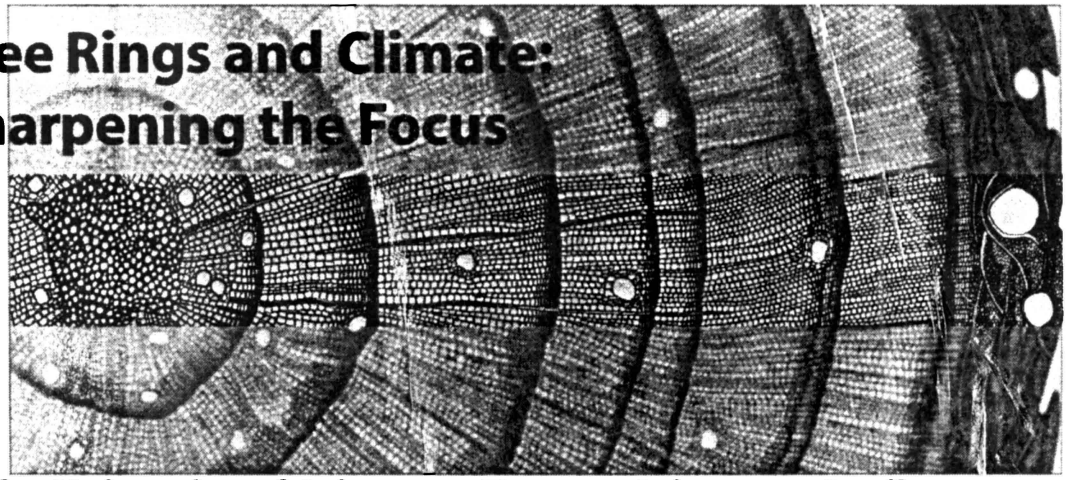
# Tree Rings and Climate: Sharpening the Focus



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**The structure and productivity dynamics of forest-tundra area in the Polar Ural Mountains for the last millennium**

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Significant spatio-temporal changes of forest-tundra ecosystems took place in the upper treeline ecotone in the eastern macroslope of the Polar Ural Mountains (66-67° N, 65-66° E) during the last millennium (Shiyatov, 1993, 2003). Within the treeline ecotone, which is located from 100 to 400 m a.s.l., Siberian larch (*Larix sibirica*) open forests dominate. Up to this day, these forests have been mainly developing under the influence of natural factors, especially climatic ones. The direct evidence of forest-tundra ecosystem changes is availability of a great number of wood remnants on the ground up to 60-80 m above the present treeline (the highest altitudinal position of open forests) and within the ecotone. They have been preserved for a long time (up to 1300 years) because of the low rate of wood decomposition in severe climatic condition. This circumstance provide us with the possibility of extending tree ring chronology back to 645 AD and of dating the lifetime of a large quantity of living and dead trees.

In order to estimate displacement of the upper treeline and forest-tundra ecosystem dynamics over the last millennium, two continuous transects were set up. The first transect 860 m long and 40-80 m wide was set up in 1960 on the eastern slope of hill (312 m a.s.l.) located in the vicinity of Tchernaya Mountain within the recent treeline ecotone, from 265 m to 190 m a.s.l. The second transect 430 m long and 20 m wide was set up in 80-s on the south-eastern slope of Rai-Iz Massif, from the highest location of wood remnants (340 m a.s.l.) to the present upper treeline (280 m). Moreover, three altitudinal discontinuous transects within the recent treeline ecotone were set up in the vicinity of Tchernaya Mountain in 2002-2003. Each transect was divided into quadrates of 20 by 20 m or 10 by 10 m. Each living and dead tree was mapped and measured. Wood samples (cuts and cores) from each living and dead tree were collected and dated by dendrochronological technique to estimate their calendar lifetime. Up to now, more than 6000 trees and seedlings were dated.

On basis of calendar lifetime data of dead trees only (more than 700 pcs) from the first transect the stand density in the upper treeline ecotone for last 800 years was estimated. It was shown, that the maximum of stand density, which was observed in XI-XIII centuries is well traced and has been dated for medieval climate warming. Warming of climate, which occurred in XVIII century, has caused the second maximum of stand density. On this data including lifetime about 400 living trees the estimation of age structure dynamics for last 800 years is received. The step change of age structure is shown, which is caused by climate change.

To make a calculation of fractional structure of biomass changing for last 800 years the data on accumulation and distribution below- and underground biomass of 20 modele trees (different age and diameter), morphometry of living and dead trees from the first high-altitude transect was

used. These results also confirm that there is high responsiveness of forest-tundra ecosystems in the Polar Urals to change of climatic conditions.

Using data obtained on the second transect, climate depending displacements of the upper treeline over last millennium were reconstructed. This time interval was divided into 5 periods, distinguished by differing directions of treeline shifting (rising or retreating) and differing rates of displacement. The periods of rising were in 850-1280, 1580-1790 and from 1910 to the present and of retreating were in 1280-1580 and 1790-1910. The highest altitudinal position of treeline was in the XIII$^{th}$ century, the lowest position was at the end of the XIX$^{th}$ and at the beginning of the XX$^{th}$ centuries. The mean rate of treeline displacement was 2-3 m/decade (from 0.5 to 6 m). The range of altitudinal treeline shift on some slopes was up to 80-90 m.

Now we concentrate attention on the recent expansion of forest-tundra ecosystems, which began 80-90 years ago in connection with climate warming and moistening. Summer temperature (since 1921) at Salekhard weather station (50 km to the east of the study area) increased by 0.9°C and winter temperature by 1.2°C in comparison with the first period of observation (1883-1920). It means that summer temperature isotherm rose 120-130 m in altitude (in this area the gradient is 0.7°C/100 m). Mean precipitation of summer months is increased from 147 to 178 mm and of winter months from 67 to 113 mm.

To estimate spatio-temporal changes of forest-tundra ecosystems which took place during the XX$^{th}$ century, we used both direct and indirect evidence (old terrestrial, aerial and satellite photographs, repeated stand descriptions of permanent plots and transects, morphological and age structure of stands, meteorological and dendroclimatic data). Special attention was given to description and large-scale mapping of forest-tundra ecosystems over the treeline ecotone. To present day the area of 3311 ha was mapped. Three maps were developed which show the state of stands for the beginning, middle and end of the XX century.

During the last 90 years a significant afforestation of treeline ecotone took place. The area under tundra with individual trees decreased from 2494 to 1919 ha or 23%, the area under sparse growth of trees from 385 to 348 ha or 10%. Interestingly, the area under open forests has not been changed (427 ha). The most impressive changes were seen with closed forests. The area increased from 5 to 617 ha or more than 100 times with the transformation of sparse growth of trees and open forests into closed forests.

Impressive changed have occurred in the structure and productivity of existing stands during the last 90 years. From the beginning of warming an intensive renewal larch and spruce occurred. Most of stands have become much denser and more productive (up to 2-5 times) and many tundra sites located within the treeline ecotone have been afforested. The degree of afforestation (including open and closed forests only) increased from 13 to 32%. To date young generation of trees is formed, which come to upper wood canopy and occupies dominating position in the majority of stands. This generation is presented basically by singlestem form of growing even on powerfully wind sites, while middle-aged generation is presented mainly multistem form of growing.

Conversion of prostrate forms to multistem forms have been occurring at the end of XIX century basically and, particularly, in 20-30-s of XX century, that is connected with improvement of the climatic conditions. Loss of the stems in multistem forms has begun after 80-s of XX century because of reinforcement of competition for the light and nutrients between stems and crowns of trees within the clones in connection with significant increasing their sizes. On many slopes the upper treeline rose 20-40 m in altitude, but on many slopes it is not reached the altitudinal position on which forests grew in the XIII$^{th}$ century.

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**References**

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