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SHORT ARTICLE ON PRELIMINARY RESEARCH

Dendroclimatic study of Siberian juniper

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ABSTRACT

For the first time, Siberian juniper (*Juniperus sibirica* Burgsd.) has been dendroclimatologically analyzed. Siberian juniper is a small shrub growing in the larch-forest – tundra ecotone in Polar Urals. The 636-year juniper ring-width chronology presented here is based on samples prepared from living and dry branches. Here we prove that this chronology is suitable for dendroclimatic reconstructions. The juniper chronology contains a mean May, June and July temperature signal in contrast to June–July signal in spruce and larch ring-widths. Dendroclimatic reconstructions can be based on Siberian juniper chronology as well as on combined juniper and larch chronology.

Introduction

Dendroclimatic studies in subarctic regions revealed important space and time dependencies of radial growth of tree species as well as of climatic conditions (Jacoby and D'Arrigo, 1989; Schweingruber et al., 1993; Briffa et al., 1995, 1998; Vaganov et al., 1996). Widely distributed and climatological sensitive larches (*Larix sibirica*, *L. gmelinii*, *L. cajanderi*, *L. laricina*), spruces (*Picea obovata*, *P. abies*, *P. glauca*, *P. mariana*) and pines (*Pinus sylvestris*, *P. sibirica*) have been used in these studies. Usually, a pronounced signal of summer season temperature occurs in these chronologies. Ring-width chronologies of subarctic trees contain information about mean July or June–July temperatures while maximum density chronologies reflect a temperature signal for the noticeably longer period (May–September) (Briffa et al., 1995).

Future subarctic dendroclimatological studies should be based also on tree ring sequences from shrubs, e.g. various willows (*Salix* spp.), birch (*Betula nana* L.), juniper (*Juniperus* spp.), mountain-ash (*Sorbus sibirica* Hedl.), bird cherry tree (*Padus avium* Mill.), and alder (*Duschekia fruticosa* Rupr.). Climate reconstruction from tree rings of these shrubs could provide more details on inter-seasonal/intra-seasonal variability of summer temperature in the cold regions.

Here we examine the potential of Siberian juniper ring-width chronologies for climatic reconstructions. Siberian juniper (*Juniperus sibirica* Burgsd.) is a typical arctic-alpine shrub with a height of up to 1.0–1.5 m. This abundant species in Polar Urals grows under the canopy of spruce-larch light forests and in the tundra beyond the tree-line. This light-requiring species prefers warm and dry rocky, south exposed slopes covered by snow in winter. However juniper avoids areas with abundant snow, where the growing season is much shorter. In consequence of these needs Siberian juniper forms narrow (2–4 m wide) strips along the upper parts of leeward slopes where snow depth ranges between 0.5 and 2.0 m (Fig. 1).

An individual juniper bush usually consists of several branches and is morphologically variable. Since branches form adventive roots old individuals are cushion-like with a diameter of 2–3 m. The oldest living branches of Siberian juniper found by Stepan Shiyatov in Polar Urals are 840 years old (Shiyatov et al., 2002). Besides dead branches remain for long centuries. Kihlman (1890) found 800 years old Siberian juniper in Kola Peninsula. Kanngiesser (1909) informs about a 2000-year-old individual in Latvia and Ward (1982) found a 544-year-old one in northern Russia. The long living Siberian juniper is one of the most promising species for dendroclimatic studies in Siberia, Ural Mountains and northern Russia in Europe.

Materials and methods

In 1997–1998 we selected 26 isolated old junipers in the eastern part of Polar Urals along the open larch forest tree-line (Rai-Iz mountain range, mountain Chernaya, 200–280 m a.s.l.) within an area about 15 km^2 centered at 66°49′N 65°33′E. From each bush we selected the most developed branch, and cut cross-section from its lower part. In addition, we took several cross-sections from dead branches.

Prostrate and bended branches have asymmetric, strip barked stems. Radial growth occurs toward the upper side. The tree-ring widths were measured along its temporal maximum radius. Finally,

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Fig. 1. Siberian juniper bushes in the slopes of mountain Chernaya, Polar Urals.

Table 1
Statistics of shrub and trees ring-width chronologies from Polar Urals.

	Average ring width, mm	Mean correlation among indexed series (common interval)	Mean sensitivity	Standard deviation	Autocorrelation coefficients	
					1st order	2nd order
Juniperus sibirica	0.22	0.37 (1845–1996)	0.25	0.22	0.56	0.24
Picea obovata	0.34	0.49 (1771–1996)	0.32	0.28	0.46	0.22
Larix sibirica	0.50	0.66 (1723–1990)	0.43	0.35	0.38	0.22

23 samples from living branches, and one dry branch were used to develop the Siberian juniper chronology. Individuals have an age of 77–483 years.

Tree-ring width indices were calculated by the corridor method (Shiyatov, 1986; Cook et al., 1990).

We compared the results (row values and indices) with those based on Siberian spruce (*P. obovata*) and Siberian larch (*L. sibirica*) from the same area. 14 individual series from living spruces and 30 series from living and dead larches were used to develop ring-width chronologies for these species.

Average monthly temperature data of the Salekhard meteorological station (50 km east of the study region) have been used to correlate ring-width indices and monthly climate data for the period 1883–1995.

Response function analyses (Fritts, 1976) were carried out using the climate data and the ring-width chronologies of three species. Linear regressions have been used to reconstruct air temperatures on the basis of separate chronologies and multiple regressions also have been used in which both the juniper and larch chronologies are used as predictors of mean June–July temperature.

Results and discussion

The general characteristics of the used chronologies are shown in Table 1.

Siberian junipers growing near the open forest tree-line in Polar Urals have very narrow tree-rings. Despite of minimal radial growth rates, the absence of a tree-ring was registered only once. Tree-ring width sequences of old juniper branches show no age-related trend. In contrast those from comparatively young branches, normally, increase from the centre to periphery.

Cross-dating between individual juniper chronologies meets many more disturbances than in those of spruce and larch. The difficulties are caused by small radial increments, the asymmetry of stems and the lower sensitivity and correlation coefficients.

The developed general chronology is 636-year old and ranges from 1363 to 1998. The living branches were used for the reconstruction back to 1515. For the extension back to 1363 we used two radii from an individual who died in 1813.

The autocorrelation in the juniper chronology is higher than those in spruce and larch. Therefore all individual chronologies were 'prewhitened' to eliminate the effect of preceding years' growth on the current year growth.

The sensitivity coefficient and the standard deviation for juniper chronology are lower than those calculated from spruce or larch chronologies. Nevertheless it is greater than conventional threshold value (0.2 according Vaganov et al., 1996).

The correlations between the juniper and the larch and spruce chronologies are relatively weak (Table 2). That could indicate the presence of different climatic signals in juniper and trees.

Polar Urals' spruce and larch tree-ring chronologies contain a pronounced July temperature response while June temperature response is much weaker. Siberian juniper ring-width indices contain temperature information on summer months (June–July), and spring month (May) (Fig. 2). This result is unexpected. An explanation of the phenomenon does not exist since for the study area there are no data available about duration and intensity of the growing season for juniper as well as for spruce and larch. If juniper ring

Table 2
Coefficients of correlation and Gleichlaufigkeit between shrub and trees chronologies.

	Juniperus sibirica	*Larix sibirica*
Picea obovata	0.33/62%	0.58/74%
Larix sibirica	0.25/60%	

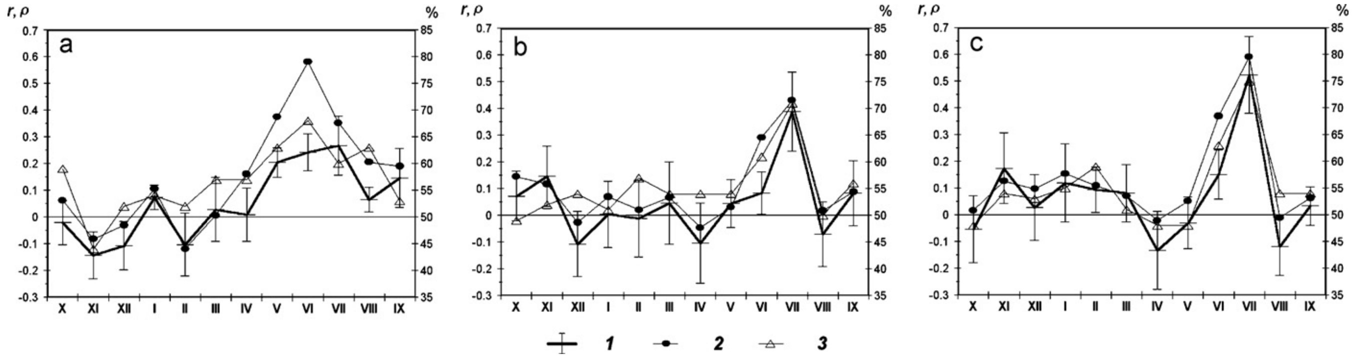

Fig. 2. Relationship between tree-ring width indices and mean temperature of selected months of the preceding (October–December) and the current (January–September) year of vegetation for Siberian juniper (a), Siberian spruce (b), and Siberian larch (c): 1 – regression coefficient (ρ) with confidence intervals, 2 – correlation coefficient (r), and 3 – Gleichlaufigkeit (%).

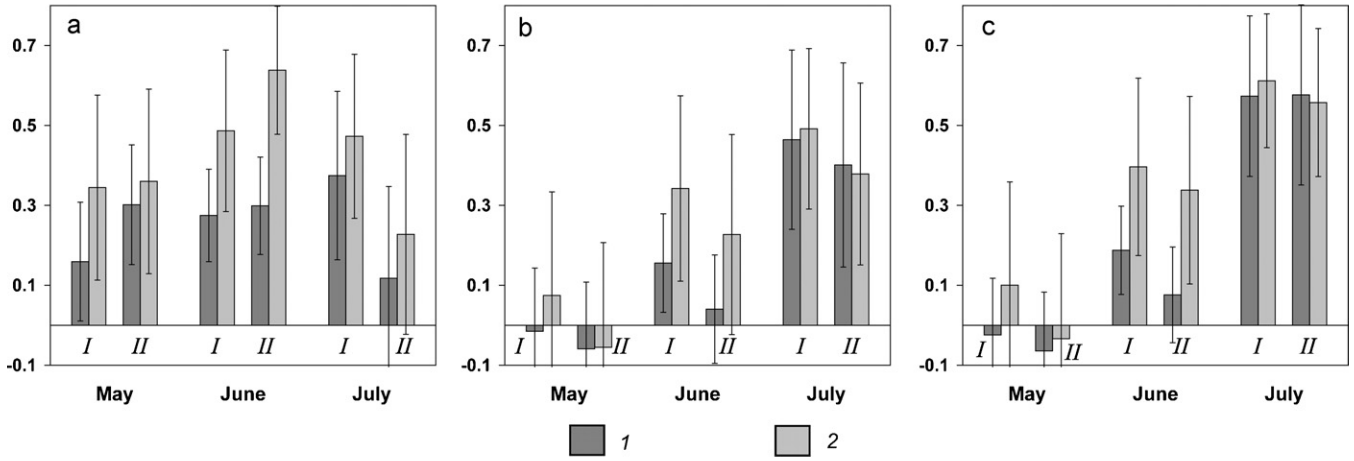

Fig. 3. Relationship between ring-width indices and May, June and July temperatures for a current year of vegetation for Siberian juniper (a), Siberian spruce (b), and Siberian larch (c); I – for 1883–1939, II – for 1940–1995: 1 – regression coefficient and 2 – correlation coefficient.

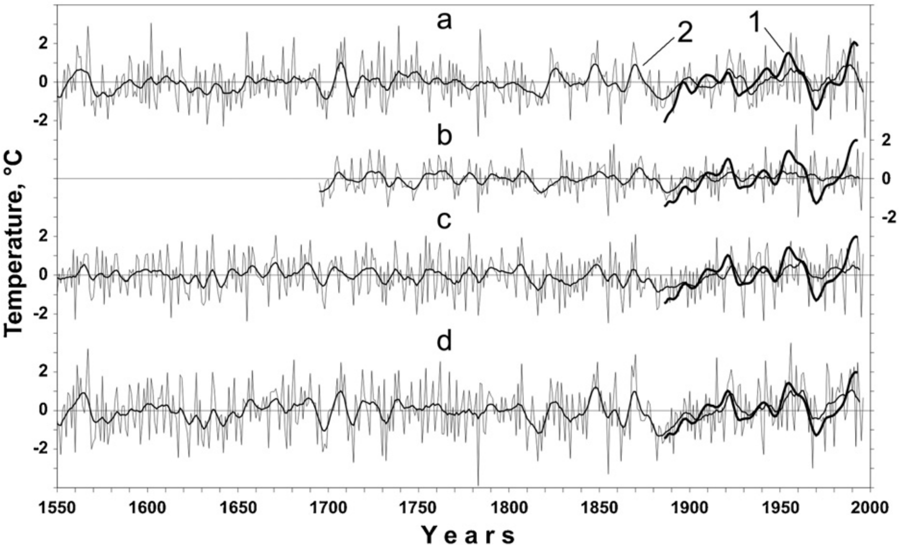

Fig. 4. Reconstruction of May–July temperature anomalies (a – from Siberian juniper data) and June–July temperature anomalies (b – from Siberian spruce data, c – from Siberian larch data, d – from combined Siberian juniper and Siberian larch data). 1 – smoothed actual air temperature curve by Salekhard weather station record and 2 – smoothed reconstructed air temperature curve.

width–mean May temperature relationship turns out to be reproducible and reliable, this open the possibility to reconstruct new climatic data.

To confirm the stability of this relationship we have calculated the regression coefficient as well as the correlation coefficient between juniper ring-width indices and the mean May, June, and

Table 3
Calibration and verification statistics.

Calibration period	1883–1939	1940–1995	1883–1995
Verification period	1940–1995	1883–1939	–
Juniperus (May–July)			
Calibration			
R^2	0.35	0.32	0.34
R^2_{adj}	0.34	0.31	0.34
Verification			
r^2	0.33	0.35	
Reduction of error	0.32	0.35	
Picea (June–July)			
Calibration			
R^2	0.22	0.12	0.16
R^2_{adj}	0.21	0.11	0.15
Verification			
r^2	0.12	0.22	
Reduction of error	0.03	0.18	
Larix (June–July)			
Calibration			
R^2	0.30	0.28	0.29
R^2_{adj}	0.29	0.26	0.28
Verification			
r^2	0.28	0.30	
Reduction of error	0.28	0.31	
Juniperus + Larix (June–July)			
Calibration			
R^2	0.59	0.49	0.52
R^2_{adj}	0.58	0.48	0.51
Verification			
r^2	0.49	0.58	
Reduction of error	0.32	0.53	

July temperatures for 1883–1939 (the first period) and 1940–1995 (the second period). It has been found that dependence of the juniper ring-width variability on the mean temperature of selected months is essentially different in these two periods (Fig. 3). In the period 1883–1939 ring width growth mainly depends on June and July temperature and in the period 1940–1995 mainly depends on May and June temperature. Influence of the June temperature on the cambial activity of spruce and larch has decreased for the last 55 years. The increasing influence of May temperature has been caused probably by humidity and air temperature anomalies which took place during the second period (Shiyatov and Mazepa, 1995): in the second period winter precipitation is one and a half times as much as the precipitation during the first period and the mean May air temperature has increased by 1.14 °C in the second period in comparison with the first period. The increase in mean June and July temperature was much less.

The reconstructed and actual air temperature curves are plotted as temperature anomalies from the mean for May–July for juniper (Fig. 4a) and for June–July for spruce (Fig. 4b) and larch (Fig. 4c). The relationships between shrub and trees growth and temperatures are shown in Table 3. It is evident that temperature reconstructions based on juniper and larch data are closer to the actual temperature curves than those based on spruce data.

Since juniper ring width depends essentially on the mean June temperature, while the larch ring-width depends mainly on the mean July temperature, it seemed reasonable to produce more reliable June–July temperature reconstruction by combining both data sets. Such a reconstruction has been produced on the base of estimation of parameters of multiple linear regression equation. The resulting reconstruction (Fig. 4d) matches better with the actual temperature curve than those based on single species (Table 3).

Conclusion

The *J. sibirica* growing at altitudinal treeline in the Polar Urals are temperature stressed and record the spring-early summer temperature in their ring-width variation. Correlation analysis for two periods 1883–1939 and 1940–1995 suggested a prevalent impact of June–July temperature on juniper growth during first period and May–June temperature in second. The composition of tree-ring variability from juniper and larch offers greater accuracy to reconstruct mean summer temperature.

A large amount of remains of junipers that died many hundreds of years ago can be found in the Polar Urals. This allows the construction of millennial length juniper chronology. Clearly, future work using tree rings of *J. sibirica* from upper and polar tree-line holds great promise.

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