ISSN 1995-4255, Contemporary Problems of Ecology, 2013, Vol. 6, No. 7, pp. 779–787. © Pleiades Publishing, Ltd., 2013.
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The Influence of the Lower Ob River Runoff on Radial Growth of Trees

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Received August 18, 2007

Abstract—The influence of the Ob River runoff in its lower reaches on the radial growth of main forest-forming tree species—the Siberian spruce (*Picea obovata* Ledeb.), Siberian stone pine (*Pinus sibirica* Du Tour.), and larch (*Larix sibirica* Ledeb.)—was studied in the north of Western Siberia in various test sites both at the riverside and at a distance of 3 to 80 km from the Ob River floodplain. Differences in responses of the radial growth to air temperature in October and repeated frost damage of tree annual rings are observed in the Siberian spruce and Siberian stone pine depending on the distance from the river. The correlations of the radial growth of trees and frost damage with the effect of the Ob River runoff are discussed.

Keywords: lower Ob, Siberian spruce, Siberian stone pine, larch, thermal effect of river runoff, radial growth of trees, frost damage

DOI: 10.1134/S1995425513070159

The influence of the air temperature during the summer season on the radial growth of trees is well known [24, 27]. The temperatures in June and July are especially important for the radial growth of trees in the subarctic region [2, 3]. The correlations between the radial growth and temperature have mainly been studied in the vast watershed areas distant from large rivers. However, the Ob River runoff has a significant effect on the climate of Western Siberia [1]. This suggests that the river runoff in an indirect manner also influences both the radial growth of trees and cell structure of annual rings.

The goal of this work was to study the correlations between the Ob River runoff, air temperature, and radial growth of trees, as well as the effect of temperature on frost damage in annual rings of trees growing both in the immediate vicinity of the river and at different distances from it.

MATERIALS AND METHODS

The wood cores sampled in the downstream of the Ob River in the Muzhi floodplain area [12] within the Yamal-Nenets Autonomous District were used in the work. The cores of living Siberian spruce (*Picea obovata* Ledeb.), Siberian stone pine (*Pinus sibirica* Du Tour.), and larch (*Larix sibirica* Ledeb.) trees were examined. The core samples were collected in test sites (TSs) both immediately adjacent to the river floodplain, reaching 50 km in its width in this region [9], and beyond the floodplain at distances of 3 to 80 km.

To clarify the specific features of tree growth depending on air temperature that are determined by the influence of river, the study involved seven TSs on both banks of the Ob River (Fig. 1). The TSs most distant from one another, TS 1 Parovat and TS 6 Lyaksym-pugor, are located along the right and left valley sides of the Ob River at a distance of 120 km. In the right bank part near Beregovoi landmark, core samples were taken from three tree species in two TSs—on the bank (TS 3) and at a distance of 3–5 km from it (TS 2). TS 4 Listvennichnyi point and TS 5 (southern shore of Voikarskii Sor Lake) are located on the left bank of the Ob River at the mouth of the Voikar River entering the Ob River; from May to September, the Voikar River runoff, dammed by the Ob waters, forms there a large lake with an area of up to 80 km^2. TS 4 is a sandy–pebbly cape, which protrudes into the lake from its northern shore as a narrow band for 500 m. TS 5 is located south of the point on the opposite side of the lake 4 km west of the Ob River floodplain. TS 7, located 80 km east of the Ob River in the Kunovat River basin, is the most distant site. The forest stands, TSs, and obtained tree-ring chronologies (TRCs) are characterized in Table 1.

The core samples were taken by borer at a height of about 1.3 m from the root collar (mainly, two samples from each individual tree). The samples were processed for further examination according to a conven-

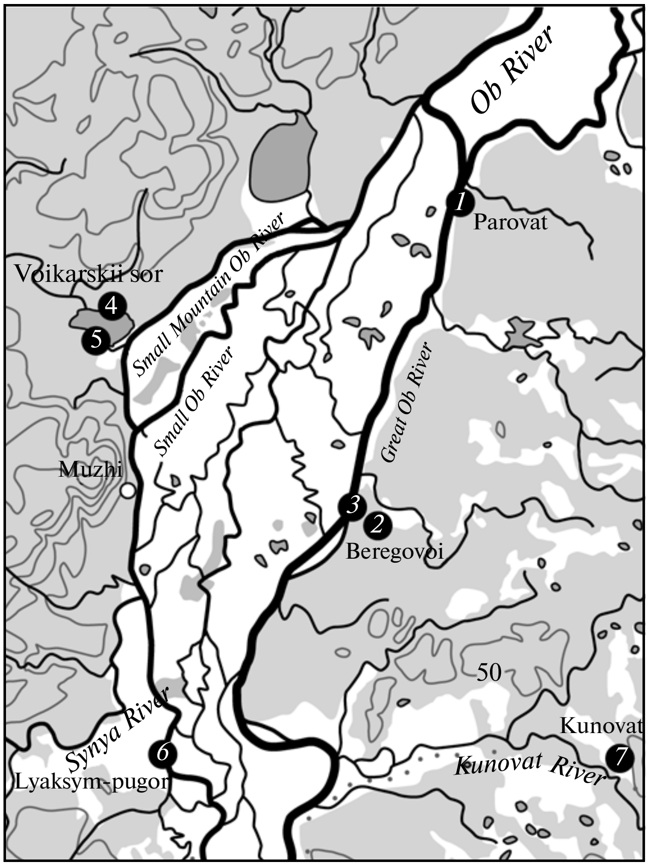

Fig. 1. Map of the examined area with test sites (*1*) Parovat (TS 1); (*2*) Beregovoi, 3 km from the river shore (TS 2); (*3*) Beregovoi, next to the river (TS 3); (*4*) Voikarskii Sor Lake, Listvennichnyi Point (TS 4); (*5*) Voikarskii Sor Lake, southern shore (TS 5); Lyaksym-pugor (TS 6); and (*7*) Kunovat (TS 7).

tional protocol [17]. The annual ring width was measured using a Lintab V measuring device. The resulting TRCs were cross-dated visually and with the help of TSAP [26] and COFECHA [26]. To eliminate the effect of tree age and other signals of nonclimate character on the radial growth dynamics, all chronologies were standardized using the ARSTAN program [25]. ARSTAN was also used to convert individual chronologies into generalized TRCs for growth indices. The residual generalized chronologies were used when analyzing the correlation of TRC with air temperature; these chronologies lack growth autocorrelation as compared with the standard chronology. The main statistical characteristics of generalized chronologies are listed in Table 2. The correlation between radial growth of trees and air temperature was analyzed using DENDROCLIM2002 [20].

Analysis of the correlation of tree growth with temperature took into account the average monthly air temperature for the period from August of the current year to September of the previous year over the period of 1883–1999 according to the data of the Salekhard meteorological station. This station is at a distance of 75 to 185 km from the examined TSs. Although there is a meteorological station in the region of the TSs (in the village of Muzhi, 150 km south of the Salekhard station), the series of its observations is 51 years shorter, while the temperatures at the sites of these meteorological stations change in a synchronous manner from May to October and have a small gradient. All this favored selecting the data of the Salekhard meteorological station.

RESULTS AND DISCUSSION

All the chronologies display high average correlation coefficients for individual series (0.60–0.70 for spruce, 0.60–0.69 for Siberian pine, and 0.67–0.78 for larch) and synchronization coefficients (0.82–0.92 for spruce, 0.83–0.92 for Siberian pine, and 0.85–0.94 for larch) and considerably differ in the sensitivity of individual tree species (Table 2). Larch is more sensitive (0.30–0.42) as compared with spruce (0.21–0.27) and Siberian pine (0.21–0.29). Presumably, the higher sensitivity of larch is explainable by its ability to annually shed its needles, while the needles of spruce and Siberian pine in the north can live for up to 7 years. The average signal-to-noise ratio in all chronologies amounts to 4–17; that is, the climate signal in the chronologies is fairly pronounced; note that the chronologies of all tree species for the TSs most distant from the river (TS 2 and TS 7) display higher signal-to-noise ratio values (Table 2).

Analysis of the correlations between tree growth and air temperature has shown that mainly the June temperatures of the current year influence in a statistically significant manner the growth of trees in the TSs remote from the river bank, TS 2 and TS 7 (Fig. 2); as for the riverside TSs, this factor is the temperatures of June–July (Fig. 3). In addition, a specific feature in the response of chronologies for the riverside TSs as compared with the TSs distant from the river was found. This distinction is the response of radial growth to the October temperatures of the previous year. The spruce, Siberian pine, and larch chronologies from TS 2 and TS 7 do not display any response to the October temperature of the previous year (Fig. 2), whereas the tree species chronologies from TSs 1 and 3–6 display a statistically significant correlation between the radial growth and this factor (Fig. 3). The only exception was an LVS chronology for the larch from TS 5, located 4 km from the Ob River main bed.

In order to explain the observed correlation of the radial growth of spruce, Siberian pine, and larch with the air temperature in October of the previous year, it is necessary to consider the specific features in the

Table 1. Characteristics of test sites and tree-ring chronologies (TRCs)

TRC code	Species	Coordinates: latitude and longitude	Length of series, years	Number of trees	Moistening conditions	Height of tree stand, m	Diameter, cm	Stand density
TS 1, Parovat (right bank)								
LPT	L	68°58′ N, 65°56′ E	1557–1999, 443	27	Fresh	15	42	0.6
TS 2, Beregovoi (right bank), 3 km from the Ob River								
EBD	S	65°15′ N, 65°29′ E	1814–1997, 184	22	Fresh	15	40	0.5
KBD	SP		1706–1997, 292	22	″			
LBD	L		1695–1997, 305	24	″			
TS 3, Beregovoi (right bank)								
EBE	S	65°15′ N, 65°25′ E	1879–1997, 119	20	Fresh	15	40	0.6
KBE	SP		1866–1997, 132	17	″			
LBR	L		1861–1997, 137	19	″			
TP 4, Voikarskii Sor, Listvennichnyi point (left bank of the Ob River)								
ELM	S	65°41′ N, 64°36′ E	1717–1996, 280	18	Fresh	17	46	0.7
LMY	L		1538–1999, 462	32	″			
TP 5, Voikarskii Sor, southern shore (left bank of the Ob River)								
KVR	SP	65°39′ N, 64°57′ E	1670–1996, 327	30	Humid	14	40	0.3
LVS	L		1732–1999, 268	14	″			
TS 6, Lyaksym-pugor (left bank of the Ob River)								
KLY	SP	64°55′ N, 64°57′ E	1670–1996, 327	34	Fresh	15	38	0.4
ELP	S		1713–1996, 284	28	″			
TS 7, Kunovat (80 km from the Ob River)								
EKU	S	64°55′ N, 66°56′ E	1764–2002, 239	11	Fresh	15	38	0.5
KKD	SP		1739–2002, 264	11	″			
LKU	L		1618–2002, 385	16	″			

L, larch; S, spruce; SP, Siberian pine.

influence of the Ob River runoff on its floodplain temperature regime.

As is known, large aquatic objects influence the meteorological regime and local climate elements over the floodplain and adjacent areas [4, 8]. To clarify this influence for the Ob River floodplain, the average monthly air and water temperatures in two floodplain areas of the Lower Ob River—Muzhi and Salekhard—were compared (Table 3). For this purpose, we used the observation data of two meteorological and hydrological stations (Muzhi and Salekhard), located immediately adjacent to the river, which was important for comparing the data and characteristics of the climate regime.

Indeed, as is evident from Table 3, the average water temperature is always higher by 1.3–2.9°C than the air temperature even in the warmest month of the year, July. Note here that the maximum difference between the air and water temperatures in the Muzhi floodplain area is observed precisely in October and reaches 6°C (in individual years, reaching even 12°C in the first half of the month). This is because the Ob River during October still remains unfrozen: the long-term average date of freezing there is November 2 [5; our own calculations].

The Muzhi floodplain area is rather vast, amounting to an area of 4800 km^2, with a total water accumulation reaching 18.3 km^3 [9] in the presence of a high

Table 2. Statistical characteristics of generalized chronologies for radial growth indices of trees

TRC code	Annual ring width (mm) and standard deviation	Average correlation coefficient of individual series	Average synchronization coefficient	Sensitivity coefficient	Signal-to-noise ratio	First-order autocorrelation coefficient
TS 1						
LPT	0.69 ± 0.40	0.71	0.90	0.32	9	0.03
TS 2						
EBD	0.57 ± 0.43	0.68	0.92	0.25	12	–0.14
KBD	0.46 ± 0.37	0.69	0.92	0.27	11	–0.06
LBD	0.36 ± 0.37	0.73	0.90	0.41	9	0.02
TS 3						
EBE	0.94 ± 0.44	0.65	0.82	0.22	4	–0.06
KBE	1.32 ± 0.46	0.60	0.83	0.21	5	–0.10
LBR	0.99 ± 0.47	0.70	0.89	0.29	8	–0.04
TS 4						
ELM	0.69 ± 0.41	0.70	0.92	0.27	12	–0.02
LMY	0.39 ± 0.39	0.67	0.85	0.42	5	0.02
TS 5						
KVR	0.41 ± 0.38	0.64	0.87	0.28	7	–0.01
LVS	0.60 ± 0.37	0.69	0.87	0.33	7	–0.06
TS 6						
ELP	0.58 ± 0.43	0.60	0.87	0.25	7	–0.04
KLY	0.36 ± 0.38	0.60	0.90	0.29	9	–0.01
TS 7						
EKU	0.75 ± 0.41	0.67	0.89	0.21	9	–0.14
KKD	0.64 ± 0.39	0.67	0.90	0.22	9	–0.83
LKU	0.49 ± 0.40	0.78	0.94	0.30	17	–0.38

heat capacity of water as a physical body. Analysis of the correlation between the Ob River water content over May–October and the air temperature gives statistically significant positive values for May and October and negative values for both June–July and the overall period of open water (Table 4). The negative correlations suggest a cooling effect of the water in June–July (the higher the runoff, the lower the air temperature) and the positive correlations indicate a heating effect (the higher the runoff, the higher the air temperature in May and October). The most pronounced warming effect on air temperature is observed in May, when the floodplain is filled with the warmer waters coming from the southern part of basin. In October, the Ob River runoff again heats the air against the background of a seasonal decrease in air temperature, since water as a heated physical body radiates heat into the atmosphere, thereby smoothing seasonal air cooling.

Presumably, this particular warming effect of the Ob River water in October is reflected in the next-year response of radial growth of the spruce, Siberian pine, and larch trees growing in immediate vicinity of the river. The mechanism underlying the warming effect may be reduced to two major physiological processes. First, the physiological events in coniferous trees during September–October are directed toward preparing for the winter dormancy period, and the more favorable the environmental conditions during this time, the better a tree is prepared for overwintering. In particular, it is known that the ultrastructural changes in the pine needle mesophyll cells, containing the

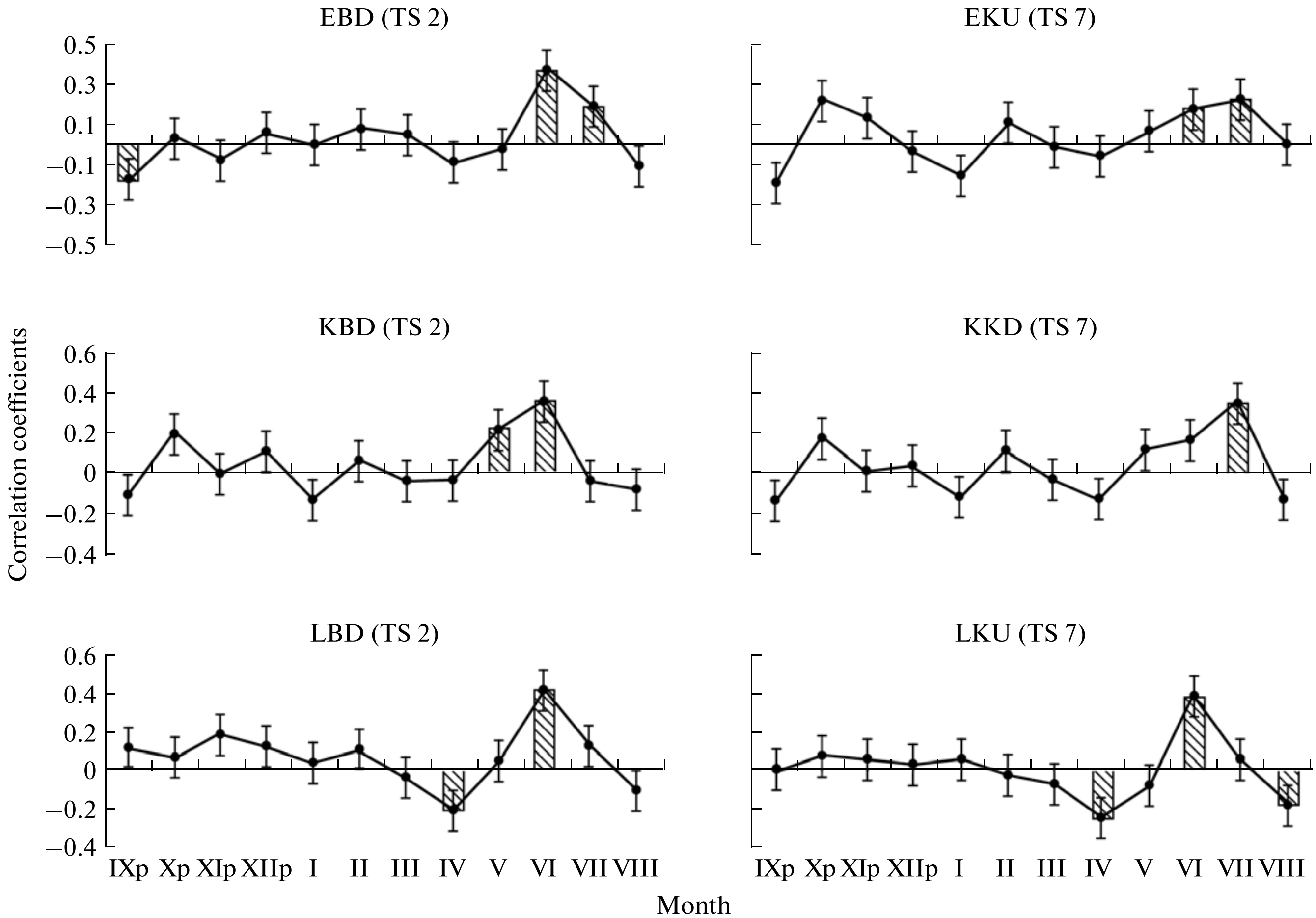

Fig. 2. Climate response functions for air temperature and confidence intervals for the generalized index TRCs for the test sites distant from the river (left, TS 2; right, TS 7) for the spruce, Siberian pine, and larch. Columns denote statistically significant correlation coefficients. See Table 1 for letter codes of chronologies.

maximal number of plastids, start in August and appear in full in September–October [15].

Second, it is known that the photosynthesis in coniferous trees (pine, spruce, and larch) during the fall season may be rather active and depends on the air and soil temperatures as well as the available soil moisture [14, 18]. Note that the photosynthetic productivity in the fall (from September 1 to the end of October–first ten days of November) may reach 14% of the annual productivity for the pine, 20% for the spruce, and 14% for the larch [13], while photosynthesis may continue even at temperatures significantly below freezing, down to –7°C [10], although assimilates are not transported in this case but rather deposited in the needles of shoots [15].

In addition to the pigments contained in needles, a considerable amount of pigments is present in the bark of shoots (especially young ones), trunk, wood, and buds, and all of them are also able to photosynthesize. It is also known that the chlorophyll concentration in the bark of shoots increases by the end of vegetation [16]. Presumably, these facts explain the specific response of the radial growth of the current year in the larch trees growing near the riverbank to the October air temperature of the previous year, since the larch needles in the north become yellow and are shed by mid-October.

Most likely, a high intensity of photosynthesis in the fall and accumulation of assimilates enhance "an easy start" of the tree-ring growth in the next year. In October, the air and soil temperature regimes in the riverine area are more favorable for photosynthetic activity of the trees as compared with the sites at a distance of several kilometers from the river, where the warming effect of the Ob River runoff is either insignificant or absent. Correspondingly, the trees from distant sites (TS 2 and TS 7) display no statistically significant response to the October temperature in the previous year.

Unfortunately, the authors have no ecophysiological data on photosynthesis dynamics under such conditions, and only field experiments can finally confirm

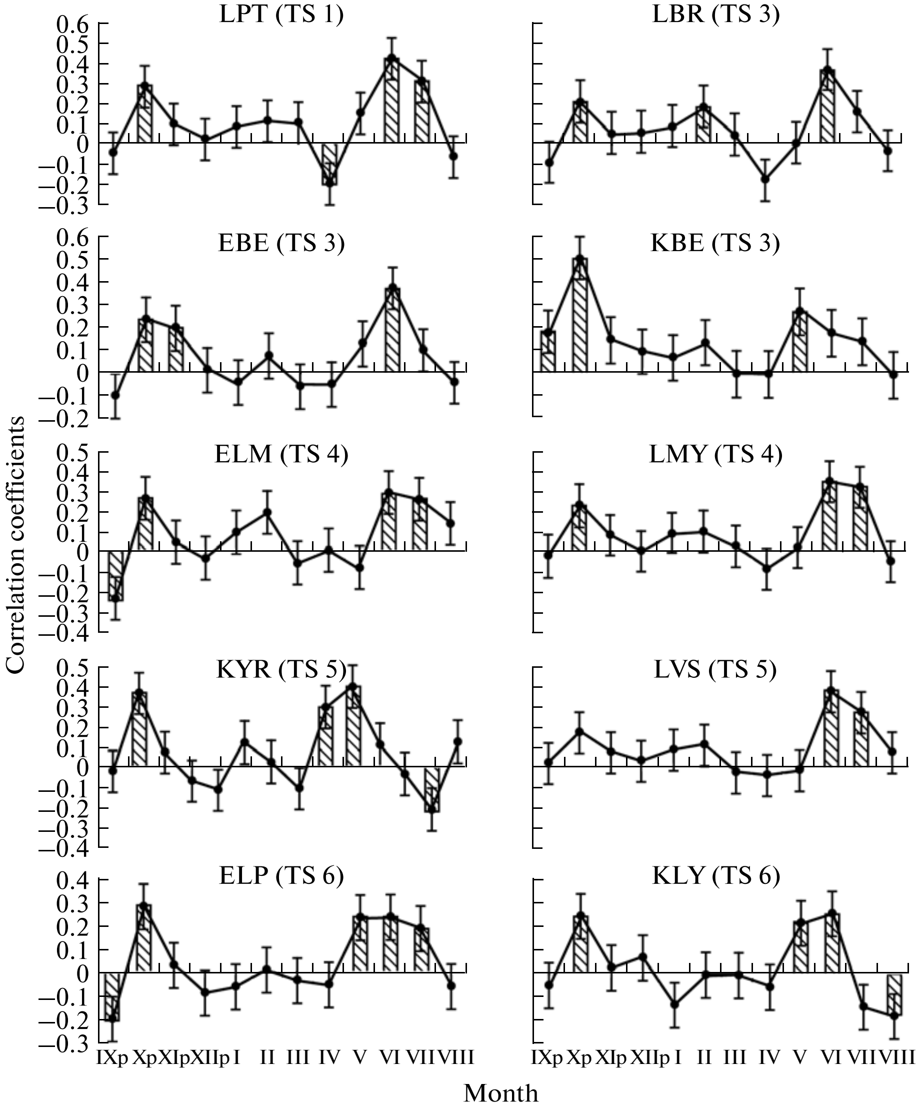

Fig. 3. Climate response functions for air temperature and confidence intervals for the generalized index TRCs for the riverine test sites TSs 1 and 3–6 (test sites numbers are parenthesized) for the spruce, Siberian pine, and larch. Columns denote statistically significant correlation coefficients. See Table 1 for letter codes of chronologies.

a positive warming effect of the Ob River runoff on a higher physiological/photosynthetic activity of the trees growing near the river as compared to those at distant sites.

Another fact demonstrating the effect of the Ob River runoff on climatic conditions and radial growth of trees may be frost rings. To find out the frost damage of annual rings, all the core samples from TSs 2 and 3 were carefully examined.

Frost rings are induced in the wood of coniferous trees by frost during the growing season, more frequently and strongly affecting young trees. The position of frost damage within an annual ring depends on the time of frost [6].

The two closest TSs, TS 2 and TS 3, were compared. Frost damage was observed in Siberian pine and spruce trees in both TSs, the damage being more frequent in the Siberian pine as compared with the spruce. No frost damage was observed in the larch core samples. Cross-dating allowed for determining the years when frost damage was formed in the annual rings (Table 5).

The frost rings of 1920 are common for all chronologies; therefore, the damage of this year was analyzed in more detail. In all specimens with damaged annual ring cells, these cells were localized to the very beginning of the growth layer (Fig. 4). The position at the beginning of the annual ring suggests that the frost attack in the year in question was at the very beginning

Table 3. Average values of air temperature, Ob River water temperature, and correlation coefficients *r* between these temperatures according to the data of the Muzhi and Salekhard meteorological and hydrological stations over the period of 1937–1987

Temperature, °C	Month						
	V	VI	VII	VIII	IX	X	V–X
Muzhi (65°23′ N, 64°43′ E)							
Water	3.8	11.1	17.8	16.1	10.4	2.9	10.4
Air	0.6	9.6	14.9	11.9	5.8	–3.1	6.6
Difference	3.2	1.5	2.9	4.2	4.6	6.0	3.8
r	0.78*	0.87*	0.81*	0.75*	0.77*	0.40*	0.82*
Salekhard (66°31′ N, 66°36′ E)							
Water	0.5	8.8	15.3	14.6	8.3	1.5	8.2
Air	–1.4	8.2	14.0	11.3	5.3	–4.1	5.6
Difference	0.9	0.6	1.3	3.3	3.0	2.6	2.6
r	0.61*	0.72*	0.80*	0.74*	0.65*	0.59*	0.83*

* The differences are statistically significant at $p < 0.05$.

of vegetation immediately after the spring reactivation of cambial cells.

Development of frost damages depend also on the tree age. In TS 2, by the year 1920, the maximum age of Siberian pine trees was 180 years and of spruce trees was 67 years. The maximum age of the sampled Siberian pine trees from TS 3 was 43 years and of spruce trees was 44 years; that is, the damaged trees were considerably younger.

In order to find the TS with strongest frosts and, correspondingly, the most pronounced frost damages in trees, it is necessary to calculate the rate of damaged trees. As is known, frost damage ceases developing after a tree has reached a certain age and morphometric characteristics. The method used for selecting the models for calculating the rate of frost damage in annual rings in forest stands varying in age in a particular year when the frosts took place was described earlier [7].

(a) (b)

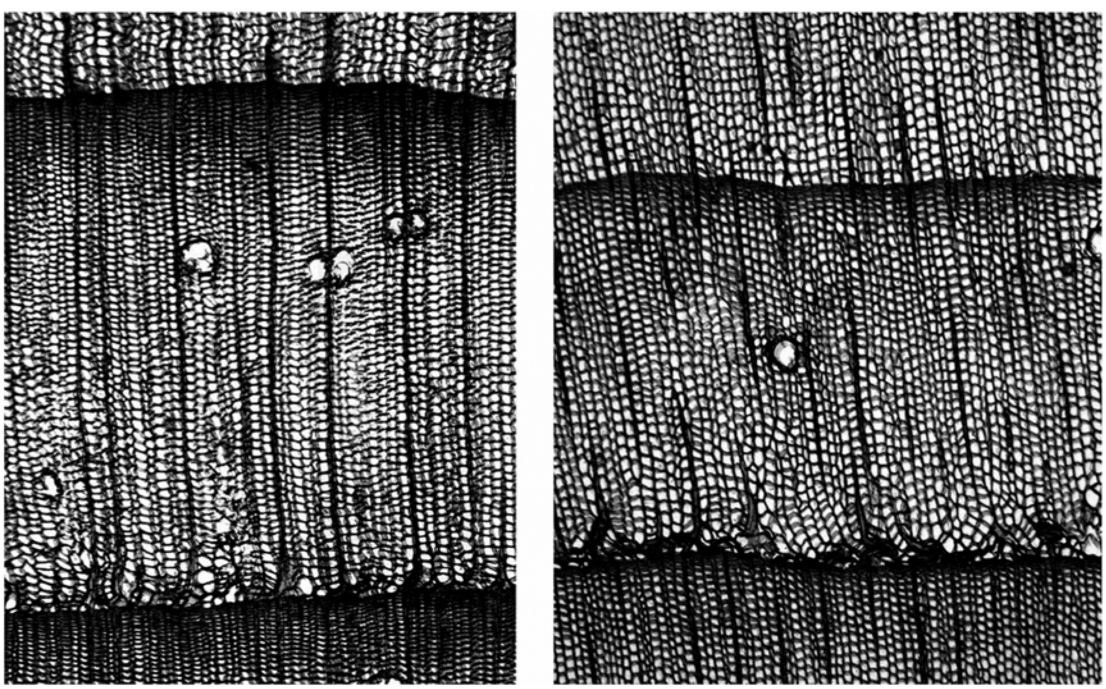

Fig. 4. Frost damage of 1920 in (a) spruce and (b) Siberian pine (magnification, ×50).

Table 4. Correlation coefficients *r* between the air temperature and Ob River water content in the Muzhi and Salekhard floodplain areas over the period of 1934–1996

Month						
V	VI	VII	VIII	IX	X	V–X
Muzhi						
0.61*	–0.33*	–0.12	–0.21	0.02	0.35*	–0.46*
Salekhard						
0.45*	–0.28*	–0.25*	–0.16	0.07	0.34*	–0.44*

* The differences are statistically significant at $p < 0.05$.

Table 5. Frost damages in all models of Siberian pine and spruce trees in test sites TS 2 and TS 3 (see Table 1 for codes of chronologies)

Year	TS 2		TS 3	
	KBE	EBE	KBD	EBD
1708			+	
1722			+	
1729			+	
1734			+	
1735			+	
1738			+	
1741			+	
1748			+	
1768			+	
1773			+	
1779			+	
1780			+	
1803			+	
1859				+
1863				+
1868	+			
1876				+
1894			+	
1898				+
1901	+			+
1907			+	
1910	+			+
1912	+			+
1917			+	
1920	+	+	+	+
1927	+	+		
1969	+			

According to this method, the model trees that in 1920 were younger than the maximum age of the damaged trees (determined for each tree species in each TS) were used for comparing the number of trees with frost damage. Thus, four Siberian pine trees with an age below 180 years by 1920 and seven spruce trees with an age below 67 years were selected in TS 2. In 1920, frost damage was detected in three and seven trees, respectively. Correspondingly, 75% of the Siberian pine and 100% of the spruce growing in TS 2 were damaged in 1920. In TS 3, seven Siberian pine trees and five spruce trees were selected as models meeting the aforementioned condition. The number of trees damaged in 1920 was smaller, namely, four Siberian pine and three spruce trees, or 57 and 60%, respectively.

Numerous literature sources suggest 30–40 years as an approximate tree age when damage ceases forming [7, 11, 19, 21–23]. It is most likely that a considerable increase in the age when trees remain sensitive to the effect of low temperatures in TS 2 results from more frequent and stronger frost attacks as compared with TS 3. The frost damage of annual rings indicates the differences in microclimate between TS 2 and TS 3 not only in the fall season but also during the first half of the growing season. The frost attacks near the river are less frequent and milder as compared with the habitats remote from the river owing to the effect of river runoff, which decreases the daily range of air temperature. The temperature falls to critical values (when cell structure is damaged by frost) during annual ring formation are considerably fewer in the former case. We believe that an increase in the rate and strength of frost damage with the distance from the river is associated with a decrease in the heating effect of the Ob River runoff on air temperature.

CONCLUSIONS

Our results demonstrate that the runoff of the lower Ob forms a specific air temperature regime during the period from May through October, thereby influencing the radial growth and cell structure of tree rings in the main forest-forming tree species—spruce, Siberian pine, and larch. The observed statistically significant correlations of the spruce and Siberian pine growth with the October temperature in the previous year suggest the feasibility of reconstructing the temperatures of past centuries. This expands the potential of tree-ring chronologies, earlier used for reconstructing only the June and July temperatures. Reconstruction of the air temperature in October can enlarge our understanding of the hydrological and climatic processes in the past as well as tree growth conditions in the valleys and floodplains of large rivers.

ACKNOWLEDGMENTS

The authors are grateful to S.G. Shiyatov, V.S. Mazepa, and R.M. Khantemirov for their helpful criticism, as well as the crew of the motor boat *Zoolog* and Ecological Research Station of the Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences (Labytnangi, Yamal-Nenets Autonomous District), for assistance in field work.

This work was supported by the Russian Foundation for Basic Research (grants nos. 13-04-01964 and 08-04-00964).

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Translated by G. Chirikova