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The impact of climate changes on forest-tundra vegetation in the Ural Mountain highlands during the 20th century

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The average air surface temperature around the world has risen from 0.3 to 0.6°C over the past 100 years and from 0.2 to 0.3°C over the last 40 years (IPCC 1995). In the arctic, and respectively in alpine regions, the estimated temperature anomalies for the same periods were twice as large as those averaged for the northern hemisphere (Kelly et al. 1982). Highland ecosystems are very sensitive to climatic changes as the temperature is a limiting factor and the climatic gradients and associated changes in vegetation patterns occur over short distances (Tranquillini 1979).
Significant seedlings establishment, increasing of crown coverage and density of stands growing within the subalpine zone is well reported for various mountain areas around the world: Canada (Kearney 1982), USA (Jakubos et al. 1993; Taylor 1995; Woodward et al. 1995; Rechefort and Peterson 1996), Northern Europe (Kullman 1986) and New Zealand (Wardle and Coleman 1992). However, seedlings establishment above the tree-line and upward shift of the tree-line have been described only in a few publications for Russia (Shiyatov 1983), Eastern Canada (Payette and Filion 1985) and USA (Shankman and Daly 1988).

Recently we study the climate dependent vegetation changes which took place during the 20th century within the forest-tundra ecotone in the Ural Mountain highlands. Thereto we use different direct and indirect data concerning the vegetational and environmental changes, namely: old descriptions and maps of forest-tundra vegetation and altitudinal position of the treeline and timberline, old landscape photos, dendroclimatic reconstructions, dendrochronological dating of dead trees remnants, age structure data of living stands, meteorological data.

The comparison of contemporary vegetation with the images of vegetation fixed on old landscape photos showed that vigorous trees regeneration and their establishment on sites, which were covered earlier with meadow and tundra communities, have occured during the last 40–100 years within the forest-tundra ecotone of the South, North and Polar Urals. In the South Urals the upper limits of open and closed forests displaced upward up to 60–80 m of altitudinal and up to 600–900 m of horizontal gradients on gentle slopes and up to 20–40 m of altitudinal and 100–300 m of horizontal gradients on steep slopes. In the North Urals the upper border of closed forest removed upward in altitude up to 20-40 m over the last 40 years. In the Polar Urals the upper border of open and closed forest displaced upward up to 20-40 m in altitude and up to 200–600 m along the gentle slopes during the last 40 years.

The comparison of old descriptions and large-scale maps (1:10000) of forest-tundra vegetation on the Polar Urals made in 1960s and 1990s and the reconstruction of the vegetation for 1910s have showed that the degree of afforestation (taking into account the area under open and closed forest) increased 2.2 times. At that, the area under closed forests increased most of all (39 times), the area under open forests increased to a less extent (1.5 times). At the same time the area under sparse growth of trees decreased by 36% and the area under single trees decreased by 16%. The upper border of open and closed forests removed upward up to 60–80 m in altitude and up to 2 kilometres along the gentle slopes over last 90 years. The greatest changes have been occurred on the sites which were supplied by viable tree seeds, i.e. at a distance no more than 40–60 m from a source of seeds (single trees and stands). The coverage of crown, density and biomass of stands increased up to 2–5 times. The young generation of trees has the common growth form even on heavily windy sites, contrary to the middle-aged generation, individuals of which have mainly multi-stemmed growth form.

An analysis of fluctuations in ring-width indices of Siberian spruce (*Picea obovata* Ledeb.) and Siberian larch (*Larix sibirica* Ledeb.) growing within the forest-tundra ecotone of the South, North and Polar Urals (Shiyatov 1986, Briffa *et al.* 1995, Vaganov *et al.* 1996) and temperature data of weather stations located in these regions showed that during the last 80–100 years climatic conditions for tree growth were favourable. At the end of 20th century the mean temperatures of the warm season (May-September) were higher by 0.6°C, 1.1°C and 1.4°C in the South, North and Polar Urals respectively, in comparison with the end of 19th century. The cold season (October-April) warming was more pronounced: for the South Urals it was higher by 3°C, for the North Urals by 4.3°C and for the Polar Urals by 4.3°C, on average. Annual precipitation has increased by 70, 100, 130 mm on average in the South, North and Polar Urals respectively during the last century.

As shown above, warm and wet climate of the 20th centuries appear to have resulted in an improvement of conditions for the growth of woody plants at the upper limit of their distribution. This changes affect strongly on biodiversity and the total area covered by typical mountain tundra communities and on the composition and structure of communities located within and nearby forest-tundra ecotone. By preliminary estimations, in the South Urals the total tundra area have been decreased by 10–30% over last century, when the annual mean temperatures have risen by about 1.4°C. If temperature will increase by 3°C in the South Urals, we expect complete disappearance of mountain tundra communities on 7 out of 16 sites, where they have still remained, and decrease total tundra area by 40-70%. Fortunately, mountain tundra areas on the other part of the Urals are larger than on the South Urals and due to not so threatened, but we expect that anticipated climate changes will reflect greatly on vegetation pattern within about 100 m zone above modern treeline.

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