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SHORT COMMUNICATIONS

Specific Features of Siberian Spruce (*Picea obovata*) Growth at the Upper Limit of Its Distribution in the Iremel' Mountain Range, Southern Urals

T. S. Babenko[a], Z. Ya. Nagimov[a], and P. A. Moiseev[b]

[a] Ural State Forest Engineering University, Sibirskii trakt 36, Yekaterinburg, 620100 Russia
[b] Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences
ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia
e-mail: moiseev@ipae.uran.ru

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As estimated by the International Panel on Climate Change (IPCC), the average temperature of the earth's surface has increased by 0.3–0.6°C over the past 100 years and by 0.2–0.3°C over the past 40 years, with the temperature rise being greater at high latitudes than in the temperate zone or in the tropics (*IPCC*..., 2001). Therefore, further global climate warming may lead to considerable changes in the biota of polar and high-mountain regions, including latitudinal (northward) and altitudinal (upward) shifts of botanical–geographic zones and, in particular, of the polar and upper forest limits. This is confirmed by the results of studies performed in Canada (Kearney, 1982; Lavoie and Payette, 1992), the United States (Denton and Karlen, 1977; Jakubos and Romme, 1993; Taylor, 1995; Weisberg and Baker, 1995; Woodward et al., 1995; Lloyd and Graumlich, 1997), northern Europe (Kullman and Engelmark, 1997), Russia (Shiyatov, 1983; Moiseev and Shiyatov, 2003), and New Zealand (Wardle and Coleman, 1992): over the past few decades, the altitudinal distribution limit of tree species has shifted to higher elevations by hundreds of meters, while the upper boundary of insular scrub forests and closed forests has shifted tens of meters.

The results of comparing the present-day vegetation pattern in different areas of the Iremel' Mountain Range (the Southern Urals) with that reconstructed from old photographs (Shiyatov, 1983; Moiseev and Shiyatov, 2003) and subsequent field studies (Moiseev et al., 2004) provided evidence that, over the past 100 years, tree vegetation in the subgoltsy and lower mountain tundra belts has been actively regenerating under the canopy of open and park forests and expanding to areas previously occupied by meadow and tundra communities. On steep rocky slopes and overmoistened gullies, the upper boundary of scrub and closed forests has shifted vertically 20–40 m and horizontally 100–300 m. These shifts on gentle slopes with well-developed soil cover reach 60–80 and 600–900 m, respectively.

In our opinion, such rapid and significant changes in the amount of forests (from open, almost woodless areas to closed forest communities) could not fail to produce an effect on growing conditions for tree species at the upper limit of their distribution. For this reason, we performed a comparative analysis of trunk growth in Siberian spruce trees that emerged in different periods of the past century at different altitudinal levels of the present-day mountain forest–tundra ecotone. Our purpose was to estimate the extent to which the aforementioned changes have improved or impaired conditions for the growth of tree species.

Studies were performed according to the procedure accepted in the INTAS-01-0052 international project, on the transect laid on the southwestern slope of Mount Malyi Iremel' in the area with well-developed soils and vegetation typical of the study region. In this transect, we distinguished the upper, middle, and lower altitudinal levels at elevations of 1300, 1260, and 1210 m a.s.l., respectively. At each level, three to six macroplots (20 × 20 m) were established so that the distances between their centers along the vertical and horizontal axes were no more than 5–10 and 50–100 m, respectively. Each macroplot was divided into four mesoplots (10 × 10 m).

All living or dead-standing trees in a mesoplot were numbered, and the parameters of each tree were determined. They included its location (azimuth and distance from the center of macroplot), life form (single-stemmed, multistemmed, or prostrate), height, and

Table 1. Taxonometric parameters of trees in test plots

Parameter	Altitudinal level		
	upper	middle	lower
Average trunk diameter at the base, cm	10.6	13.5	24.2
Average trunk diameter at breast height, cm	7.5	10.4	20.3
Average trunk height, m	3.3	5.3	10.5
Average tree age, years	48	74	100
Average crown diameter, m	1.7	2.75	5.0
Number of spruce trunks per hectare	1417	1450	1480
Total number of trunks per hectare	2050	1608	1600
Stocking density	0.30	0.52	0.71

trunk diameters at the base and at breath height. In living trees, we additionally measured diameters of the crown projection (along and across the prevailing wind direction), its length, and tree age (by core samples).

To study the course of tree growth and determine taxonometric parameters of tree stands beyond the macroplots, 70 model spruce trees were selected by the method of proportional (stepwise) representation (by 30 trees at the upper and middle altitudinal levels and 10 trees at the lower layer). In each tree, we determined the Kraft class of growth and development and parameters of the crown (shape, diameter, and length) and marked the northern side of the trunk. After the tree was cut, its age and trunk length were determined and then crosscut samples were taken at the root collar, breast height (1.3 m), the middle parts of upper 1-m or 2-m segments, and the top of the last segment.

It should be noted that crosscuts are most suitable for dating and characterizing radial tree growth, as their analysis makes it possible to assess the tree increment along any radius, reveal various disturbances of tree ring formation, and determine the location of partially missing rings.

In the laboratory, two perpendicular lines (diameters) indicating north–south and east–west directions at the place of tree growth were drawn through the center of each crosscut and wood along these lines was carefully smoothed to make tree rings more distinct. In more than 700 crosscuts prepared in this way, the width of each tree ring at four points (intersections with the lines) was measured in a LINTAB III semiauto-

Table 2. Boundary values of tree diameters by age and rank groups at different altitudinal levels

Altitudinal level	Rank group	Age group			
		30–50	50–70	70–90	90–120
Upper	1	2.0–4.5	3.8–8.0	6.7–12.4	
	2	4.6–5.5	8.1–10.2	12.5–13.7	
	3	5.6–8.0	10.3–13.4	13.8–15.9	
	4	8.1–11.1	13.5–17.2	16.0–20.7	
	5	11.2–19.4	17.3–27.4	20.8–24.8	
Middle	1	2.0–5.1	6.4–10.5	10.5–15.0	
	2	5.2–7.0	10.6–13.4	15.1–17.5	
	3	7.1–9.2	13.5–16.6	17.6–22.3	
	4	9.3–11.5	16.7–22.3	22.4–24.5	
	5	11.6–22.3	22.4–35.7	24.6–41.7	
Lower	1			10.0–18.0	8.0–26.0
	2			18.1–25.0	26.1–33.0
	3			25.1–29.0	33.1–36.0
	4			29.1–32.0	36.1–43.0
	5			32.1–43.0	43.1–60.0

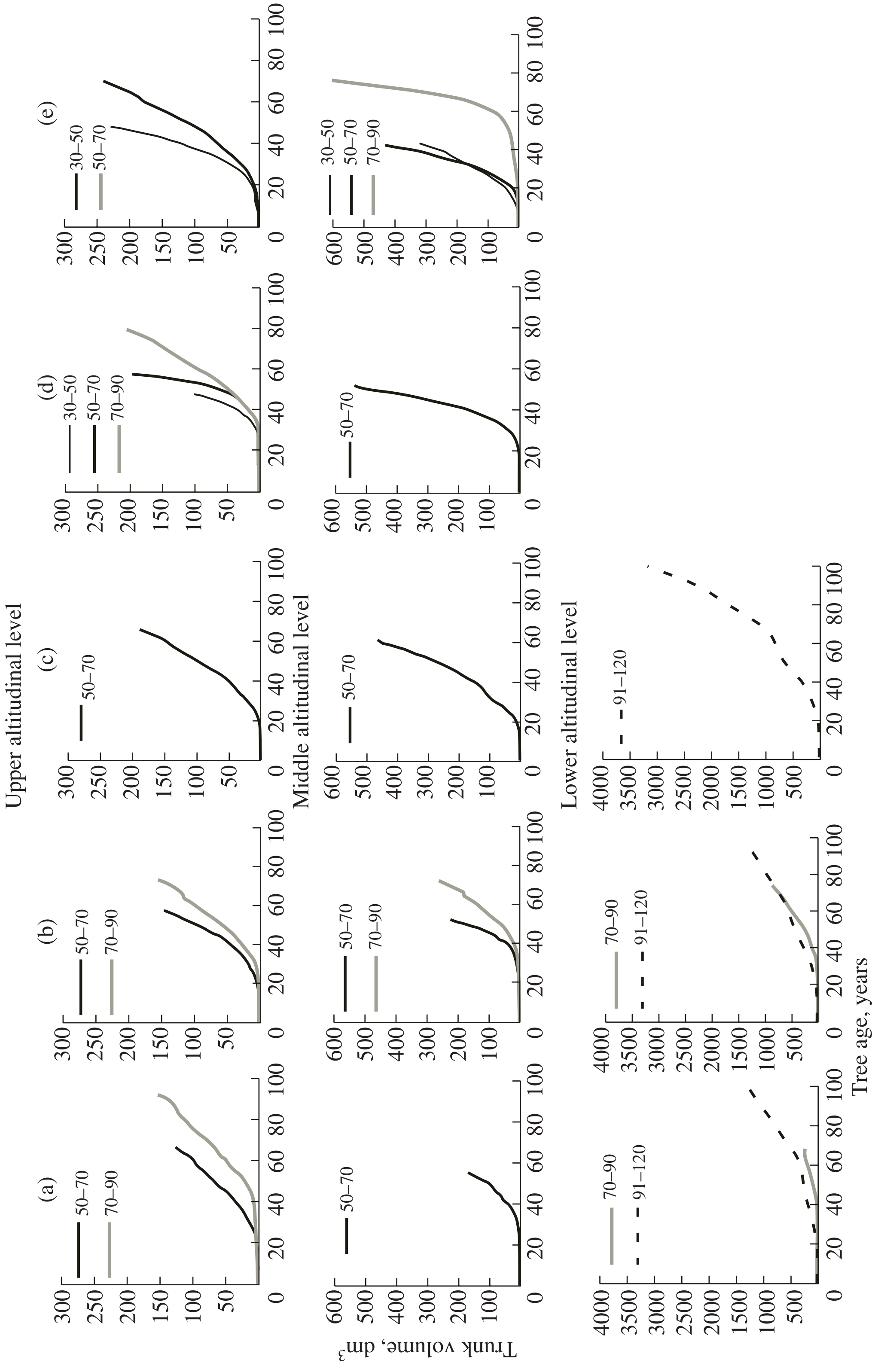

Fig. 1. Age-related changes in the volume of spruce trees. Rank groups: (a) group 1, (b) group 2, (c) group 3, (d) group 4, and (e) group 5.

matic measuring device with the TSAP 3.0 program package.

These measurements and subsequent calculations allowed us to determine the basic taxonometric parameters (diameter, height, and volume) of each tree by years of its life.

Taxonometric data on tree stands in the plots and model trees beyond them (Table 1) provide evidence for considerable differences in structure and growth between stands located at different altitudinal levels of the subgoltsy belt. The most noteworthy fact is that the average tree age decreases with an increase in elevation. This decrease and more severe site conditions at higher elevations account for the lower taxonometric parameters of tree stands. Thus, tree stands at the upper level are inferior to those at the lower level with respect to average tree diameter (by a factor of 2.4), average tree height (by a factor of 3.6), average crown diameter (by a factor of 2.9), and stocking density XXX (by a factor of 2.4).

The range of variation in the age of spruce trees proved to be wide and depend on elevation, being 30–89 years at the upper altitudinal level, 36–89 years at the middle level, and 67–115 years at the lower level. This fact indicated that it would be expedient to analyze these tree stands differentially, by age groups. Taking into account corresponding age distributions, we distinguished three such groups (30–50, 51–70, and 71–90 years) at the upper and middle levels and two groups (70–90 and 91–120 years) at the lower layer.

In any stand, specific features of tree growth depend on their rank (Tret'yakov et al., 1952; Maslakov; 1981; etc.). Therefore, we took into account the distribution of trees by diameter at each altitudinal level and divided them into five conditional rank groups. Table 2 shows the boundary values of tree diameters in different age and rank groups.

The results of this study confirmed the expediency of analyzing specific features of tree growth at different elevations by differentiating trees into age groups (generations) and, within them, into rank groups. Data on age-related changes in the volume of spruce trees (Fig. 1) are presented accordingly. Their analysis provides a basis for the following conclusions:

(1) At each altitudinal level, the trunk volume in trees of the same generation is greater, the higher their rank by diameter. This fact does not need special explanation, and deviations from this trend are accounted for by technical details of model tree selection.

(2) At the upper and middle altitudinal levels, the growth of trees of the same rank groups (by volume) is more intense, the younger the generation to which they belong: the curves of trunk growth are markedly steeper in younger trees than in trees of older age groups. Under conditions of the study region, cenotic factors can hardly be crucial for spruce growth. In particular, this follows from data shown in Table 1: tree stands at the three altitudinal levels have low parameters of density XXX.

(3) At the lower level, the growth of trunk volume is more active in older trees: growth curves in the younger generation are less steep than in the older generation.

In our opinion, this trend is apparently explained by competitive relationships: spruce stands at the lower level have fairly high stocking density, and young tree generation grows mainly under the canopy of older trees.

Thus, the results of this study show that the dynamics of spruce tree growth by volume markedly differ depending on the time of tree establishment at the upper forest boundary.

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