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Interrelations between climatic changes and northern and alpine Holocene pine-limit movements – deduced from stable-isotope signals of ^{14}C-dated subfossil pines (*Pinus sylvestris L.*) on the Kola Peninsula, northwestern Russia

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Introduction

This paper focusses on dendroclimatological investigations carried out in the tree-line region of the Kola Peninsula in northwestern Russia (Fig. 1). This region is located at the dividing line between northern Scandinavia[1] and the eastern European polar regions of Russia[2].

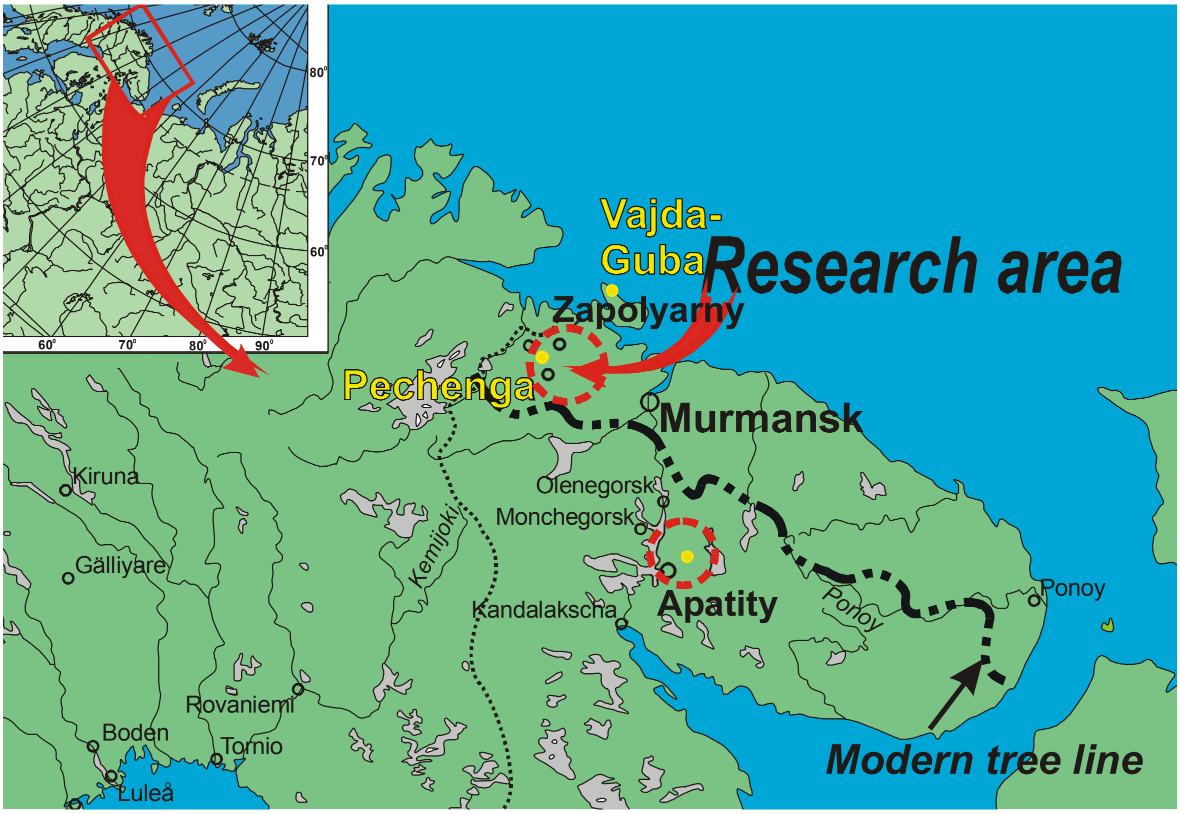

Figure 1: Map of northern Scandinavia showing the locations of the study areas (red) and the selected meteorological stations (yellow circles).

[1] Northern Scandinavia has been the subject of both dendroclimatological and isotope-geochemical studies (e.g., Eronen 1979; Kullman 1995; Eronen *et al.* 1999 (dendroclimatology); Sonninen, Jungner, 1995; McCarrol, Pawellek, 2001 (isotopes)).
[2] This region so far has been only sporadically studied (e.g. MacDonald *et al.* 2000).

The area's climate is affected not only by the Gulf Stream and the North Atlantic, but also by the landmass of the Eurasian continent.

Study area

Our work took place in two areas of the Kola Peninsula (Fig. 1). The first area is located in the Khibiny low mountains in the central part of the Peninsula, ca. 400 kilometres South of Murmansk (ca. 67–68°N; c. 33–34°E). These mountains have a maximum height of about 1200 metres above sea level. The second area is located in the northern part of the Peninsula, near the border to Norway East of the town of Zapolyarny, in the tundra lowlands about 50 km beyond the modern occurrence of pines (> 69°N; approx. 31–32°E).

The climate on the Kola Peninsula is oceanic, with relatively mild winters and strong winds. The annual mean temperature is ca. –1°C, and rainfall up to 600 mm is characteristic for the area (Handbook for climate SSSR 1964; 1968). The strong influence of the sea is expressed in regional differences between the meteorological data. Near the coast of the Barents Sea, summer temperature is lower and winter temperature higher than in the interior of the peninsula. Thus the modern mean January temperatures at the Pechenga and Vaida-Guba meteorological stations are –10.9 and –5.5°C respectively, the mean July temperatures vary in the range of *c.* 12.8°C and 9.7°C, and annual precipitation is 575 and 690 mm respectively. The growing season is limited to the period between late May and late August.

Results and discussion

Khibiny low mountains. The data set of subfossil wood was collected at various sites in the eastern and western Khibiny mountains, in the area of the tundra zone located ca. 100–140 m above the modern pine tree line. At the current tree line, immediately below the sites of the subfossil finds, increment wood cores were taken from living Scots pines. Most of the subfossil wood that was studied consisted of pine species (Fig. 2, upper part).

The ^{14}C ages of the samples range from ca. 1400 to 300 years BP (Fig. 3). The majority of the subfossil pines date back to the period between 1000 and 800 years BP, corresponding to a calibrated age of about 1000–1300 AD. This period coincides with the Mediaeval Climatic Optimum, a warm phase of the Holocene that occurred in many parts of Europe. For this period, a tree line can be reconstructed that is at least 100–140 m higher than the current tree line. This phenomenon can be mainly attributed to the higher mean summer temperature between 1000 and 800 PB. Given the fact that we only found subfossil trunks of pine above the present-day pine forest, most likely the vegetation distribution in the Khibiny region has not changed since this optimum (Hiller et al., 2001).

Figure 2: Upper part: Subfossil pine log (c. 1000 ^{14}C years BP) at the site where it was found in the mountain tundra of Khibiny. The dead trees lying on the surface are gradually decomposing and will have disappeared within less than 2,000 years (Naurzbaev and Vaganov 2000). Lower part: This subfossil pine log (c. 5000 ^{14}C years BP) from the Zapolyarny region can easily be seen from the lake shore. We mostly found well-preserved logs and pine stumps in small, shallow lakes with a silty bottom.

The dendrochronological examination of the subfossil discs and the increment cores from living trees was carried out at the University of Hohenheim. It resulted in various modern tree-ring chronologies and one tree-ring chronology of about 600 years spanning the period AD 915–1508. The latter chronology could be synchronised with the pine tree-ring chronology from Finnish Lapland (Timonen, 1999). Results indicate that the ring widths of subfossil and modern pines closely resemble each other (r_{mean} >0.7), implying a climatic forcing of the signal.

Climatic parameters, which in part determine the characteristics of tree rings, were studied using $\delta^{13}C$ and $\delta^{18}O$ values of the latewood (LW) cellulose derived from five pine trees that were about 70 years old (Boettger et al., 2002). These values were compared to the temperature and precipitation data from the weather stations near the study area (Fig. 1). A significant correlation was found between the carbon-isotope values of cellulose of LW from living tree cores and the average temperatures for July and August, the end of the vegetation period ($r_{July/August} \approx 0.5$; n = 44). The carbon-isotope and oxygen-isotope values of individual tree rings from living and subfossil trees correlate well with each other ($r \approx 0.8$; n=93). According to Saurer (1997), in such a case the isotope ratios in the period of LW-formation probably are a function of moisture conditions. The short summer in Khibiny is a season with relatively little humidity. For the summer months, we found (a) a much less pronounced correlation between $\delta^{13}C$ values and precipitation amounts, and (b) a positive correlation between the carbon-isotope and oxygen-isotope values on the one hand and precipitation in the autumn and winter of the previous year (i.e., the time of snow accumulation) on the other hand. Although these studies are still underway, the climatic isotope signatures of the pines from these locations are already emerging.

The mean carbon-isotope content of the samples from the period of the Mediaeval Climatic Optimum was found to be significantly heavier than the mean content of living pines in the same region (Fig. 4). Distinct shifts in isotope values indicate higher temperatures and lower humidity, owing to reduced stomatal apertures and increasing evaporation fractionation in the source water. These results indicate a significantly warmer and probably also drier climate in mediaeval times than it is currently the case in the region of Khibiny or even in central Germany (by comparison, recent pines from the Leipzig region in central Germany have a mean $\delta^{13}C$ value of c. –25‰ vs. PDB).

The oxygen-isotope and hydrogen-isotope values of all subfossil and living samples from the Kola Peninsula fluctuate widely around their average values. This variability might be related to the air masses responsible for rainfall as they move across the region. If we assume that the source of the precipitation remained unchanged (i.e., the North Atlantic), marked differences must have occurred in its seasonal distribution during the 2nd millennium and even during the past few decades.

The results of the isotope studies together with the findings of the tree-line movements clearly and independently confirm that the Mediaeval Climatic Optimum (AD 1000-1300) was the most pronounced warm phase on the central Kola Peninsula in the last 1,500 years or so.

Northwestern section of the Kola Peninsula. A second collection of subfossil Scots pines was sampled in the northwestern part of the Kola Peninsula (> 69°N; approx. 31–32°E), in the small lakes in the modern tundra environment about 50 km North of the current forest border, East of the town of Zapolyarny (Fig. 2, lower part). Their dominant storage position – the crown part towards the lake shore and the root part embedded deeper in the lake gyttja – indicates that the trees were preserved *in situ*, and that the lake level at that time was lower than it is today. Sometimes we also found trunks embedded in the peat shore, about 1 m underneath the surface of the water, their crowns easily visible from the shore.

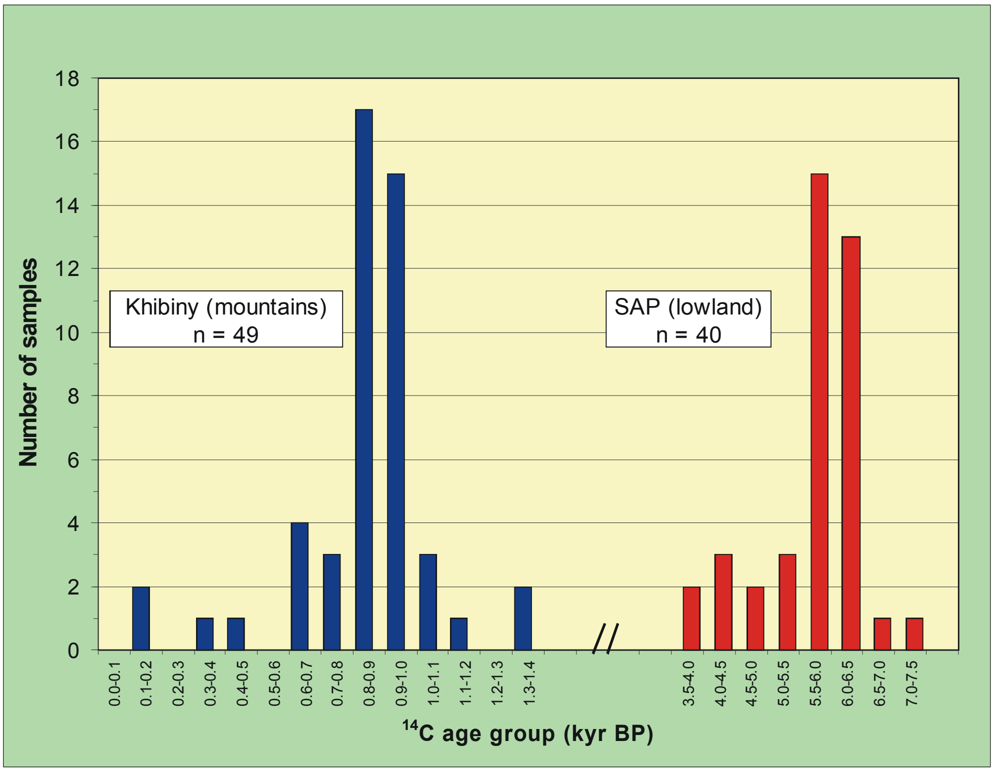

Figure 3: Age distribution of Khibiny and Zapolyarny subfossil pine woods.

Radiocarbon dating indicates that the trunks belonged to a pine forest that existed about 7,000 to 3,500 ^{14}C years ago (Fig. 3). The forest most likely reached its maximum size around 6,000 ^{14}C years ago. Based on comparisons with results from Finnish Lapland by Eronen (1979) and Eronen and Huttunen (1987), and on findings from the northeastern part of the Kola Peninsula published by MacDonald *et al.* (2000a), we conclude that the northern forest border first retreated in the East, during the Late Holocene temperature decline after ca, 4,000 ^{14}C years BP, and that it retreated later in the western part of the region. Nowadays this area is covered by tundra and characterized by a climate that gradually grows colder along the coast in an easterly direction.

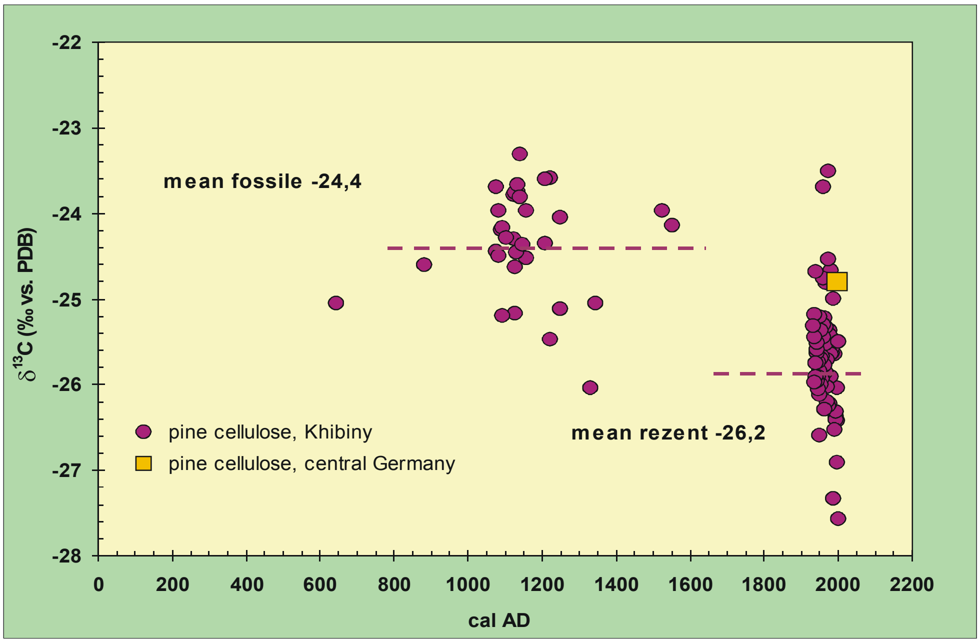

Figure 4: δ^{13}C values for cellulose from samples of living and dead Pinus sylvestris L. from the Khibiny low mountains in the central Kola Peninsula.

Our findings are supported by the results of the isotope studies on the material (Boettger *et al*., in press). On average, the mean δ^{13} C, δ^{18}O and δ^{2}H values of pine cellulose from the mid-Holocene are found to be ca. 1.1‰, 0.9‰ and 10‰ heavier than the values of living pines from the forest border in this region. This could well be explained by the higher temperatures and (simultaneously) reduced moisture supply at the studied sites during the mid-Holocene. Hence our results tally in suggesting that during the mid-Holocene, between ca. 7000 and 3500 ^{14}C years BP, the climate on the northwestern Kola Peninsula was warmer and drier than it is today. The mid-Holocene warm phase therefore must have been a general North-European climatic phenomenon, tied in with global climate.

Summary

1. The isotope signatures of pine cellulose in the studied areas of the Kola Peninsula are controlled by the climate.

2. a) The Mediaeval Climatic Optimum was the most pronounced warm phase on the Kola Peninsula in the last 1,500 years or so. During this interval, the alpine forest border in the Khibiny mountains was situated at least 100–140 metres higher than it is today. The vegetation distribution in the region has not essentially changed since this time.

b) During the mid-Holocene, the climate on the northwestern Kola Peninsula was warmer and drier than it is today.

c) These conclusions are unambiguously confirmed by the results of the isotope studies.

Hence the warm periods we found were not just a climatic phenomenon in central Europe, but also a general North-European climatic phenomenon, tied in with global climate.

References

Boettger T, Friedrich M, Kremenetski C, Hiller A, Gehre M, 2002. Climatic response of stable isotope variations in wood cellulose of pine (Pinus sylvestris L.) and their tree-ring width on the Kola Peninsula, north-western Russia. In Proceedings of the " International Conference on the Study of Environmental Change Using Isotope Techniques", Vienna, Austria, 23-27.04.2001, IAEA-CN-80/86, p. 243-251.

Boettger T, Hiller A., Kremenetski C, 2003. Mid-Holocene warming in north-west Kola Peninsula, Russia: northern pine limit movement and stable isotope evidence. – *The Holocene* **13/3** (in press)

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**: 93-114.

Eronen M, Huttunen P, 1987. Radiocarbon-dated subfossil pines from Finish Lapland. *Geografiska Annaler*, **69A**: 297-304.

Eronen M, Lindholm M, Saastamoinen S, Zetterberg P, 1999. Variable Holocene treeline dynamics and changes in natural environments in northern Finnish Lapland. Chemosphere: *Global Change Science*, **1**: 377-387.

Handbook for climate SSSR, 1964; 1968. vol. 2: 1964, 144 pp., vol. 4: 1968, 174 pp.

Hiller A, Boettger T, Kremenetski C, 2001. Medieval climate warming recorded by radiocarbon dated alpine tree-line shift on the Kola Peninsula/Russia. *The Holocene*, **11**: 491-497.

Kullman L, 1995. Holocene tree-limit and climate history from the Scandes Mountains, Sweden. *Ecology*, **76**: 2490-2502.

MacDonald GM, Gervais BR, Snyder JA, Tarasov GA and Borisova OK, 2000. Radiocarbon dated Pinus sylvestris L. wood from beyond tree-line on the Kola Peninsula, Russia. *The Holocene*, **10**: 143-147.

McCarrol D, Pawellek F, 2001. Stable carbon isotope ratios of Pinus sylvestris from nothern Finland and the potential for extracting a climate signal from long Fennoscandian chronologies. *The Holocene*, **11**: 517-526.

Naurzbaev MM, Vaganov EA, 2000. Variation of early summer and annual temperature in east Taymir and Putoran (Siberia) over the last two millennia inferred from tree rings. *Journal of Geophysical Research*, **105/D6**: 7317-7326.

Saurer M, Aellen K, Siegwolf R, 1997. Correlating $\delta^{13}C$ and $\delta^{18}O$ in cellulose of trees. *Plant, Cell and Environment*, **20**: 1543-1550.

Sonninen E, Jungner H, 1995. Stable carbon isotopes in tree rings of a Scot pine (*Pinus Sylvestris L.*) from northern Finland. In Frenzel B, Staufer MM & Weiss MM (Eds), Problems of stable isotopes in tree rings, lake sediments and peat-bogs as climatic evidence for the Holocene, *Paläoklimaforschung/Palaeoclimate Research,* **15**: 121-128.

Timonen M, 1999. Developing a supra-long ring-width chronology for northern Finland. Final report on Advance project. In Analysis of Dendrochronological Variability and Associated Natural Climates in Eurasia - the Last 10 000 years (ADVANCE-10K), ENV4-CT95-0127, Final Report to the Commission of the European Communities Directorate General XII: 36-42.