Akademie der Wissenschaften und der Literatur

Paläoklimaforschung
Palaeoclimate Research

Volume 9

Special Issue: ESF Project
"European Palaeoclimate and Man" 4

Editor: Burkhard Frenzel

Associate Editor: Birgit Gläser

1993

European Science Foundation
Strasbourg

Akademie der Wissenschaften
und der Literatur · Mainz

Oscillations of the Alpine and Polar Tree Limits in the Holocene

Edited by Burkhard Frenzel

Co-edited by Matti Eronen, Karl-Dag Vorren & Birgit Gläser

81 figures and 8 tables

SEMPER BONIS ARTIBUS

Gustav Fischer Verlag · Stuttgart · Jena · New York · 1993

Der vorliegende Sonderband wurde mit Mitteln der European Science Foundation (Straßburg) und der Akademie der Wissenschaften und der Literatur (Mainz) gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autoren.

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Technische Redaktion: Dr. Birgit Gläser, Hohenheim/ESF

Die Deutsche Bibliothek – CIP Einheitsaufnahme

Oscillations of the alpine and polar tree limits in the holocene
: 8 tables / ed. by Burkhard Frenzel. Co-ed. by Matti Eronen
... - Stuttgart ; Jena ; New York : G. Fischer, 1993
(Palaeoclimate research ; Vol. 9 ; ESF project "European palaeoclimate and man" ; Special issue 4)
ISBN 3-437-30735-5 (Stuttgart ...)
ISBN 1-56081-374-1 (New York ...)
NE: Frenzel, Burkhard [Hrsg]: Paläoklimaforschung / ESF project "European palaeoclimate and man"

Gesamtherstellung: Rheinhessische Druckwerkstätte, Alzey. Printed in Germany.

ISBN 3-437-30735-5
US-ISBN 1-56081-374-1
ISSN 0930-4673

The upper timberline dynamics during the last 1100 years in the Polar Ural Mountains

Stepan G. Shiyatov

Summary

Based on studies of the age structure of larch stands growing at their upper limit in the Polar Ural Mountains and on the dendrochronological dating of trunk and root remains of dead trees, a detailed reconstruction of the open larch forests and the upper timberline dynamics during the last 1100 years was made. The role of climatic fluctuations in the alteration of the altitudinal position of the upper timberline and the larch stands structure is discussed.

Résumé

La dynamique des clair-bois du larix et de la limite supérieure forestière pendant les dernières 1100 ans etait reconstruit en detail sur la base de l'étude de la structure de l'âge des peuplements du larix qui poussent à leur limite supérieure dans les montagnes de l'Ural polaire et par le datage des restes des troncs et des racines des arbres morts par l'analyse des cernes. Nous discutons le rôle des fluctuations climatiques dans le changement de la position de la limite supérieure forestière et de la structure des peuplements du larix.

1. Introduction

Usage of direct evidence is of great interest in the studies of the upper timberline dynamics. This evidence comprises primarily the locality of living trees and wood remains of dead trees which have been preserved *in situ* and are found above ground and in various deposits (alluvial, lacustrine, and peat). If we know the location and age of living trees and the calendar time of their appearance and disappearance, we can determine the upper timberline shifts in various time periods with high accuracy.

Numerous explorers (SUKACHEV, 1922; GORODKOV, 1926; SOCHAVA, 1927; ANDREEV, IGOSHINA & LESKOV, 1935) observed a great number of dead trees and wood remains in various degrees of decomposition around the upper timberline on the eastern flank of the Polar Ural Mountains. Such wood is especially abundant in the Sob River Basin. The dating of the wood by the dendrochronological method has shown that some trees died 600-800 years ago (SHIYATOV, 1979). Wood remains of trees are often found above the present timberline. In particular, large areas (up to 192 hectares) of completely dead larch stands were discovered on the east slope of the Rai-Iz Massif. In this area special studies were carried out to reconstruct the upper timberline dynamics during the last millennium and to reveal factors which determine these dynamics.

2. Objects and methods of investigations

The Rai-Iz Massif is situated just to the north of the Polar Circle.The open forests at the upper timberline consist exclusively of Siberian larch (*Larix sibirica* Ldb.). The range of timberline altitudes varies between 280 and 350 m a.s.l. Two large (192 and 39 hectares) and seven small (from 0.2 to 3.8 hectares) completely dead larch stands were found above the present timberline at the watershed of the Kar-Doman-Shor stream. The earlier upper timberline had an altitudinal range between 350 and 410 m a.s.l. There are many standing and lying trunks and roots in various stages of decomposition in these areas (Photo 1) and a large number of dead trees and wood remains in the open larch forests.

To understand the upper timberline dynamics we used data on the age structure (exact age determination of 315 trees), and the regional spread of individual age generations of trees. To determine the life span (in calendar years) of the dead trees, 80 cuts were taken from trunks and roots in various locations. In order to estimate the upper timberline dynamics for the time intervals beyond the maximum age of living trees, a transect 430 m long and 20 m wide was set up across the second largest area (39 hectares) where all trees had died. The transect began at an elevation of 340 m a.s.l. where the highest remains were found, and ended at the present timberline at an elevation of 280 m a.s.l. All remains on the transect were mapped (249 trees). For the tree-ring analysis cuts from trunk and root remains were taken as close to the base of trunks and roots as possible to estimate the time of appearance and dying off of trees with maximum accuracy. On account of the high degree of wood decomposition, cuts could not be taken from 40 remains. Thus, cuts were taken from 209 wood remains only (107 from roots, 102 from trunks). In addition, 16 larch seedlings were found on the transect, their age being up to 80 years and their height up to 4 m. Their locality was also mapped. Ring widths were measured in each cut. Ring widths were plotted and used for relative and absolute dating of rings, for the discovery of missing rings, and for choosing appropriate curves to calculate indices. Based on chronologies obtained from old living trees (the maximum ages of living trees are 350-400 years in this region), it was possible to achieve an absolute dating of the samples taken.

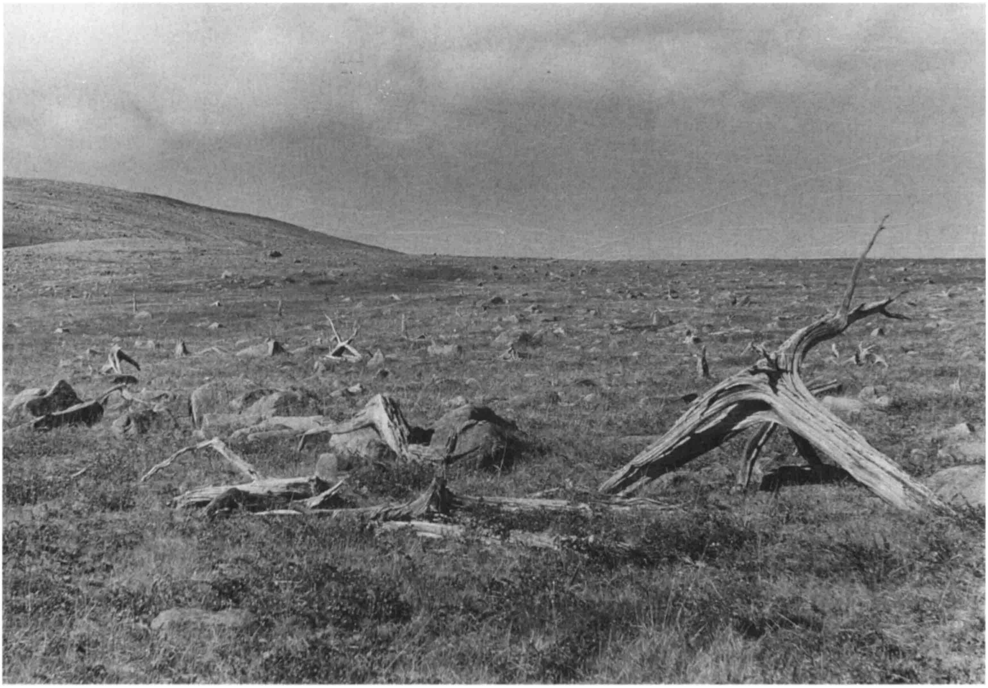

Photo 1 A view of the dead larch stand above the present timberline on the east slope of the Rai-Iz Massif

3. Results of investigations

The structure analysis of present larch stands growing near the upper timberline has shown that they consist of few morphological groups differing in height, diameter, growth form, and crown development. Age determination of trees has shown that these groups also differ in age. In other words, during certain time periods the regeneration was intensive whereas it was weak or lacking during others. Three age generations in the larch stands were distinguished in the area studied:

(1) the over-aged generation which emerged in 1630-1690. At present this generation is represented by a small number of individuals in stands;
(2) the middle-aged generation which emerged in 1780-1850. Presently this generation prevails in larch stands;
(3) the young generation which emerged since the 1920s and is now in the final stage of formation.

Thus, during the last 350 years there were three time periods favourable for regeneration and formation of larch generations and two time periods when regeneration was very weak or lacking. According to KOMIN's classification (KOMIN, 1963), the larch stands at their upper limit of spread may be attributed to cyclic or stepped uneven-in-age distribution.

Using morphological traits one can define which age generation the trees growing at the upper timberline belong to. This enables the estimation of the upper limits of the above-mentioned age generations. It means that we can reconstruct the upper timberline for those time periods when the formation of age generations ceased.

The analysis of the maps shows that the last 350 years saw significant displacements of the upper timberline in the Polar Ural Mountains, especially during the period when the middle-aged generation came into being. This generation occupied the driest and best drained sites. The over-aged generation grew on wet sites, the young generation develops on sites with varying moisture.

As shown in Fig. 1, the most ancient wood was found in the middle part of the transect. The oldest tree-rings were formed in the second half of the ninth century. Probably trees appeared in the lower part of the transect at this time, but their remains have not survived. During the ninth and tenth centuries larch stands were very sparse. The upper limit of isolated trees was at an elevation of 325 m a.s.l. (90 m along the slope from the beginning of the transect) and the upper limit of the light forest was at an elevation of 305 m a.s.l. (210 m from the beginning of the transect).

Intensive regeneration started in the first half of the twelfth century and proceeded until the end of the thirteenth century. The most favourable growing conditions for larch were in the twelfth and thirteenth centuries. Larch stands were most dense during the last millennium. At the beginning and especially in the second half of the eleventh century there was an intensive rise of the upper timberline (from 305 to 340 m a.s.l., corresponding to a relative distance of 190 m along the slope). In the twelfth century the upward movement of the upper timberline slowed down. The maximum was reached in the middle of the thirteenth century (Fig. 1).

At the close of the thirteenth century larch growing conditions deteriorated and comparatively young trees (100-150 years old) began dying off on a large scale. The uppermost trees died out at first.

The most intensive thinning of stands and upper timberline retreat took place towards the close of the fourteenth century. From the end of the thirteenth to the end of the fourteenth centuries the upper timberline sank from 340 to 310 m a.s.l., corresponding to 180 m along the slope.

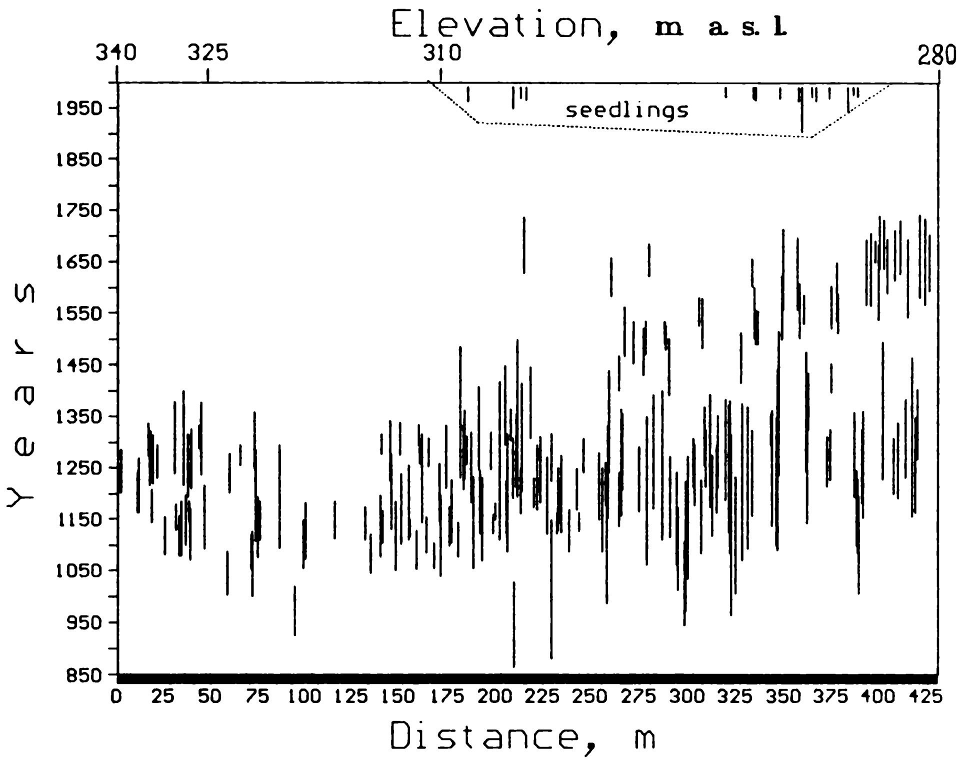

Fig. 1 Distribution of dated wood remains and larch seedlings along the transect

In the first half of the fifteenth century the deterioration of forests came to an end. Moreover comparatively favourable conditions for regeneration were observed in the lower part of the transect.

During the second half of the fifteenth century a further retreat of the upper timberline took place from 310 to 300 m a.s.l.

In the sixteenth century tree growing conditions were again more favourable than in the second half of the fifteenth century. Larch stands increased in density and the upper timberline remained stationary at approximately 300 m a.s.l.

In the first half of the seventeenth century a new retreat of the upper timberline took place (70 m along the slope, corresponding to 300 to 290 m a.s.l.). In the second half of this century the decline of the open larch forests ceased and in the lower part of the transect there was intensive regeneration. During this period the over-aged generation formed, of which some trees are still alive.

In the second half of the eighteenth century all trees growing on the transect died off and the upper timberline retreated to 280 m a.s.l.

In the nineteenth century not one single living tree stood on the transect. The first larch seedlings reappeared at the beginning of the twentieth century at an elevation of about 290 m a.s.l. There are 16 seedlings on the transect now. They are mainly 20-30 years old. In Fig. 1 the seedlings are shown in the upper part of the drawing. Formation of the young larch generation only took place in the lower part of the transect at an elevation of 280 to 310 m a.s.l.

4. Discussion

Thus, during the last 1100 years the upper timberline and the larch stands density altered significantly in the Polar Ural Mountains. From the ninth to the thirteenth centuries larch colonization of the formerly treeless tundra sites took place. The maximum development of open larch forests at their upper limit of spread was observed in the thirteenth century.

During this period the upper timberline moved 35 m upwards, corresponding to a distance of 210 m along the slope. Then forest deterioration and the upper timberline decline began and this process continued to the end of the nineteenth century. From the end of the thirteenth to the end of the nineteenth centuries the retreat of the upper timberline was 60 m in altitude or 430 m along the slope.

The displacements of the upper timberline took place with different intensity in various time periods. However, it can be noted that the advancement of the open larch forests upwards was usually slower than their retreat.

As there was no evidence of forest fires or other catastrophic phenomena in the study area and also no evidence of significant human influences on open larch forests, the forest dynamics were most probably caused only by climatic changes.

To reconstruct the past climatic conditions we used the 1009-year tree-ring chronology of Siberian larch obtained from wood of living trees and wood remains. All wood samples (cuts and cores) were collected in the study area. Of greatest influence upon the tree growth variability was the air temperature of June and July (the correlation coefficient is 0.78). In Fig. 2 one can see the reconstructed air temperature averages for every 20 years of the last millennium (GRAYBILL & SHIYATOV, 1989). During this period summer temperatures fluctuated significantly, their variability range exceeding 1.2°C in various 20-year-intervals.

Two long-term periods can be distinguished: the warm period from the tenth to thirteenth centuries and the period of cooling from the fourteenth to the end of the nineteenth centuries. The warmest period was in the twelfth and thirteenth centuries, the coldest one was in the nineteenth century.

It is not difficult to see that the long-term temperature oscillations coincided very well with the altitudinal changes of the upper timberline. In other words, during the Medieval climatic warming or the Little Climatic Optimum open larch forests at the upper limit of their spread moved to a higher elevation by 60-80 m, compared to their present altitudes. Climatic cooling during the Little Ice Age has resulted in larch stands decline and the upper timberline retreat. There are also short-term fluctuations (of several decades duration) which influenced larch forests dynamics.

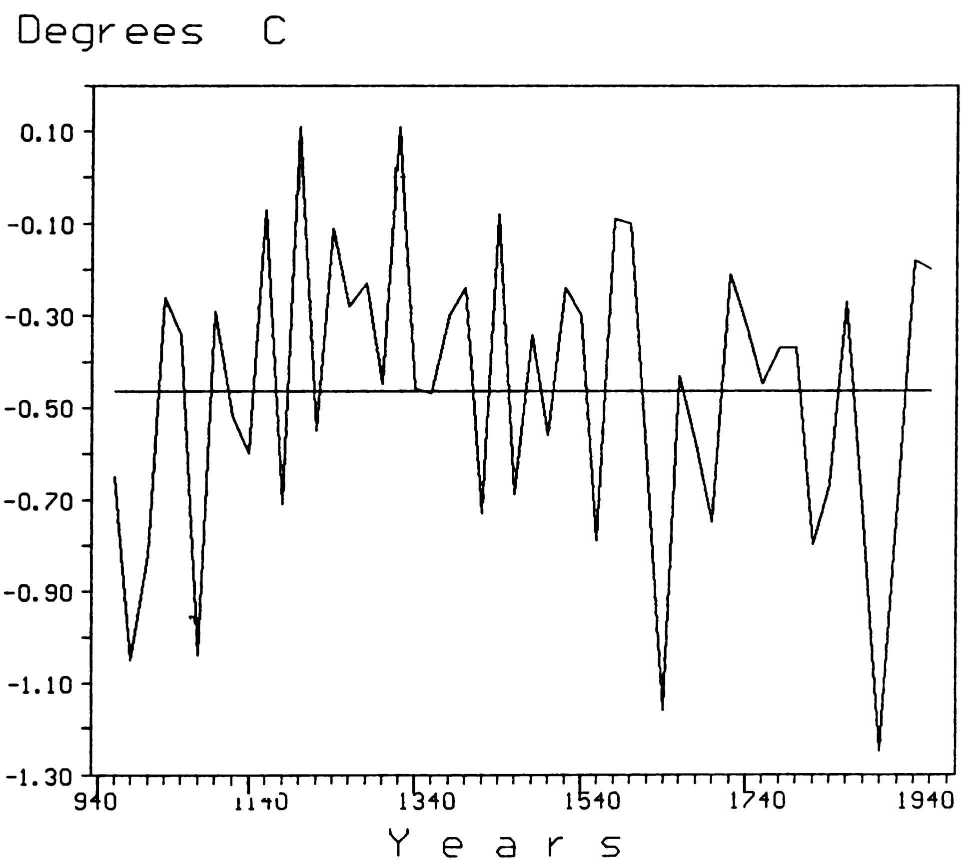

Fig. 2 Twenty year averages of reconstructed average June-July temperature departures (redrawn from GRAYBILL & SHIYATOV, 1989).

The dying off of trees is basically related to cold periods of no less than 20-30 years duration. Such cold periods occurred from the late thirteenth century to the early fourteenth century, in the middle of the fourteenth century, in the first half of the sixteenth century, in the beginning and the end of the eighteenth century. Formation of a single age generation requires favourable climatic conditions during no less than 50-60 years. However, larch seedlings can emerge and grow in cold climatic periods because less heat supply is needed for their growth and development during growing season than for adult trees. Therefore, the appearance and existence of seedlings are not so closely connected with the beginning of the warm period as is the disappearance of trees with cold periods. The alternation of warm and cold periods which is typical of the region causes the formation of cyclic and stepped uneven larch stands. The analysis of the time of appearance and disappearance of trees, from which only trunk and root remains have survived, suggest that in the past the age structure of larch stands was the same as today. We intend to make a further, more detailed analysis of the age structure of dead stands.

Deterioration of forests and lowering of the upper timberline continued up to the beginning of the twentieth century. In connection with the present warming larch seedlings have started to settle in tundra communities since the 1920s. This process was rather intensive and larch seedlings appeared in the lower part of the transect (Fig. 1). The occupation of the tundra by forest would have been more active if more viable seeds had been blown into the treeless areas.

The above-mentioned relation of individual age generations to sites with different moisture conditions is supposed to have been caused by changes in the humidity of climate. The larch stands that were forming from the ninth to the seventeenth centuries are confined to the wettest sites. To all appearance, the climate then was dry and continental.

In the eighteenth and nineteenth centuries, when the middle-aged larch generation was under formation, the humidity increased significantly.

Therefore, during this wet period the advancement of the upper timberline was rather intensive but restricted to the driest slope sites.

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