.

Sirén, G. 1961. Skogsgränstallen som indikator för klimatfluktuationerna i norra Fennoskandien under historisk tid. Communicationes Instituti Forestalis Fenniae 54(2). 66 pages.

— 1993. Pine seed-year frequency in the subarctic of Finland: a pilot study. World Resource Review, Vol. 5, No. 1: 95 - 103.

— 1998. Results and conclusions of pine advance studies in subarctic Finland in the 20th century. (In this publication, pages 7 - 16).

Timonen, M. 1996. Lapin metsien kasvun vaihtelu viimeisen 500 vuoden aikana. In: Hökkä, H.; Salminen, H. & Varmola, M. (editors) Pohjoisten metsien kasvu - ennen, nyt ja tulevaisuudessa. Metsäntutkimuspäivä Rovaniemellä 1996. Finnish Forest Research Institute. Research papers 589: 32 - 41.

— 1998. Dendrochronological Analysis at Pine Timberline. (In this publication).

Veijola, P. 1998. The northern timberline and timberline forests in Fennoscandia. Finnish Forest Research Institute. Research papers 672. 242 pages.

GPS traversing the Scots pine treeline of northern Finland - research and related survey problems

Pierre-André Forest

1 Introduction

As one of professor Gustaf Sirén's final projects at the concluding stages of his 50-year research career, this particular project involves the precise measuring of the pine treeline in northernmost Finland. The objectives are (1) to determine the location of the treeline, as defined by professor Sirén (Sirén 1998); (2) to measure the precise geographic location of the treeline using global positioning system (GPS) technology; (3) to study the physiological characteristics of trees at the treeline; and (4) to study the influence that known seed years have had on developing the treeline.

Treeline information is intrinsically spatial, and as a result the geographic information system (GIS) technique for acquiring, storing, and analysing data of the treeline is being adopted for this project. As a highly accurate and efficient positioning technique, GPS is used to facilitate the acquisition of spatial data for GIS purposes.

The basis of this paper comes from material collected in the Enontekiö research area during the winter, spring and summer of 1997. Since the GPS technique is relatively new to timberline and treeline research in many circumpolar regions, this paper can be of interest to researchers planning to use the GPS.

2 GPS in a nutshell

The Global Positioning System (GPS) is based on an arrangement of twenty-four satellites that orbit around the earth, along six separate trajectories. This network of satellites is maintained by the US Department of Defence (DoD), and the system was designed to offer coverage over any location on earth 24-hours a day.

Basically the system operates on signals emitted from the satellites which are then picked up by a GPS receiver on earth, thus allowing measurement of an approximate distance to the satellite from the receiver position. To measure a two-dimensional position (X-Y), at least three satellite signals must be received simultaneously. For three-dimensional positions (X-Y-Z) to be calculated, the receiver must track four or more satellites at a time. The advantage of this system is that it is more precise and easier to use than traditional navigational tools, and it is less subject to interference from weather systems. Furthermore, field data is organised and can be quickly exported to a PC, saving data entry time and expense.

All GPS satellites have several atomic clocks and computers which are used to transmit a steady stream of data, and each satellite positions is tracked very closely by the DoD monitoring stations. Because location information is of major strategic importance, the DoD limits the accuracy of the signals available to civilian receivers. This accuracy limit is created by the introducing of a random distortion of the signals sent by each satellite, and this distortion is called Selective Availability (SA). There are certain variables in SA that exists. For example, over a period of 24 hours the effect of the randomly introduced errors cancels out so a 'true' location can be available as long as the receiver is stationary for the full period. However, this 'true' location is subject to variations in physical factors (i.e. effects of ionospheric delay and tropospheric error) over which the DoD has no control.

One method to overcome the problems caused by SA and the various atmospheric disturbances is known as Differential GPS (DGPS). For DGPS to work, two or more GPS receivers must be used simultaneously. Basically it works when one reference or fixed receiver is located at a known location while the position of the mobile receiver is also being monitored. What happens is that measurements from at least four common satellites are tracked simultaneously at both sites, and the data corrections are then calculated and transmitted via controlled radio link from the fixed receiver to the mobile receiver. The DGPS capability is primarily based on the fact that GPS error sources are very similar over a region of approximately 500 km and are, therefore, virtually eliminated by this differential technique. As a result the DGPS technique allows much greater accuracy of positions (+/-2m), otherwise the risks of standard SA errors would apply (i.e. 300-500m).

3 Survey area and survey procedures

The *Pinus sylvestris* treeline area in northern Finland is marked by seasonal fluctuations of solar radiation, with a 2-month long winter twilight period, and continuous daylight for a longer period in summer. North of the coniferous forests, mountain birch (*Betula pubescens ssp. czerepanovii*) is the prevailing species.

For this project the *Pinus sylvestris* treeline is divided into three research areas. To the west from the Swedish border town of Kaaresuvanto to the Norwegian border near Kieritunturi, is located the **Enontekiö** research area. Then in north central Lapland along the Norwegian border from Karigasniemi to the small village of Petsikko along highway E75, is the **Utsjoki** research area. The third research area **Petsikko,** covers the north-eastern part of Lapland from the village of Petsikko to the Norwegian border near Galmmesjärvi. The traversing distances along the treeline in these research areas are approximately 200, 80 and 110 km respectively (Fig 1). The project is going to be completed in May 1998.

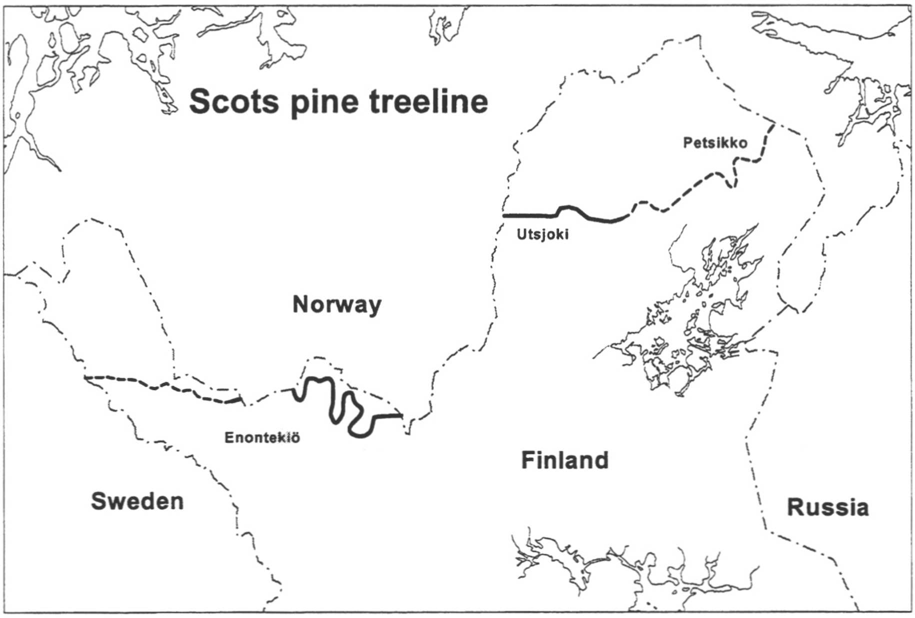

Figure 1. The northern *Pinus sylvestris* treeline and the research areas.

At the start of each field trip the coordinates for the last recorded tree were entered in the GPS receiver to navigate to that location. Upon which time observations were made to determine the number of mature pine trees in the vicinity. On the vast and open snow covered treeline region it is not difficult to notice the solitary pine trees, as most of the birches are covered by snow. To ensure that we did not travel into isolated groups or small stands of pines not forming a contiguous treeline, we travelled along the northern extent of the treeline and up to the top of fells and eskers to get a better view of the landscape.

The GPS we use for satellite observations is the Trimble Pathfinder GeoExplorer six-channel receiver, with single frequency C/A code tracking. By connecting a real-time differential correction (RTDC) receiver to the GPS unit, the DGPS differential correction method is utilised to enhance positional accuracy. The Radio Data System (RDS) method is used to broadcast the RTDC signals, and the transmission comes from the Finnish Broadcasting Company (YLE) Radio FOKUS service. The correction update rates are 10 seconds or better, and offered at an accuracy level of 2 metres. For GPS observations, the necessary receiver operation modes and effects such as loss-of-lock were considered and programmed into the GPS receiver's software. A minimum of 30 observations is collected for each tree location, and the average subsequently calculated. The PC software program in use for GPS data analysis is Pfinder, version 2.40 (Trimble Navigation, Ltd. 1991).

3 GPS research complications and improvements

3.1 Winter and spring

Travelling along the treeline during the later part of winter is facilitated by the fact that the snow covers the dense stands of mountain birch, and because of the increase in day light, the snow forms a hardened surface. Under these conditions a snowmobile can travel faster, for long distances, and can carry heavier loads. The best months for this work are April and May. However, there are technical limitations in operating sensitive electronic equipment under cold climate conditions of Lapland even in late winter and early spring. The GPS equipment was not designed for use in temperatures below -10 °C. I present here the following list of our experiences and problems in using GPS:

- to begin with, the compact and lightweight data correction receiver for RTDC signals was found to consume a substantial amount of energy while recording observations. For that reason the connection between the battery and the RTDC receiver had a manual power switch, to ensure that the power was used only long enough to guarantee that the satellites and RTDC signals were received. Nevertheless, several recordings had taken 15-20 minutes each, when normally it would take 3-5 minutes.

- extra batteries seemed to be necessary; all internal and external GPS batteries had to be tested, recharged or replaced before each field trip.
- the display light on the battery charger was faulty, and batteries were usually under-charged. The battery charger was replaced once.
- suitable arrangements had to be made to protect the GPS equipment from exposure to adverse conditions.

By the middle of May the snow began to loose its holding capacity because of warmer temperatures. Consequently, we were restricted to work during the cooler morning hours before conditions deteriorated. Ultimately, the weather and higher water levels made transport impossible, thus, the fieldwork was postponed until July.

3.2 Summer

The main challenge to perform during the summer months (July - August) what we expected to do during the winter months, came from the fact that progress is slow. For in the summer many obstructions exist (i.e. rivers, lakes, swamps, dense scrub forests, etc.), that during the winter are covered by the snow pack. Progress delays subsequently increase the costs of doing research, therefore, easy access to these isolated sites was desirable. To facilitate access we contacted the Finnish Border Guard and local reindeer herders for information about possible access routes. They were most helpful in giving us details about uncharted trails, potential hazards, and detours.

After the first summer field trip at the treeline, we realised that the most complicated aspect was the treeline itself. Progress in the field had been slower than expected and without knowing in advance where the Scots pine treeline was located; made it difficult to plan access routes and adequate fuel supplies in advance. Thus resulting in a greater demand on equipment and resources. Using remote sensing images was not possible because locating individual trees was almost impossible, as the images were usually taken during the summer months. For this purpose the best remote sensing images would need to be taken during late autumn or early winter, when the contrast between individual pine trees and other types of vegetation are greatest. However, these types of images are not very common and when they are they are very expensive.

4 Summary

Apart from those mentioned in this paper there are many other considerations that are important to take before venturing out into isolated areas for days or even weeks at a time. To succeed, details such as permit dates, resource availability and even climatic conditions must all fit into the same window of opportunity. The actual execution of a GPS survey is greatly facilitated by good planning, and no matter how much money is spent on the technology, a well-planned survey will save both time and money.

References

Leick, A. 1993. More on Kinematic GPS. ACSM Bulletin, March/April, Department of Spatial Information, University of Maine.

Leick, A. 1995. GPS Satellite Surveying John Wiley & Sons Inc. New York, NY. 2nd ed.

Sirén, G. 1998. Results and conclusions of pine advance in subarctic Finland in the 20th century. In this publication, pages 7 - 16.

The research on climatic factors at the arctic treeline of Scots pine

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The purpose of the research is to study the effect of climatic factors on the arctic treeline of Scots pine (*Pinus sylvestris* L.). The concept treeline is here defined using professor Gustaf Sirén's definition: the treeline is reached when the distance between distinct trees higher than 5 m or older than 50 years exceeds one kilometre (see Siren's article in this publication).

There are five study areas, each equipped with a weather station. They are all located along the arctic treeline of Scots pine (Fig. 1). A cluster of circular monitoring plots has been established around each weather station. The area of each plot is 500 m^2, the radius being 12.6 metres. The layout of the plots is shown in Fig. 2. The number of circular monitoring plots in each research area totals 41.

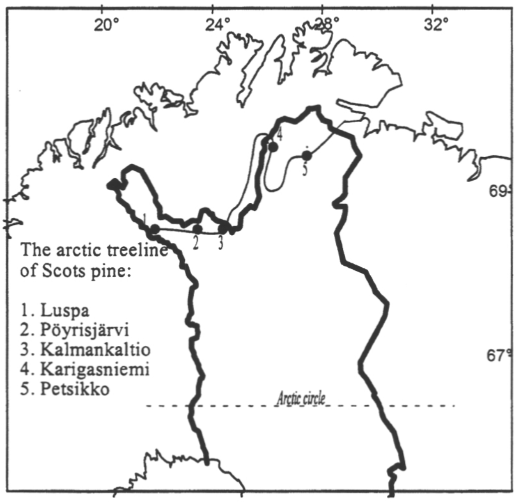

Figure 1. The locations of the study areas.

A general description of soil type, topography, exposition and number of mountain birches is made on each plot. All the pines (height > 2 m), established seedlings (height 20 cm - 2 m) and colonizing seedlings (height < 20 cm) are mapped on each plot, and their diameter, height and age are measured. The state of health, number of cones and the distance from each seedling to the nearest pine are also estimated. Cones are collected from 5 - 10 treeline pines in each study area. The seeds will be x-rayed and the seed quality will be expressed using embryo classes. The expected germination percentage and regeneration capacity will be determined on the basis of this seed maturation analysis.

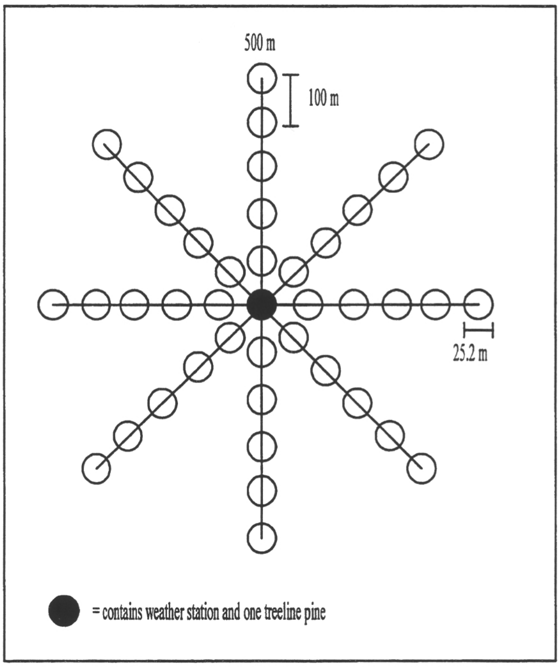

Figure 2. Each cluster is composed of circular monitoring plots, with a radius of 12,6 metres. The central plot is located such that there is a solitary pine in the centre, and the radial plots are spaced every 100 metres along each of the four cardinal points of the compass and each of four half-cardinal points. The monitoring plots are all located within a distance of 500 metres from the central plot.

The treeline ecosystem reacts very sensitively to small fluctuations in climate even and it is thus a very dynamic research object. For this reason the measurement of tree parameters and seed collection will be performed every year. The number of mature seeds and young seedlings, tree growth and species composition will be investigated using the annual follow-up measurements. The climatic parameters and the fluctuation in climate in successive years are obtained from the data collected by the weather stations (Fig. 3). Each weather station measures and stores the following weather parameters:

- wind speed and direction
- air temperature
- soil temperature
- barometric pressure
- humidity
- rainfall
- solar radiation
- temperature sum
- evapotranspiration

Figure 3. "GroWeather" weather station at the arctic treeline of Scots pine in the Pöyrisjärvi study area.

The weather parameters will be measured throughout the year at one-hour interval. At the arctic timberline the transition zone between the timberline and treeline is broad compared to the corresponding zone on the alpine timberline on the slopes of the fells. In order to study the thermal differences between the timberline and treeline special electronic thermometer has been installed on the timberline 5 - 10 kilometres to the south of each weather station.

Northern Lapland nature survey

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1 Introduction

Is the timberline of Scots pine changing? Are mountain birch forests damaged by autumnal moth recovering? The nature survey of Metsähallitus - the Forest and Park Service, will provide an answer to these questions and many others.

The point is, that in nature survey every hectar of the study area is classified according to the nature type. The survey area includes all the protected and wilderness areas of Northern Lapland and other areas not used for commercial forestry. Altogether the survey area covers about 2,5 million hectares, which accounts for almost 30 % of the land area administered by the Forest and Park Service.

2 Why a nature survey?

There exists a comprehensive data base of Finland's forests. They have been surveyed for about 100 years, mainly for forestry purposes. However, the nothern fell and timberline region was surveyed only back in the 1940s. Thus, the information concerning the northernmost region is inaccurate and outdated.

Interest towards northern nature is increasing. Decision makers need information about nature, its current state and changes occurring. Information is needed for planning the use and management of northern natural resources on a sustainable basis.

The Forest and Park Service needs information for land use planning and management, for instance in protected and wilderness areas. The nature survey gives a firm basis for monitoring environmental changes.

The results of the nature survey can be used also by researchers, reindeer herders, berry pickers and anyone who is interested in northern nature. The survey does not aim at establishing new protected areas.

3 How is the survey done?

The biotopes are identified and their boundaries are marked on aerial infra-red photographs. In addition to aerial photographs, information from other sources, such as old surveys, topographic maps, previous studies and local inhabitants, is utilized.

The varios nature types are identified according to topography, vegetation, trees and natureless of the site. Nature types include rock, mineral soil, peatland, water and built environment. From the tree layer tree coverage, volume and species are listed amount other things. Naturalness of a compartment is estimated using sign and knowledge of earlier timber harvests, deterioration of vegetation and amount of buildings or their remnants.

The interpretation of aerial photographs includes two main phases. In the summer the surveyers work out in the field studying how different nature types can be distinguished on aerial photographs.

These so-called interpretation keys give a basis for interpreting the whole area from the areal photographs. This generalization is done during winter time as office work. Compartments are formed for differing sites and each site is attributed to specific nature type. This data together with other information on every compartment is saved in a geographical information system.

4 What is the outcome of the nature survey?

The most important outcome will be a modern and continuously updated geographical information system covering almost the entire northern Lapland. The results of the work will also be published as a book featuring the nature and the nature types of northern Lapland. In addition, the data base will make it possible to produce maps and reports for various purposes.

This project has been started in the beginning of 1996 and it has to be completed by the end of year 1999. The budget for this is about 10 million FIM. European Community has granted about 2 million FIM for survey of Urho Kekkonen National Park.

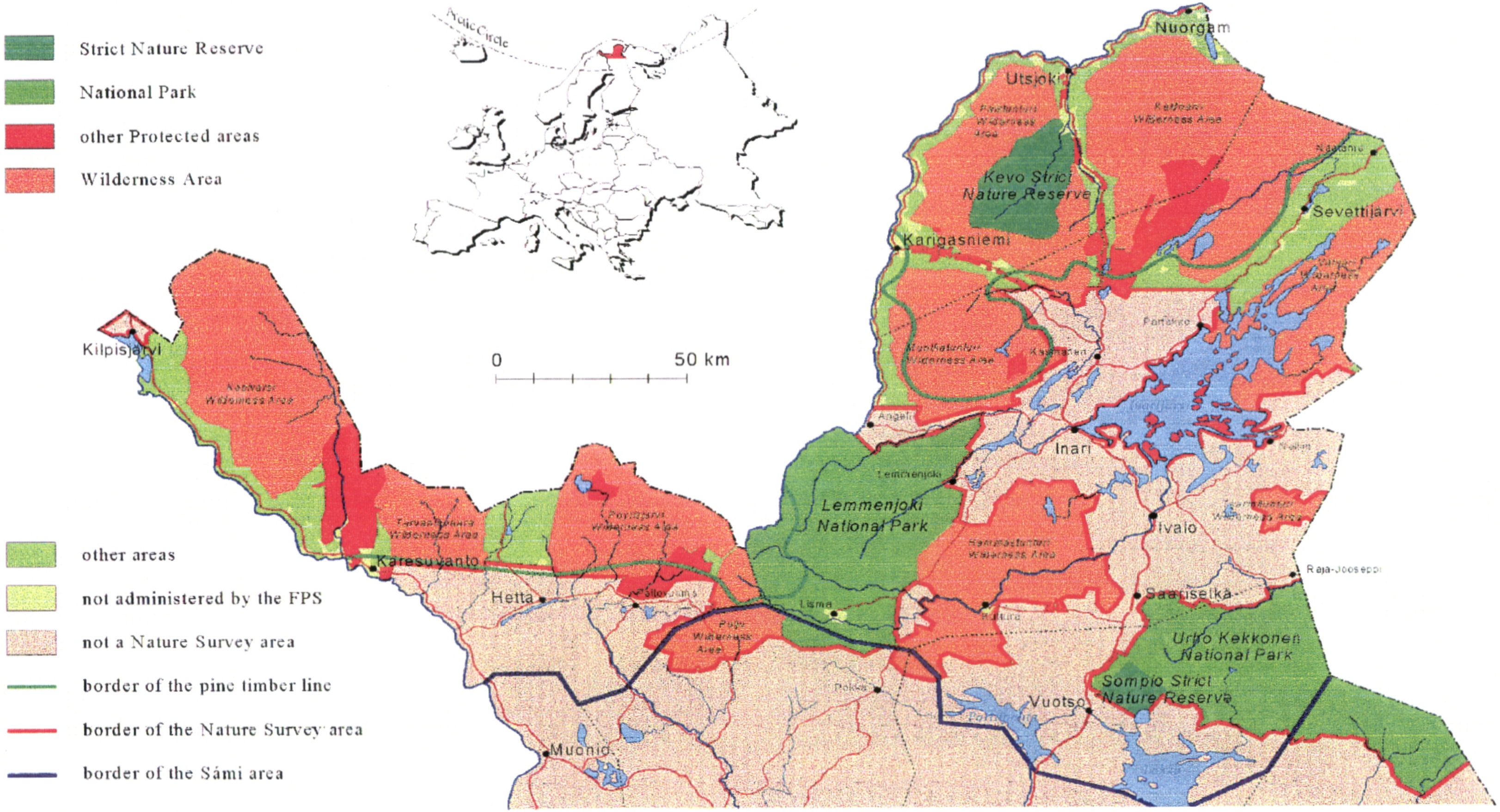

Figure 1. The area of the Northern Lapland Nature Survey.

Brief description of Pasvik Nature Reserve

O.A. Makarova

Zapovednik Pasvik

The joint Norwegian-Russian nature conservation area, Pasvik Nature Reserve, lies on either side of the river Pasvik, along the border between the two countries. The Zapovednik Pasvik on Russian side was established by the decree of the goverment of Russia 16th of July 1992 for preservation of pine forests and monitoring of the ecosystems of the North.

The area of this zapovednik makes 14 727 ha and is streched by a narrow band along the River Pasvik from Hevoskoski Hydroelectric station to the lake Salmijärvi. Coordinates for the area are 69° 07' - 69° 25' northern latitude and 29° 17' - 29° 57' eastern longitude.

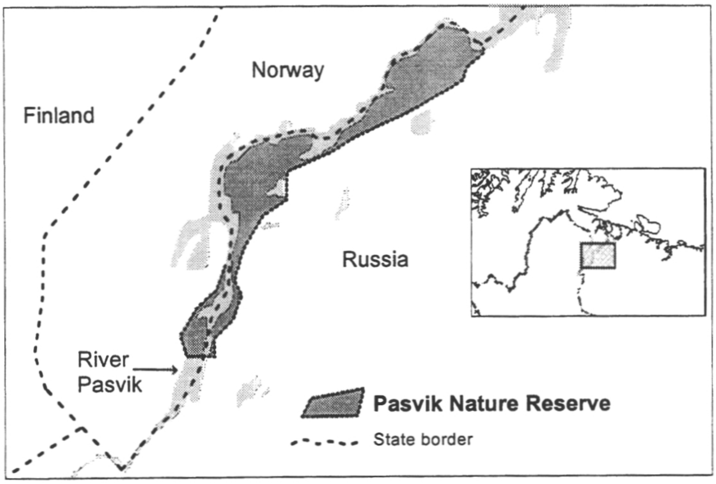

Figure 1. The location of Pasvik Nature Reserve.

Main ecosystems of the zapovednik are: forest 44%, bogs 29% and aquatoria 22%. Main tree species are *Pinus lapponica* and *Betula pubescens*. The forest area is 6 553 ha (55%) and it is mostly submitted by pine forest (86%). More often there are five types of pine forest: *Pinus+Vaccinium myrtillus, P.+Vaccinium vitis idaea, P.+Ledum palustre, P.+lichens* and P.+*rock.* All age classes exist, but middle-aged and old forests are most common. There are some sites where the pine forest has never been cut. Pine forest reaches also to the highest point of the area, mountain Kalkupää (357 m asl).

The birch forests (14% of the forest area, >900 ha) are distributed on the coast of the river and lakes, in the lowest areas. Main types of birch forests are: Myrtillus, Spaghnum and riparian types. Spruce, *Picea sibirica* is extremely rare. These numbers are from the latest forest inventory in 1978. We can not make yet a special forest investigation in Pasvik zapovednik, but we are carrying out round-the-year observations in the nature with a Russian technique ”Chronicle of nature”. For instance the natural regeneration of pine and other species in forest fire areas is followed within this monitoring program.

In 1993 L. G. Isaeva, a researcher from the neighboring Laplandski zapovednik, studied the influence of the emissions from the factory ”Pechenganickel” in the southern part of the Pasvik zapovednik. No visible damage was found in the forests, only some trees suffering from fungi diseases were found. The list of insect and mite species of the area was completed by the researcher, too.

Taking into account the geographical location of the zapovednik, which represents the northernmost pine forests of Europe, a comprehensive investigation of the area is reasonable. A series of permanent monitoring plots along the border from north to south shall be established and measured every fifth year. This task ought to be realized by the organisation of nature protection co-operation between Russia and Finland.

In Jäniskoski village there are several monitoring points. Their monitoring methods ought to be standardized and their operation should be arranged according to a common plan. Setting up a common central monitoring station would be appropriate, too.

Other projects that have been carried out by the zapovednik are as follows: inventory of flora, investigation of the places of last settlements, phenology project with the Norwegian party and other zapovedniks of the Murmansk region, and zoological research, that has been reported in several publications.

Determination of the border between pretundra and taiga forest zones in the northeastern part of European Russia

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Forest vegetation is the most important element of the biosphere on the wide northern plains, where permafrost and excess moisture are typical features. This northernmost forest vegetation region has been called pretundra forests, "pritundravye lesa" by the majority of Russian forest researchers (Shennikov 1940, Melehov 1959, 1966 etc.), although the breadth, geography, borders and geobotanic nature of this concept are still being discussed. These forests are considered to represent a distinctive subarctic type, thus forming a uniform forest vegetation zone. It consists of separate forest islands on the tundra, the forest tundra proper, the northernmost part of the taiga, and the forests in the river valleys within this area.

The irreversible destruction of the extreme edges of the forest vegetation and the exploitation of the pretundra forests, including reindeer pastures, has lead to legislative action. A protection belt, with strict regulations on the use of nature, was established in the northern part of the pretundra forests by a decree of the Russian government in 1959. This protection belt extends to 150 kilometres to the south of the northern timberline. However, the borders of the pretundra forest zone have not been defined as a whole. Data concerning the characteristics of the pretundra forests, forest soil and forest stands in northern Russia have been collected since the 1950's, and it provides us with the means to solve this problem.

The criteria for pretundra forests have been defined with the help of the climatic, landscape-ecological and silvicultural parameters that are used in the zonation of forest vegetation in Russia. The criteria are as follows:

- the area belongs to the cold region (Shashko, 1967)
- the values of bioclimatic potential are low (less than 0,8 - 1,2 according to Koloskov, 1963)
- the value of the hydrothermic coefficient is at least 1,3 (Seljaninov 1955)
- a high proportion of open and poorly stocked forest areas (the average per cent of peatland and tundra is 25 - 30)
- the decomposition activity is very low
- low forest productivity (the average site quality class is V or poorer: the mean height at the age of 100 years is less than 15 m)
- open or very sparse stands dominate and the degree of crown closure is low; in the rooting layer, however, the forest is closed
- the mean height of mature and over-mature stands is less than 15 metres (the dominant species are *Pinus sylvestris* and *Picea abies ssp. obovata*)
- the regeneration capacity is low (the conifers have only a 5 -10 per cent likelihood of satisfactory seed maturation, the reforestation of burned and clearcutted areas takes a long time)
- moss, lichen and dwarf shrub forest site types are dominant

The climatic, landscape-ecological and silvicultural properties of the northern parts of Archangel region and The Komi Republic were analysed by scanning strips with a spacing of 1,5 - 2 degrees longitude and 10 - 30 minutes latitude. The results show, that in the areas north of latitude 64° or 64° 50' N the variation in these parameters is very low. The values remain almost unchanged up to the border of the tundra. The growth period is short (no more than 122 - 125 days), the period of active growth especially (78 days). The values of the index describing the adequacy of temperature are low (no more than 70 - 80). The soil moisture and relative air humidity are high (78 - 82 per cent). All these features are reflected in the special characteristics of the soil and vegetation, as well as in the low growth and productivity levels of the forest vegetation. The natural border between the pretundra and taiga forest zones was determined on the basis of these criteria. Its distribution is shown on the map below (Fig. 1).

This, the real border of the forest vegetation zones, lies 40 - 100 kilometres south of the southern border of the official protection belt (see map in fig.1). This provides justification for extending the protected area. The sensitivity of the pretundra nature to anthropogenic impacts and the extremely low regeneration capacity of the forest vegetation support the extension of the protection belt southwards to the northern border of the taiga forest proper. However, official verification of this is necessary, because there are everincreasing signs showing that the natural northern ecosystems are threatened. Forest fragmentation and the extension of treeless areas are facts. These are caused both by the destruction of the structural complexes in nature and by pollutants derived from industrial activities. Official verification for protecting the whole pretundra forest zone would promote the sustainable development of these areas. The pretundra forests are important for the stability of the climate and they maintain a unique gene pool and biodiversity (that so far has survived in a great part of the zone). This vegetation zone also contains abundant reserves of fresh water with a low mineral content. The forest administration in the pretundra forest area has to aim at conservation of the whole ecosystem, and at developing the area in such a way that all important standpoints (both social and ecological) are taken into account.

References

Koloskov, P.I. 1963. O bioklimaticheskom potentsiale i ego raspredelenii po territorii SSSR. Tr. NIIAK, vyp. 23 Gidrometeoizdat. 127 pages.

Melekhov, I. S. 1959. Sostoyanie i zadachi taezhnogo lesovodstva. Lesovodstvo i agrolesomelioratsiya. VASHNIL. Gos. Izd-vo selskoi lit-ry: 15 - 39 .

— 1966. Lesa Severa evropeyskoy chasti SSSR. In: Lesa SSSR. T.I.- M.: Nauka. 60 - 69.

Seljaninov, G. T. 1955. Klimaticheskoe raionirovanie SSSR dlya selsko-hozyaistvennykh tselei. Pamyati akad. L.S. Berga. - M. - L.

Shasko, D. N. 1967. Agroklimaticheskoe raiyonirovanie SSSR. Kolos. 335 pages.

Shennikov, A. P. 1940. K botanicheskoi geografii lesnogo severo-vostoka Evropeiskoi chasti SSSR. Tr. BIN AN SSSR, ser. 3, Geobotanika, vyp 4, M. - L., AN SSSR. 35 - 46.

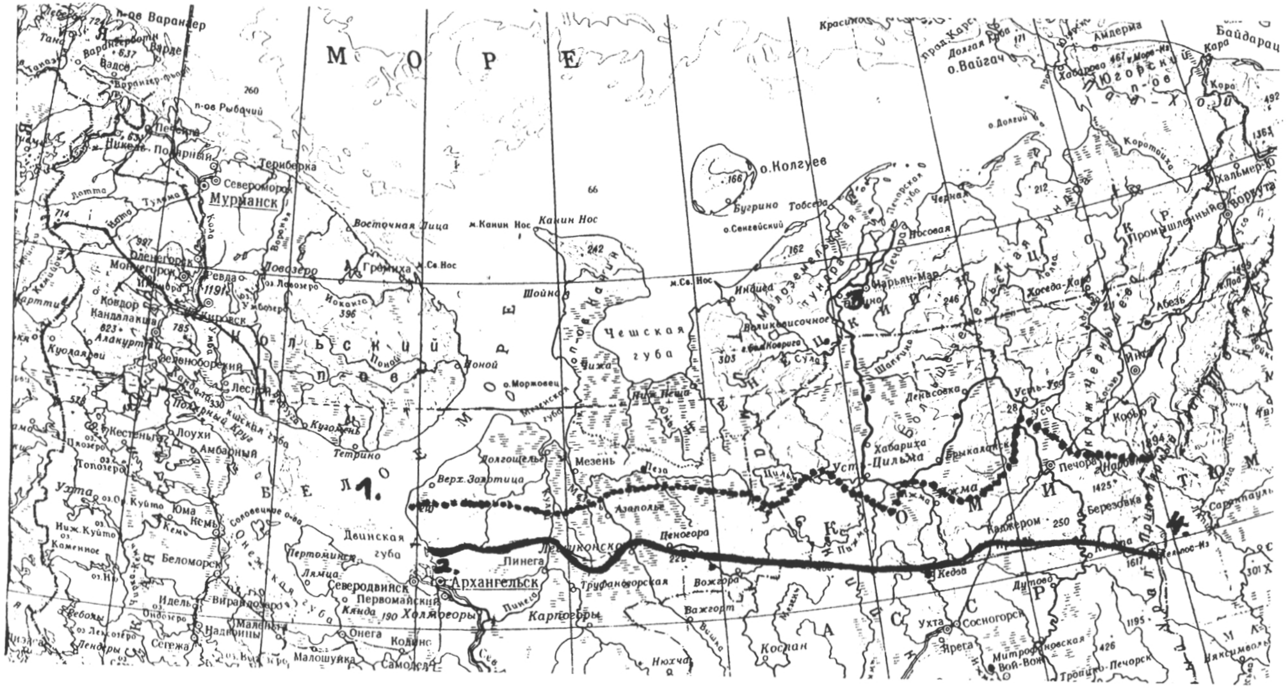

Figure 1. The southern border of the pretundra forests in Archangel region and The Komi Republic.
……. The border of the official protection belt (1959) —— The southern border of the pretundra forest zone.
1 = White Sea 2 = Archangel City 3 = River Pechora and Narjan-Mar 4= Ural mountains.

The main features of the timberlines in the Baikal area

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1 Baikal area

Lake Baikal is the deepest lake in the world, 1637 m, and one of the largest: the area is 31 500 square kilometres and the length more than 600 kilometres. The water of the lake is very clean and the water ecosystem is rich with many endemic species (Ermikov 1996). The protection of Lake Baikal is a big issue in the Russian nature protection. Lake Baikal and its watershed form a world level nature area which was chosen an Unesco World Heritage object in December 1996.

The Baikal area can be defined in many ways using geographical and plantgeographical arguments. The watershed area of Lake Baikal is a clear definition and in nature protection the lake and its watershed are commonly viewed as one entirety. A so called area of atmospheric impact with breath of 200 kilometres on the western side of the lake is in the protection plans included in the Baikal area. From this distance emissions of industry in the Angara valley have impacts on Lake Baikal (Ermikov 1996). The watershed area of the lake is 57 million hectares. About 30 million hectares of it is located in Russia and the rest in Mongolia. More than 300 rivers are flowing into Baikal. The Selenga river beginning from Mongolia is superior in length and flow. The waters of Lake Baikal are flowing down to the Arctic Ocean via the rivers Angara and Jenisey.

In plantgeopraphy the definition Baikal Siberia is used. It is divided up into Predbaikal on the western side of the lake (Irkutsk oblast) and the eastern Zabaikal (Republic of Buryatia and Chita oblast). In geology Baikal Siberia can be divided into the Siberian plateau covering a big share of the Irkutsk oblast and the Sayan-Baikal mountains (Peshkova 1985).

The following large mountains are included in the Sayan-Baikal mountain area: in the south East-Sayan which continues as the Hamar-Daban range along the eastern shore of Lake Baikal, the Primorsky and Baikal ranges in the west, the north-western Stanovoy mountains and the eastern Jabnonoy mountains. Between Lake Baikal and the Jablonoi mountains are many smaller mountain ranges e.g. Ulan-Burgaz and Barguzin. The mountains on the western coast of Lake Baikal form a narrow mountain chain compared with the large mountain area on the eastern side in Buryatia. The mean surface elevation of the slightly regulated Lake Baikal is 456 m a.s.l. and the highest peaks around it reach the height of 3 000 m a.s.l. When analysing the nature of the Baikal area mountain ranges and valleys between them are usually used as basic units.

Since the area is located in the middle of a large continent the climate is continental: moderately continental in Predbaikal, clearly continental in Zabaikal and ultra continental in the northern valleys. In winter in December-March, the Siberian anti-cyclone stays in the area causing cold calm and sunny weather. In April-June a dry windy weather period dominates and the majority of the annual precipitation is falling at the end the warm summer in July-August at which time summer floods are usual. Precipitation and temperature fluctuate greatly according to the exposure and height belts.

2 Vegetation zones and altitude belts

The northern part of Baikal Siberia is located about on the 58th latitude and the southern part on the 50th . From the zonal viewpoint this area is located on the border between boreal forests and steppe. The Baikal area belongs to the southern Siberian mountainous taiga, where the area close to Lake Baikal is called Pribaikal province (Baikal Atlas 1993). Imetkhenov (1997) considers the Baikal area as an important ecotone between the humid and arid zones where also the transition of livelihoods and culture is clear. Theoretically, omitting the impact of mountains the zone of steppes should begin about on the 55th latitude but in fact zonal steppes are found only in the Chita oblast south from the 53rd latitude (Peshkova 1985). All the subzones of taiga, from the southern boreal to subalpine, are found in this area as height belts of mountains. Sokolov (1997) divided East-Siberia in ecological regions for forestry. In this division the largest part of Baikal Siberia was defined as mountainous middle taiga. In Baikal Siberia boreal forest meets steppe direct without nemoral forests between them and steppes extend on valley bottoms deep into boreal forests. Forest steppe does not form the zone of its own (Peshkova 1985).

The main groups of the height belts are: steppe - forest steppe, forest and alpine belt. For a more detailed division many alternatives have been presented. The altitude belt complexes of vegetation containing the main groups low mountains, middle mountains and high mountains are commonly used (Fig. 5, page 118). Usually the light taiga (pine, larch) is located lower than the dark taiga (sembra pine, Siberian fir and Siberian spruce) but a great variation is found in the location of different tree species.

3 The lower timberline

Steppes are found in valleys nearly everywhere in the Baikal area. In the middle part of Buryatia in the valleys of the Selanga river and its tributaries the border between steppe and forest can be seen at the height of 500-1000 m a.s.l. In the north steppes reach the height of 700 m a.s.l. and at the southern end of Lake Baikal the height of 1200 m a.s.l. (Peshkova 1985) Smaller patches of steppes are found in the light taiga on steep, southern slopes. The ground vegetation of these patches, which are called "uburi" or "solnepeki", differs clearly from the vegetation of the surrounding taiga (Panarin 1979). The steppes of the Baikal area are regarded as relicts of the ancient warmer climate period (Lukicheva 1972, Panarin 1979). *Pinus sylvestris* usually forms the treeline against steppe but in some places also *Larix sibirica. Ulmus pumila,* in height of 3-6 meters, is often found in the Selenga valley on the border of pine forest and steppe (figure 2). On the western side of Lake Baikal in the valley of the Angara river birch dominated forest steppes grow and on the cold plateau of the north-eastern Buryatia steppe borders *Betula platyphylla - Larix gmelini* - forest.

Herding, agriculture, settlement and other human activities have for thousands of years concentrated in the valleys (Imetkhenov 1997). Therefore the treeline in sight today is not the natural one. The steppes inside the boreal forest are at least partly regarded as "stepoids"or openings located on the border of forest and steppe caused by cuttings, fires and herding (Lukicheva 1972). Utilisation of forests close to the treeline continues today.

Drought is considered the main factor on formation of the lower timberline but the temperature of soils has also an effect on it (Borzhonov et al. 1982). The lowest annual precipitation, about 200 mm, is met on the western coast of Lake Baikal in the Olkhon area and in the northern Buryatia in the Barguzin valley (Baikal Atlas 1993). Results of plantations of protection forest belts for fields indicate that on the great part of the steppes in Buryatia forests can be created by using e.g. species *Ulmus pumila, Pinus silvestris, Populus suaveolens* and in the most difficult conditions *Salix*-species (Budaev et al. 1982). These results support the view on the "stepoid" origin of steppes (Fig. 1 - 2, page 117).

The location of the border between forest and steppe has fluctuated according to the changes of climate. The soils, with high content of humus and found in the dry pine stands on treeline, originate from steppe with rich grass vegetation. By analysing the properties of soils conclusions can be drawn on the fluctuation of the treeline (Korsunov 1997). According to my observations on steppe close to treeline very few tree plants are found although in the same conditions natural regeneration is abundant inside the forest. It is possible that intensive herding has an effect on the lack of tree plants.

4 Alpine timberlines

The altitude of the alpine treeline and timberline is different in different parts of the Baikal area. In the north in the Stanovoy mountains treeline is at the altitude of 1100-1300 m a.s.l. and in the south on the East - Sayan mountains at the altitude of 2000-2200 m a.s.l. (Peshkova 1985). Tree species composition of timberline alternates and many species can form the timberline. Treeline has been described as a part of the subalpine belt and timberline as the highest part of the forest zones defined according to the dominating tree species. Around Lake Baikal two different series of altitude belts are found. The origin of these series are the differences in precipitation and moisture conditions (Table 1). The most common vegetation complexes of the subalpine and "podgoltsovii" belts in the Pribaikal area are described in table 2. The alpine treeline and timberline are almost unaffected by man. Timberline forests are uninhabited and difficult to reach. In some areas reindeer herding is carried on. Mining and tourism have impacts on forests only in restricted areas.

Table 1. The main types of the altitude belt classification of the mountains around Lake Baikal (Molozhnikov1986).

Main type	Location	Altitude belts
Humid and cold	the western (northern) slopes of the mountains on the eastern side of Baikal, e.g. Hamar-Daban ja Barguzin	Alpine Subalpine Dark taiga
Dry and cold	the eastern slopes of the mountains on the western side of Baikalin and the eastern (southern) slopes of the mountains on the eastern side	Open mountain, "goltsovii" Below the open mountain, "podgoltsovii" Light taiga Steppe

Table 2. The most common vegetation complexes of the treeline and timberline belt in the mountains of the Pribaikal area based on the data presented by Molozhnikov (1986).

Vegetation complexes	**Height of bushes and trees, m**	**Altitude, m a.s.l.**	**Comments**
1. Scrubland			
Rhododendron aureum	0,2-0,3	1300-2000	a very typical bush
Salix-species	0.5-2,5	1100-1800	limestone bedrock
Betula middendorfii	1,0-3,5	1100-2100	the northern part of Baikal
Betula exilis ja *B.rotundifolia*	0,4-0,7	500-2200	close to permafrost
Duschekia fruticosa	3,0-4,0	500-1900	often as undergrowth
Pinus pumila	1,5-3-0	1000-2000	the most common bush

2. ***Pinus pumila*** **scrubland with a sparse tree stand**			density of trees under 0,2
Larix sibirica, L. sczekanowskii ja *L. gmelini*	5,0-7,0	1000-1500	the northern part of the western Baikal
Pinus sylvestris	5,0-12,0	1150-1250	the northern part of Baikal, on sandy soils on the southern slopes
Picea obovata +Abies sibirica +Pinus sibirica	5,0-8,0	1000-1500	in general snow > 1 m
Betula lanata	3,0-4,0	1100-1500	the northern part of Baikal, much snow, humidity
3. ***Betula lanata*** **stands**	5,0-7,0	1100-1500	the northern part of Baikal
4. ***Abies sibirica-Betula lanata*** **"parklands"**	6,0-16,0	1100-1400	the northern part of Baikal
5. Sparse stands of ***Abies sibirica-Betula lanata***	8,0-12,0	1100-1400	
6. ***Abies sibirica*** **krummholz stands**	1,5	1100-1400	steep east and north slopes
7. The highest closed stands			
Abies sibirica		to 1550	Hamar-Daban, Barguzin
Pinus sibirica		to 1600	Hamar Daban
Picea obovata		to 1600	the northern part of Baikal, lichen type
Betula lanata	5,0-7,0	1100-1400	the northern part of Baikal
Pinus sylvestris		to 1000	seldome on the alpine timberline
Larix gmelini		to 1450	the northern part of Baikal

5 The impact of Lake Baikal on the climate and vegetation

Although the climate in general is continental the climate of the Baikal coast has maritime features during the period of the open water. Besides the water masses of Lake Baikal the surrounding mountains have an effect on the climate of the coast by causing inversion. The vegetation period begins on the coast later in spring and it is clearly cooler than further from the coast. Also the humidity is higher on the coast. The mean temperature of summer is on the coast 4-6 degrees lower than in inland. The mean temperature of winter is 5-8 degrees higher, since Baikal is freezing not until December-January. The coastal climate resembles the climate of the subalpine belt of the neighbouring mountains or the climate of the cold Ohotsk Sea (Tjulina 1976, Baikal Atlas 1993). As a result of the special features of the coastal climate the false subalpine, "lozhnopodgoltsovii", vegetation belt is found on the north-eastern coast of Lake Baikal. Above it a more favourable vegetation belt is located covered by the species of light taiga (Table 3) (Fig. 4 and 5, page 117). The small open patches in the false subalpine belt are in principle tundra-steppe (Molozhnikov 1986).

Table 3. Characteristics of the false subalpine belt on the Baikal coast compared with the subalpine belt and the light taiga based on the data presented by Molozhnikov (1986).

Belt	Altitude, m a.s.l.	Vegetation	Vegetation period, days	Phytomass, tons/hectare
Subalpine and "Podgoltsovii"	1200-1400	Sparse stands of *Larix, P.sibirica, P. obovata* and *Pinus pumila*	95-100	16-20
Light taiga	458-1200	*Larix* and *P. sylvestris* stands, birch and aspen	120-130	50-200
False subalpine, "lozhnopodgoltsovii"	458-480	Sparse stands of *Larix* and *P. sibirica* and *Pinus pumila*	100-105	15-50

Tjulina (1990) put forward the view that the locally maritime climate of the Baikal coast has effects on the forests in the northern part of Baikal in the Barguzin mountains so that the tree species composition of treeline changes with the increasing level of continentality when moving from the coast to the east: Abies *sibirica-Betula lanata*-“parks” > *Picea obovata- Betula middendorfii* > *Larix gmelini - Pinus pumila* (see Fig. 3 - 4).

6 Conclusions

The steppes of Baikal Siberia are partly “stepoids” or human induced relicts of the earlier warmer and dry climatic period. The lowest pine dominated forest belt has clear signs of long lasting anthropogenic impact. Also forest harvesting for wood industry concentrated in the 20th century on these pine forests easily in reach. Pine forests regenerate well in general although intensive herding hampers the development of young plants. On steep southern slopes and in burnt areas regeneration is not successful and after clearing the site forest vegetation may turn into steppe vegetation. For preventing of erosion shelter plantations are needed on marginal agricultural lands.

The alpine treeline and timberline can be formed in the Baikal area by *Larix sibirica*, *L.szekanowskii*, *L.gmelini*, *Pinus sylvestris*, *Pinus sibirica*, *Picea obovata*, *Abies sibirica* and *Betula lanata*. On treeline many brush species are common and Pinus pumila is the most important of them. The occurrence of Pinus pumila so far in the west as in the Hamar-Daban range and the occurrence of Betula lanata in the Barguzin mountains are in Siberia the most western examples of the vegetation type of the Pacific Ocean (Tyulina 1976). Treeline and timberline can be formed exlusively by one of the species mentioned above or by 2 or 3 species together. Most of these species combinations are met in the other mountains in Siberia and in the Russian Far East. Only in the Baikal Larix sibirica and Abies sibirica are found at timberline together with Pinus pumila (Molozhnikov 1986).

Although *Pinus sylvestris* is found at the alpine treeline on sandy soils on southern slopes, it is not a typical tree species of the high altitude vegetation belts but above all the dominating tree species at the dry lower timberline. Diverging from the European view it has been presented that the best parameter interpreting the location of the northern timberline of pine in Buryatia is the isotherm of - 28..30 ° C of the mean temperature in January (Baikal Atlas 1993).

In mountains with variable topography and altitude where the amount of precipitation and humidity alternate, the timberlines formed by many species have big differences in altitude an structure. Generally, in formation of the altitude belts of vegetation in mountains the continental and the maritime, "primorskiy," types are described. In Mongolia the arid and the boreal type of altitude belts were defined (Lukicheva 1972). Tyulina (1976) concluded that the cold-humid type of altitude belts in the Baikal area, having some maritime features, is a transition type between the humid altitude belt types of Ural-Tiensan and Altay-Sayan. Besides continentality and humidity the significance of the properties of bedrock in formation of altitude belts has been put forward. In an area with limestone bedrock both the vegetation zones and the altitude belts differ clearly from the zones and belts on of another kind of bedrock (Lukicheva 1972, Tyulina 1990).

Inventory and research of timberlines in Baikal Siberia have been done mostly by botanists. In forest research timberlines are nearly passed maybe therefore that timberline forests are outside forest utilisation. The hydrological effects in formation of runoff, sembra pine seeds and game are considered as main commodities produced in the high altitude forest vegetation belts. The research of timberline areas is nowadays cut down mostly for economical reasons. The long term observation series and sample plots of many institutes and protected areas offer in future a good base to continue research with international cooperation.

References

Baikal Atlas. 1993. Roskartografia. Omsk. 160 p.

Borzhonov, K.T., Puntsukova, S.D. and Tugutov, V.E. 1982. Lesnoy kompleks Baikalskogo regiona. Nauka. Novosibirsk. 88 p.

Budaev, H.R., Budaeva, S. E. and Dambiev, E. Ts. 1982. Zhashchitnoe lesorazvedenie v Buryatskoy ASSR. Buryat kn. izd. Ulan-Ude.182 p.

Ermikov, V., Meshkova, N., Prittwitz, N. and Podoinitsyna, O. (eds.) 1996. Nastayashchee i budushchee Baikalskogo regiona. The present and future state of the lake Baikal region. Chast 1 - Part 1. Studija Dizain infolio. Novosibirsk. 111 p.

Imetkhenov, A.B. 1997. Priroda perekhodnoy zony ha primere Baikalskogo regiona. Izdatelstvo Sibirskogo otdeleniya Ran. Novosibirsk. 231 p.

Krasnoscshekov, Yu. N. and Gorbachev, V.N. 1987. Lesnye pochvy basseina ozera Baikal. Nauka. Novosibirsk. 187 p.

Lukicheva, A.N. 1972. Zakonamernosti vertikalnoy poyasnasti, syazannye s osobennostami reliefa i gornykh porod. In: Tjulina, L.N. (ed.) Geobotanicheskie issledovanija i dinamika beregov i sklonov na Baikale. Trydi limnologicheskogo instituta tom 13(33) vyp. 4. p 3-70.

Molozhnikov, V.N. 1986. Rastitelnye soobshchestva Pribaikala. Nauka. Novosibirsk. 270 p.

Panarin, I. I. 1979. Lesa Pribaikala.Tipy lesa,mikroklimat, kharakteristika lesoobrazujuschcikh parod. Nauka. Novosibirsk. 223 p.

Peshkova, G.A. 1985. Rastitelnost Sibiri. Predbaikale i Zabaikale. Nauka. Novosibirsk.144 p.

Sokolov, V.A. 1997. Osnovy upravleniya lesami Sibiri. Izdatelstvo SO RAN, Krasnoyarsk. 308 pages.

Tyulina, L.N. 1976. Vlazhnyi Pribaikalskiy tip poyasnasti rastitelnosti. Nauka. Novosibirsk. 319 p.

Tyulina, L.N. 1990. Gornye lesa severnogo Pribaikala. Nauka. Novosibirsk. 118 p.

Korsunov, V.M. professor, the Buryat Biological Institute. Personal communication 20.9. 1997.

Figure 1. The lower timberline between pine forest and steppe on the western coast of Lake Baikal in Goloustnaya.

Figure 2. *Pinus sylvestris* and *Ulmus pumila* on steppe in the valley of the Selenga river.

Figure 3. In front, a false subalpine forest on the coast of Lake Baikal, 460 m a.s.l., in Ust-Barguzin. In background mountains of the Sjatoy Nos peninsula, where the highest peaks reach the altitude of 1800 m a.s.l.

Figure 4. The most common and important bush species in the subalpine belt, *Pinus pumila,* on the Baikal coast in the false subalpine belt. Ust-Barguzin.

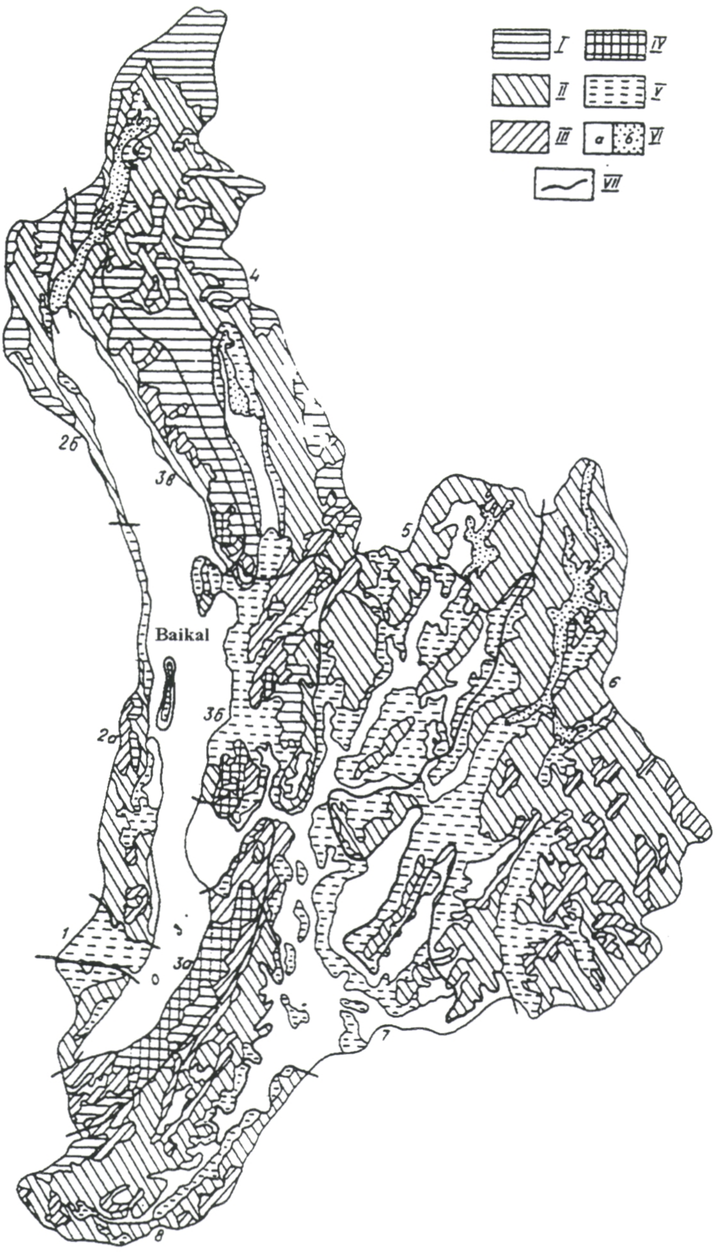

Figure 5. The most important altitude belt complexes in the Baikal basin I-VI and the provinces and districts of forest vegetation 1-8 (Krasnoschcekov and Gorbachev 1987). Altitude belt complexes: I. Alpine and mountain tundra II. Forests dominated by *Larix*-species III. Forests dominated by *Pinus sibirica* IV. *Pinus sibirica - Abies sibirica* forests V. The lowest coniferous forests (*Pinus sylvestris)* and forest steppe VI. The complex of meadows and steppes: a. meadows and steppe b. meadows and scrubland VII. Border of forest vegetation provinces and districts .

Treatment of forests in the proximity of the timberline in Finland

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1 Forest treatment during the period 1950-1990

The first steps of present-day forestry practice in northernmost Finland were taken in the 1950s although fairly extensive selection felling of sawtimber were carried out in the 1920s and 1930s in districts such as the eastern and south-eastern parts of Inarinjärvi. During the Second World War, in the early 1940s, firewood and construction timber were harvested for use by the military.

As distinct from the practice elsewhere in Finland, the almost exclusive forest treatment method applied in northernmost Finland for several decades when dealing with old-growth forests was extensive application of the seed-tree method without intervening non-felled strips (i.e. plantation forestry was not resorted to). Even today, the first round of silvicultural treatment is being applied in northernmost Finland's natural forests.

Wilderness issues became the focus of interest in the media towards the end of the 1980s. This was a manifestation of the change in values which had taken place under the surface over a long period of time. In the 1970s and 1980s, the signals telling of these changes and their significance were misinterpreted and consequently the change in action modes took off at a pace that, in retrospect, was too leisurely.

2 Forest treatment in the 1990s

The multiplicity of nuances in the criticism levelled at "intensive forestry" compelled forestry practitioners to come out into the open and take part in the debate. Twelve wilderness areas were established in Lapland as the result of the work done by the Wilderness Committee, which was appointed with the purpose of addressing the wilderness issues; more than 90% of the area covered by these wilderness areas is in northernmost Lapland. Instead of sustainable wood production, the wilderness areas were allocated the goal of developing the sustainable use of natural resources and their protection applying the principle of the multiple-use. In accordance with the Wilderness Act, wilderness forests have been divided into pristine forests and forests treated in a nature-emulating manner. These were provided with a directive called "*Ohje erämaa-alueiden luonnonmukaisesti hoidettavien metsien käsittelystä* (1992) [trans. "Directive on the treatment of forests to be treated in a nature-emulating manner"] which is nowadays also applied in commercial forests in the proximity of the timber line in wilderness areas. Extensive, "steamroller-like" application of the seed-tree method has been discarded and the treatment of the forests is being developed in the direction of greater diversity and degree of naturalness. The needs of other forms of forest use are emphasised in planning.

Natural or near-natural, pine-dominated, old-growth forests continue to form the point of departure in forest treatment and the practise of forestry. In the light of the compartment-specific forest inventory conducted in 1995-1996 in the state-owned woodlands within the municipality of Inari, the proportion of mature stands within the sphere of commercial forestry was found to be 40% of the area of such forests. Forests over 100 years old account for 56% and those 200+ years of age for 33%. Due to earlier forest treatment practices, which placed heavy emphasis on regeneration, young (age 1-40 a) forests account for 29%. Dryish heathland forest soils account for 63%, dry heathland forest soils for 27%, and moist heathland forest soils for 9%.

Areas not included in the above figures, but falling partly within the sphere of commercial forestry, included those parts of the Hammastunturi wilderness area, which are treated in a nature-emulating manner, the forestry parts of Enontekiö, and the to-be-established Juutua outdoors area. Forestry treatments may be extended also to those parts of the Vaster wilderness area that are to be treated in a nature-emulating manner if the Ministry of the Environment approves the care and use plan currently in the process of formulation.

Despite the extensive conservation areas established in northernmost Lapland, old-growth forests continue to be above-average in abundance also in areas where commercial forestry is practised. In coming years, too, felling will focus on old-growth forests. Due to environmental considerations, the objective will be to apply extended rotations and regeneration in stages in order to minimise the regeneration feelings proper in the near future.

The Finnish Forest and Park Service is preparing new treatment directives for application in forests entrusted to its care in the proximity of the timberline. These are at currently being circulated among local and regional interest groups to enable opinions to be brought forward. The intention is to apply these directives in pine-dominated protection forests, pine-dominated commercially used forests within zoom homelands and more southerly pine forests at high altitudes where the low effective temperature sum and/or packed snow impose constraints on the practising of forestry. Pine dominance means that the proportion of pine is at least half of the stand volume.

Forest treatment is based on adhering to the principles of caution and emulation of nature. This means minimising of ecological risks, application of measures emulating natural forest development, the preservation of wilderness elements, and appreciation of the various forms of use that there are for forests. The endeavour in doing so is to ensure continuous-cover forests also during periods of inclement climate and thereby also the retention of their natural biodiversity and multiple-use values.

The principles of nature-emulating forest treatment include the following:

- measures complying with natural forest development
- appreciation of all the various forest uses
- preservation of wilderness elements
- preservation of the aesthetic values of the forests
- preservation of the natural variation and biodiversity of the forests
- preservation and enhancement of the vitality of forests stands and of individual trees

Natural stand development is hastened by modifying the spatial arrangement of trees within stands by removing trees that have succumbed in the natural competition. Regeneration conditions are created by providing room for growth.

The objective in forest treatment is to retain natural variation and diversity. This is achieved by applying different felling methods in versatile and flexible ways, and by marking off felling operations so that they comply with the topography and the existing growing stock. Felling operations are carried out stage by stage, avoiding abrupt growing-stock boundaries and straight lines. All existing tree species are retained in the composition of the new stand. Decayed broadleaved trees, other dead and dying trees, and windthrown trees are retained on the sites.

Edge zones possess great ecological and scenic value. These are pinpointed in the planning stage and important edge zones (e.g. shores of watercourses, edges of low-stocked mires and of treeless mires) are left untreated in regeneration feelings. In the case of increment feelings, edge zones can be treated lightly and with great caution and reducing the impact of treatment when nearing the edges.

Preparatory felling, preparatory felling with clearings to promote restocking, opening up of small openings to facilitate natural regeneration, and felling in stages resulting in seed-tree stands are the felling methods applied. Structurally all-sized forests are dealt with by applying feelings designed for structurally all-sized forests. In the case of regeneration taking place in stages, the tree crop is harvested in stages and ensuring at the same time the emergence of the new tree generation. Due to the chosen mode of operation, the annual treatment areas are bigger than those accustomed to when using the traditional seed-tree method. However, the visible impacts of felling on the landscape are less pronounced as the resultant changes are not abrupt and the features of the old forest are preserved longer.

3 Forest treatment in the year 2000 and beyond

The effects of forest treatment methods on forest biodiversity are being investigated, e.g. using annual random-sample-based surveys. Research has also been focused during the current decade on the effects of present-day forest treatment methods on bird life, insects and mushroom crops. A long-term follow-up study was launched this year focusing on the effects of forest treatment on reindeer pastures. On the basis of the information so far obtained from studies, the treatment of forests can be steered so that potential harmful effects are minimised.

Forest treatment modes, timber harvest volumes and methods applied in caring for forest ecosystems must also be examined from the points of view of the foremost interest groups. Persons responsible for forestry have to internalise not only the functioning of forest ecosystems, but also the sets of values subscribed to by the central interest groups and the changes taking place in these values.

The proportion of Arctic areas protected in Finland amounts to 33%; in Norway it is 26%, in Sweden 21%, and in Russia 4%. In addition to this, there are several new conservation area projected for Lapland. In addition to what may be called official conservation plans, various NGOs and conservation bodies have their own proposals. All in all, one can say that already now the proportion and representativeness of conservation areas in Lapland are manifold greater than the international level. The problem with Lapland, and especially with northernmost Lapland, is that there the proportion of what may be called "pristine natural forests" is considerable, whereas in most other parts of Europe such forests have been destroyed. These pristine forests; the Last Wildernesses, have been the subject of growing international interest during the past few years.

Forest biodiversity can be influenced, *inter alia*, by the choice of treatment methods and silvicultural methods, and by taking invaluable nature items into consideration in forestry activities. In the case of comprehensive long-range planning of the wider areas, too, forest biodiversity can be retained and the need for the total conservation can be reduced by applying ecological landscape planning. Wide-in-scope and open co-operation in the use of forest-based natural resources and the reconciling of often conflicting objectives are preconditions for the practising of forestry in northern timberline forests.

Sustainable use of northern timberline forests

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1 Background

The Arctic Environment Protection Strategy (AEPS) was adopted by the Arctic countries - Canada, Denmark, Finland, Iceland, Norway, Sweden, USA and USSR - in 1991 at Rovaniemi, Finland. To implement the AEPS, five working groups have been instituted: Arctic Monitoring and Assessment Program (AMAP), Conservation of Arctic Flora and Fauna (CAFF), Emergency Prevention, Preparedness and Response (EPPR), Protection of the Arctic Marine Environment (PAME) and Sustainable Development and Utilization (SDU). The working groups collect scientific and governmental information about the Arctic issues in concern, and produce common strategies, guidelines and background material for the use of all stakeholders. The produced material serves as an information source for hindrance of degradation of the environment and guidance of the development in the Arctic.

The Arctic Council was established in September 1996 by all the Arctic states, and the programs of AEPS continue under its umbrella. One of the key objectives of the Arctic Council is to promote sustainable development in the circumpolar Arctic region. Sustainable development is defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their needs. Sustainable development, therefore, requires thorough information about the natural and cultural conditions of the region and special attention needs to be paid to the planning approach.

2 Goal

Following the initiative of Finland made in 1995, a project on timberline forests was taken on the Agenda of the Sustainable Development Working Group and a background paper was prepared (Vormisto 1995). In September 1997 the task was included in the CAFF work plan. Now, Finland (Ministry of Environment together with Finnish Forest Research Institute) is preparing a concluding study on the scientific information on the sustainable use of timberline forests from all Arctic countries. It will serve as an information base for various uses dealing with human activities in the most northern forest areas.

3 Statement for sustainable development in northern timberline forests

It would be important for international Arctic cooperation to create a statement for sustainable development in northern timberline forests. For this we may need to create clear criteria and indicators to describe the sensitive timberline vegetation zone. Therefore, we need good information from countries on national rules and legislation concerning all aspects of timberline forests. Also Environmental Impact Assessment (EIA) provides a mechanism for implementing sustainable development and ensuring wise use of timberline resources. EIA is used to predict the environmental consequences of proposed human actions, whether these are individual projects, groups of related projects or government policies. However, we need more strategic approaches to ecological impact assessment for surveys, evaluation and for the monitoring of ecological impacts.

Should we develop a list of precautionary actions outlining what we recommend for people operating in the timberline forest? What these could be?

The statement should answer at least the following questions:

1) When are you in a timberline forest (map, criteria, indicators)?
2) How should I, my community or my business company behave in timberline forest?
3) What the Arctic Countries should include in their northern policies so that the timberline forests will stay viable ecosystems?

4 Regional overviews

The northern timberline forests are a significant source of resources in the Arctic. Although the utilization of timberline forests by the wood industry is still limited and the most timberline areas are still largely intact, many activities occur in the zone or are dependent on it.

The timberline forests form a circumpolar transition zone between the northern taiga and the tundra. The tree growth is restricted and often displays low regeneration capacity, it is therefore likely that this zone will be sensitive to environmental changes. Although there exists a considerable amount of scientific information on this region in the Arctic countries, an ecological synthesis of the circumpolar boreal forest-tundra transition zone has not yet been produced. Also, the development of a set of criteria for evaluation of the zone requires the cooperation of stakeholders, researchers, authorities, experts and project planners.

The northern timberline forest is a circumpolar transition zone of vegetation between northern boreal forest and tundra. Its northern and southern limits are transitional and are therefore difficult to fix exactly. In strict definitions the timberline is only few kilometers wide, but when talking about the zone of timberline forests, its width can be several hundred kilometers. So, the timberline forests include the timberline and the forests close to it. The timberline is then the forest limit, while a treeline is a northern limit of growth of certain tree species (Fig. 1). The following tree species (only main species are listed) form the treeline (close to tundra) in different circumpolar areas:

Fennoscandia (including part of Kola peninsula): Mountain birch (*Betula pubescens ssp. tortuosa*)
Kola peninsula - Ural Mountains: Siberian spruce (*Picea obovata*)
Siberia: Siberian larch (*Larix sibirica*) and Dahurian larch (*Larix gmelini*)

Far East: Dahurian larch (*Larix gmelini*), chosenia (*Chosenia arbutifolia*), birch (*Betula ermani*)
North-America: Black spruce (*Picea mariana)*, white spruce (*Picea glauca*)
Greenland: Mountain birch (*Betula pubescens ssp. tortuosa*)
Iceland: Mountain birch (*Betula pubescens ssp. tortuosa*)

Fig. 1. The tree species which comprise the northern circumpolar treeline (Tasanen & Veijola 1994).

5 Timberline forests in Arctic Countries

There does not exist any single phytosociological classification system, which would cover all timberline communities over the whole circumpolar region. No single study provides an overview of this issue, so that it would be possible to draw an exact map of circumpolar forests.

However, there does exist several individuals' scientific studies on various problems concerning timberline forests, where also definitions for timberline forests can be found. Also, each Arctic country has some concepts for the timberline forests, which can be a basis for a common definition or criteria for timberline forests. The existing definitions by countries are listed shortly below (this list needs to be checked and completed by the experts of each Arctic country).

Russian Federation: *Predtundrovye lesa*, the direct translation means *forests close to the tundra*. These forests include patchy forest stands, which are found from tundra region, whole forest-tundra and also the northernmost part of taiga. This area is about 45 million hectares, and about 47% of it is forests.

It seems that the definition used by the Russian Federation is most advanced and could serve as valuable input for this work. The studies on timberline regions and tundra are considered a research subject of its own. It is called "tundravedenie," which focuses on phytogreographical research and has long traditions in Russia. Russia contains the Earth's largest expanse of timberline forests (mostly in Siberia), and they have already, long ago, been given a special status in the forest policies of Russia. The first Act on shelter forests was approved in 1888.

Based on extensive research in permafrost areas of the Sukachev Forest Institute (Krasnoyarsk) has proposed moving the strict protection zone further south, which would greatly increase protection of some of the most fragile landscape, covering some 15 to 20 percent of the forest land of Siberia and the Far East. The network of protected areas would be gradually adjusted as the resource information needed for assessing the environmental and biodiversity value of a given area becomes available. However, the protected status would not limit subsistence timber use by the aboriginal population.

United States, Alaska: There is great deal of difficulty in defining distinct vegetation zones in Alaska. The complex physiographic patterns, the presence of permafrost, the fire-vegetation relationships, and the oceanic influence along the western coast have prevented the establishment of a south to north zonation of vegetation types similar to those described for Canada and Russia. Both the Alaska Range and the Brooks Range break the general north-south trend of climatic zones. There does not exist any protection forest classification in Alaska. See also Canada.

Canada: *Forest tundra*, open (lichen) woodland. As the climate becomes more severe poleward, permafrost is continuous, and the shallower and colder active soil layer provides a rooting zone that is less favorable for trees. Consequently, forests become more open and trees grow shorter, finally occurring as narrow ribbons along rivers and scattered individuals on protected slopes. Fire plays a major role in the lichen woodlands and forest-tundra, effectively eliminating tree establishment during years of cooler summers. In the transition zone from forest to tundra, unbroken forest occupies less than 75% of the land surface above the water table (upland), or less than 75% of the area is unbroken tundra, i.e., 25% of the land area or more is occupied by an admixture of forest and tundra. The timberline forests are relatively intact and there does not exist any shelter forest classification.

Greenland/Denmark: Mountain birch is the only forest-forming tree, which has immigrated to Iceland and Greenland. *Woods and schrubs of* *mountain birch are restricted to the southwesternmost part of Greenland.* However, it is likely that Greenland and Iceland are part of the boreal forest zone even though conifers do not naturally occur there.

Iceland: Although there is evidence that pre-settlement Iceland was abundantly forested, Iceland today is a barren land. Only 1 percent (1250 km^2) of its area is woodland. The lack of forests in Iceland is due to the wholesale destruction (charcoal-burning, grazing) of the original woodlands. Originally natural birch woodland would have occurred below 400 meters elevation, however, grazing by sheep (and horses) over centuries has prevented tree growth in large areas. Most of the native woodlands consist of shrubby trees, with mountain birch as the dominant species. About 14% of the land area is climatically suitable for reforestation. The main objective of the protection forests is to prevent erosion of exposed soils.

Norway: *Montane forests (fjellskog)* are forests where the climate conditions, especially low temperature and wind, strongly limit the seed production, maturation and germination. Regeneration and growth of the forests are uncertain. Montane forests cover about 2.5 million hectare, which is 1/3 of the total forest area of Norway.

Sweden: *Sub-montane forests (fjällnära skogar)* form a continuous belt along the chain of mountains which stretch from the province of Dalecarlia to northern Lapland. The border is based on so called forest cultivation line (skogsodlingsgräns) which was set at the beginning of 1950s by the Forest Service (Domänverket). The border was re-established in 1991 by the Swedish Government and extended to also include private land. The regeneration capacity and the profitability of forest management decreases above the forest cultivation line. The law defines sub-montane as, “forests with difficulties in regeneration and which are above the forest cultivation line according to forest inventories". The entire alpine region covers an area of about 9 million hectares, of which 1.6 million hectares are productive timberland.

Finland: The northern protection forest zone where forestry activities are restricted (suojametsäalue), forests at high altitudes (korkeiden alueiden metsät) and the Inari commercial forest region. The Protection Forest Act was formed in 1922, with the aim of preventing degradation of northern forest areas and to prevent the forest line from declining due to human impact. The southern limit of this forest region goes to where the effective temperature sum is about 700 d.d. The forest region was determined by using climatic records, and because they were not complete in 1922, the Inari region was left out of the protection region although the effective temperature sum is around 700 d.d. Forests at high altitudes are described as, forests which are lying higher than 250-330 m above sea level and have been considered unsuitable for timber production on an extensive scale due to the difficulties in applying normal regeneration practices. The land area in forest protection zone is 3 150 000 hectares, and 95 % of it is owned by state. The amount of productive forest land inside this zone is 800 000 hectares.

However, the new forest act issued in 1996 replaces the old 1922 Protection Forest Act. This new act states that, "The Council of State may designate areas as protection forest areas where preservation of the forest is necessary to prevent retreat of the timberline. In protection forest areas, the forest shall be managed and utilised with special care and in such a way that the measures do not result in retreat of the timberline. The Council of State may issue necessary general regulations about the forest management and use in protection forest areas. Before the government decision concerning a protection forest area is taken, the forest owners, relevant municipalities and other authorities are to be heard. In addtion negotiations shall be held with the Sami Parliament."

6 Criteria and indicators for northern timberline forests

It might be difficult to get a consensus on the southern limit of timberline forests because the forestry policies in each Arctic country differ from each other, which might also affect this discussion. It is possible that the southern limit could be drawn according to the definitions of the individual countries. Or, would it be possible to agree on a biologically defined southern limit for northern timberline forests for the whole circumpolar region? This is one issue which could be discussed internationally.

In order to draw a map of the circumpolar timberline forest zone we would need scientific *criteria* to define it. These criteria can be found in several studies. A comprehensive list of the criteria for timberline forest should be agreed by experts, because it creates a basis for discussion of sustainable development within these forests. It would also be good if we could find general *indicators* for timberline forests to be used by the wider public, therefore people can know when they are operating in timberline vegetation zone and which requires special precautionary behavior.

7 Wildlife

The most untouched forests in the world are found in the far northern regions. The reason for their untouchness is because of the high costs of timber extraction in these remote areas. The timberline forests grow largely in so remote areas that their utilization may never be economically beneficial. Because of the remoteness, the timberline forests have been disturbed less than other boreal forests. In general, timberline forests are still dominated by native tree species and they are big enough to maintain viable populations of native vegetation and animal species. Also, they are still large enough to recover from major natural disturbances such as fire or insect damage. It is notable, that northern timberline forests provide habitat for the large carnivores and herbivores which cannot be found, or are rare in more temperate areas. The vast relatively intact ecosystem of northern timberline forests offers one of the opportunities to sustain natural landscapes on a scale large enough to preserve genuine wilderness and *allow wildlife populations to fluctuate naturally*.

8 Traditional knowledge

Timberline forests are home to many indigenous peoples of the arctic. The traditional ways of living (trapping, fishing and hunting) in the North are often closely connected to timberline forests. The timberline forests are especially important for the Russian small nations in the North which live on nomadic reindeer herding. The dependence of culture and subsistence living of indigenous peoples on timberline forests is an important issue that should be studied thoroughly for this work. Protecting the environmental quality of timberline forests is also important for issues of cultural survival by indigenous peoples. *Traditional knowledge* should be used in understanding the possible consequences of predicted impacts and in reducing uncertainties. Traditional knowledge is defined as accumulated knowledge held by indigenous peoples on the arctic environment, and the management of its resources for present and future generations.

9 Threats to the northern timberline forests

The main threats to the timberline forests should be discussed internationally so that strategies to combat them could be developed. Below are some serious threats have been identified:

Because of their untouched nature, the northern timberline forests differ fundamentally from fragmented or otherwise managed boreal forests. In large scale forest areas, *fragmentation* may be the greatest and most potentially damaging threat to timberline forest. Habitat fragmentation affects the survival of both individuals and populations either through an increase in isolation or a decrease in the amount of resources available. The natural isolation of arctic regions maintain genetic diversity, but man-made fragmentation typically leads to a reduction in genetic diversity. If timberline forests are fragmented, they may become too small to support their full complement of species. Fragmentation is caused by the building of infrastructure, such as oil and gas pipelines (and hauling roads), roads, tourist courts, etc. However, fragmentation by *commercial logging* poses the greatest threat to the continuity of timberline forests, with the addition of roadbuilding for timber transportation. The regeneration of forests in timberline areas is a slow process because of the harsh climate. This is an important starting point when sustainable forestry practices in timberline forest areas are considered. In addition to timber production as the sole criterion of sustainability, one needs to emphasize the importance of biodiversity conservation in forestry. This means that forest management should not endanger the functioning of ecosystems and their long-term production capability. Landscape ecological approach as well as the participation of indigenous and other local people in the planning of forestry practices are good examples of tools for how to proceed in forestry planning.

The other very visible threat to timberline forests is the problem of *overgrazing* by reindeer and sheep in these areas. The situations vary in different countries, for example in Scandinavia, and especially in Finland, the problem of too large *reindeer* stocks prevent the regeneration of birch forests in many areas. Also, it has already caused problems to the herding itself due to the lack of lichen pastures. Currently, the overgrazing of reindeer seems not to be a problem in the Russian north. However, as the building of infrastructure for gas and oil fields takes place, this may limit the movements of nomadic reindeer herders and causes more pressure on the limited amount of pastures and have lead to overgrazing, which will in turn effect the wider ecology of the timberline forests. *Sheep grazing* is the greatest threat to birch forests and birch afforestation in Iceland and Greenland.

The *pollution* may have several damaging effects on the timberline forests, as they already grow in the limits of their existence because of the harsh natural conditions. Any extra stress may have serious impacts. The local pollution sources seriously affect the surrounding forests. For example, sulfur dioxide has damaged a vast area of forest around metallurgical smelters in Nikel and Monchegorsk in Kola, as well as in Norilsk in Siberia. The forests have been killed totally 10 - 130 km from the smelters. In spite of the seriousness of the local contamination, the pollution from *long range transportation* causes more wide spread threat to the species of the timberline forests.

Two global threats, *climate change* and ozone depletion, are predicted to have a great effect on the Arctic, in which the timberline forests may react very visibly towards. Climatic warming may cause timberline forests to creep northwards threatening the species of tundra, also the warming climate will enable new species to spread into the timberline regions affecting their ecological balance. Because there are few arctic species and their populations are often great, this may cause dramatic changes. The possibility of *insect damage* may increase as the temperature increases. The insect damage in northern forests is often wide spread like the spruce bark beetle damage in Alaska and autumn moth damage in Fennoscandia.

Selected literature

Ahti, T. & Oksanen, J. 1990. Epigeic lichen communities of taiga and tundra regions. Vegetatio 86: 39-70.

Arctic environmental protection strategy 1997: Guidelines for environmental impact assessment (EIA) in the Arctic. Sustainable development and utilization. Ministry of the Environment of Finland. Helsinki, 50 p.

Arctic Pollution Issues: A State of the Arctic Environment Report. AMAP, Arctic Monitoring and Assessment Programme, Oslo 1997, 188 p.

Circumpolar Arctic Vegetation Mapping Workshop. A compilation of abstracts and short papers presented at the Komarov Botanical Institute, St. Petersburg, Russia March 21.25, 1994. Edited by D. A. Walker and C. J. Markon. Open File Report 96-251. U.S. Department of Interior, U.S. Geological Survey, National Mapping Division.

Fennoscandian Tree-line Conference at Kevo-Abisko 1977. Holarctic Ecology 2: 201-283, 1979.

Furman, E. 1997. Conservation of arctic flora and fauna. Discussion paper on threats to arctic biodiversity. Finnish Environment Institute, Helsinki. Draft.

Hanski, I. & Gilpin, M. E. 1997. Metapopulation Biology: Ecology, Genetics and Evolution. Academic Press, San Diego.

Heikkinen, O. 1984. The timber-line problem. Nordia 18: 105-114.

Holtmeier, F-K. 1997. Timberlines: Research in Europe and North America. Finnish Forest Research Institute, Research Papers 623: 23-36.

Johansen, B. E., Johansen, M.-E & Karisen, S: , R. 1993. Vegetasjons- og beitekartlegging i Finnmark og Nord-Troms. Norut informasjonsteknologi as. Rapport IT 2020. Tromsö, p. 60. (In Norwegian)

Kaitala, S. 1997. Biodiversity, conservation and sustainable forest management in North-West Russia. Ministry of Environment of Finland. Helsinki, p. 42.

Kumpula, J., Colpaert, A., Kumpula, T. & Nieminen, M. 1997. The winter pasture resources of the Finnish reindeer management area. Research report. Finnish Game and Fisheries Research Institute. Reindeer Research Station. Kaamanen. 43 p. (In Finnish)

Nikolov, N. & Helmisaari, H.1992. Silvics of the circumpolar boreal forest tree species. Pp. 13-83; in Shugart, H. H., Leemans, R. & Bonan, G. B. ed.; A systems Analysis of the Global Boreal Forest. Cambridge University Press.

Russia. Forest Policy during Transition. A Word Bank Country Study. The World Bank, Washington, D.C. 1997, p. 279.

Sirois, L. 1992: The transition between boreal forest and tundra. Pp. 13-83; in Shugart, H. H., Leemans, R. & Bonan, G. B. ed.; A systems Analysis of the Global Boreal Forest. Cambridge University Press.

Tasanen, T. & Veijola, P. 1994. Metsänraja tutkimuskohteena - kirjallisuuskatsaus. In: Tasanen, T., Varmola, M. & Niemi, M. ed.; Metsänraja tutkimuskohteena. Finnish Forest Research Institute, Research Papers 539: 80-145. (In Finnish)

Treweek, J. 1996. Ecology and environmental impact assessment. Journal of Applied Ecology 33: 191-199.

Tuhkanen, S. 1984. A circumpolar system of climatic-phytogeographical regions. Acta Botanica Fennica 127: 1-50.

Tuhkanen, S. 1993. Treeline in relation to climate, with special reference to oceanic areas. Pp. 115-134; in Alden, J., Mastrantino, L. & Odum, S. ed.; Forest development in cold climates. Plenum Press, New York.

Veijola, P. 1996. The northern timberline and timberline forests in Fennoscandia. PhD-thesis, manuscript. University of Helsinki, Helsinki.

Vormisto, J. 1995. Discussion paper on sustainable use of northern timberline forests including reindeer grazing. Ministry of Environment of Finland. Helsinki. Report, p. 43.

World Resources Institute. The last frontier forests. Washington, D. C. 1997, p. 42.

FRAMEWORK FOR TIMBERLINE RESEARCH

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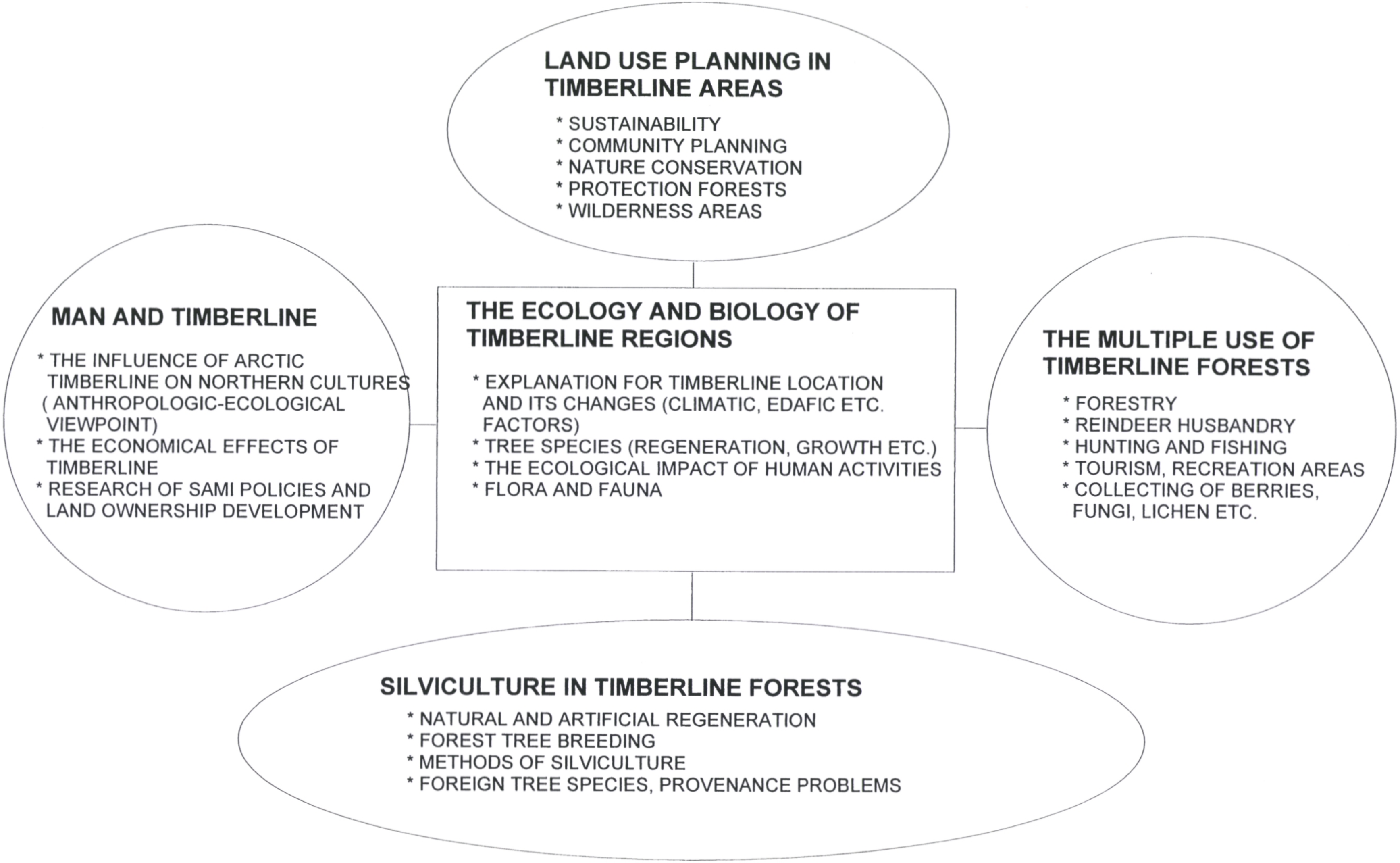

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