Climatic effect on the accretion of Siberian stone pine (*Pinus sibirica*) at the south of Tomsk Region

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On the basis of data on the tree rings of Siberian stone pine growing near villages at the south of the Tomsk Region, and the temperature and precipitation for the warm period, a 3D model is constructed, which relates the tree growth to the temperature and precipitation. A limiting role of precipitations in the formation of tree rings is demonstrated. A synchronism is revealed in the radial accretions in different forests.

Introduction

The available experimental data indicate that the dependence of the plant state on the main climatic parameters usually obeys the Shelford's law: every characteristic has an optimum, deviations from which toward any side worsen the state of a living organism. Very often the measure of fitness of a population or species of plants (at least, in the first approximation) has normal distribution relative to the point of the ecological optimum along the coordinate of the gradient of each characteristic.[1]

The environmental factors, affecting the growth and development of trees, include the illumination, temperature, precipitation, soil humidity, organic substances, seed years, insects, animals, forest fires, and others. The limiting factor, which is at the maximum or minimum and therefore exerts the strongest influence on the growth and development of plants, always plays the leading role. In this way the modernized Libikh's principle realizes: the quality of an ecological niche is controlled to the largest extent by the environmental characteristic, which most strongly deviates from its ecological optimum, accepted as a norm for this type of plants. Thus, the fluctuations of the air and soil temperature affect the tree growth, changing the intensity of the photosynthesis, respiration, division, and growth of cells. Usually, the growth increases, as the temperature increases up to a critical value for a plant, and then rapidly decreases.[2]

Most of the investigators consider that the Siberian stone pine has wide amplitude of fitness to the environmental conditions. This means that this species is very flexible and can occupy a rather wide ecological niche. Thus, the Siberian stone pine is not demanding to heat and duration of the vegetation period. It is considered as a frost-resistant continental wood species. This tree grows on different soils, withstands both the excess and deficit of moisture in the soil, but prefers regions with sufficient moisture.

The aim of this study was to reveal the dependence of the wood accretion in the Siberian stone pine on the place of its growth, as well as the influence of the heat and moisture on the tree ring width.

Characterization of the initial material

To study the spatiotemporal structure of the tree rings, we used the information about the tree ring width of the Siberian stone pine at six sites near Tomsk. We have sampled cores of 15 to 20 model trees in the Ipatovo pine forest, giving the information about the tree ring width in the period from 1919 to 1986, the forest near Yarskoe village for the period from 1893 to 1985, Koninino for the period from 1893 to 1983, Konevo for the period from 1893 to 1986, Petukhovo from 1896 to 1986, and Plotnikovo from 1902 to 1986. In addition, we used, in our analysis, the series of monthly mean air temperature and precipitation in Tomsk for the periods equal to the periods of accretion of the model pine trees. Since the forests considered lie within 40 km from the city of Tomsk, the meteorological station of Tomsk can be considered as representative for this study.

Spatiotemporal structure of tree rings of Siberian stone pine

Since the series of variability of the absolute tree ring width carry various signals (age-related changes, influence of the soil conditions, competitive relations, impact of different catastrophic factors, etc), the dendroclimatology includes specialized techniques, which allow the influence of non-climatic factors to be excluded or, at least, strongly decreased due to indexing. In this case, the absolute accretions are

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converted to the relative ones.[3] In our study, we used the series of the tree ring widths, representing the accretion of the pine wood, smoothed using the Shpalte's technique by the method of constant sums of smoothing segments.[4]

To estimate the influence of changes in the temperature and precipitation on the growth of the Siberian stone pine, we took the sums of precipitation and temperature for the station Tomsk in the warm period (May–September), which fully includes the vegetation period. For each site, we have calculated the average index of accretion of the Siberian stone pine. The next stage of the study was the determination of the correlation between the temperature and precipitation sums and the wood accretion index based on the initial data and the data, subjected sequentially to the 3, 5, 7, and 9-year moving smoothing. In addition, the temperature and precipitation series were reduced to the same range, that is, standardized:

$$X_{st} = \left(X_f - \bar{X}_f\right)/\delta, \qquad (1)$$

where X_f is the actual value, X_{st} is the standardized value; δ is the rms deviation; $\bar{X}_f$ is the average sum of temperature or precipitation.

To pass from the standardized precipitation and temperature sums to the actual one, the following equation should be used

$$X_f = X_{st}\delta + \bar{X}_f. \qquad (2)$$

The calculated average values and rms deviations of the temperature and precipitation sums, smoothed by the nine-year sliding averaging, are summarized in Table 1. It follows from the table that the average values and the rms deviations of the temperature and precipitation are nearly independent of the period.

Table 1. Average values and rms deviations of the sums of temperature *T* (°C) and precipitation *Q* (mm) for the warm period (May–September)

Site	Sum	Period, years	Average (*X*)	rms dev.
Ipatovo	*T*	1919–1986	67.2	4.2
	Q		293.7	60.2
Yarskoe	*T*	1893–1985	67.2	4.2
	Q		295.5	63.6
Koninino	*T*	1893–1983	67.2	4.2
	Q		294.9	64.0
Konevo	*T*	1893–1986	67.1	4.2
	Q		295.3	63.2
Petukhovo	*T*	1896–1986	67.1	4.3
	Q		293.6	63.4
Plotnikovo	*T*	1902–1986	67.0	4.2
	Q		295.7	62.4

The average values of the temperature and precipitation sums for the vegetative period for different sites are nearly identical and equal to 67–67.2°C and 293.7–295.7 mm. The rms deviations for the temperature and precipitation are 4.2–4.30°C and 60.2–64.0 mm, respectively.

In addition, it follows from the analysis of Table 2 that as the smoothing period increases, all the sites are characterized by the 1.5 to 2 times increase of the correlation coefficient between the wood accretion index and the total amount of precipitation. A weak or no correlation with the temperature sum was found. The results obtained indicate the limiting role of precipitation in the wood accretion.

Table 2. Correlation coefficients between the meteorological indices and the ring accretion indices of Siberian stone pine for the studied sites as functions of the period of averaging

Index	Period, years	Ipatovo	Yarskoe	Koninino	Konevo	Petukhovo	Plotnikovo
Q, mm	1	0.46	0.38	0.25	0.36	0.40	0.41
	3	0.62	0.57	0.33	0.48	0.57	0.51
	5	0.68	0.69	0.37	0.55	0.65	0.56
	7	0.73	0.79	0.44	0.65	0.71	0.64
	9	0.75	0.84	0.46	0.74	0.74	0.67
T, °C	1	–0.10	–0.02	0.0	0.08	–0.07	0.05
	3	–0.17	–0.05	–0.06	0.11	–0.02	0.02
	5	–0.24	–0.10	–0.07	0.13	–0.04	0.0
	7	–0.27	–0.16	–0.09	0.14	–0.05	–0.04
	9	–0.28	–0.25	–0.20	0.15	–0.09	–0.07

For the more illustrative interpretation of the dependence of the accretion index on the temperature and precipitation sums, we have drawn the empirical and smoothed (by polynomial (2)) dependences of the wood accretion on the "temperature–precipitation" system:

$$P = a_0 + a_1 t + a_2 q + a_3 t^2 + a_4 q^2 +$$
$$+ a_5 tq + a_6 t^3 + a_7 q^3 + a_8 t^2 q + a_9 tq^2,$$

where $a_0 \ldots a_9$ are the coefficients of the regression; t are standardized temperature sums; q are standardized precipitation sums for May–September.

The characteristics of the approximation are given in Table 3.

The analysis of Table 3 shows that the correlation coefficient between the actual and model values is high and equals to 0.77–0.89 for five sites. The only exception is Koninino, where the correlation coefficient amounts to 0.49, which is explained by either improper selection of model trees or local features. Having in mind the value of the explained variance, we can state that the wood accretion of the Siberian stone pine is determined, to a sufficient extent (60–80%), by the meteorological factors: heat and moisture, but mostly by moisture. This conclusion is interesting, especially, under the conditions of warming. Under these conditions, not only the temperature, but also the precipitation conditions change.

As an example, Figs. 1 and 2 show the dependence of the accretion index on the temperature and precipitation sums for Yarskoe. The standardized temperature sums t and precipitation sums, smoothed by the nine-year averaging, are plotted along the axes X and Y, respectively.

Table 3. Characteristics of the approximated dependence of the accretion index of the Siberian stone pine on the temperature and precipitation amount in forests of Siberian stone pine near city of Tomsk

Index	Site					
	Ipatovo	Yarskoe	Koninino	Konevo	Petukhovo	Plotnikovo
Number of points	68	93	91	91	91	85
Average of the initial series	97.91	97.68	98.62	101.55	97.93	96.85
Average of the model	97.91	97.68	98.62	101.55	97.93	96.85
Variance of the initial series	290.61	136.92	165.24	139.06	227.13	121.43
Variance of the model	176.43	108.98	40.06	108.61	178.68	72.77
Variance of noise	114.18	27.94	125.17	30.45	48.46	48.66
Correlation coefficient between actual and model values	0.78	0.89	0.49	0.88	0.89	0.77
Fraction of explained variance	60.71	79.59	24.24	78.10	78.67	59.93
Fisher criterion	2.13	4.32	1.16	4.02	4.12	2.17

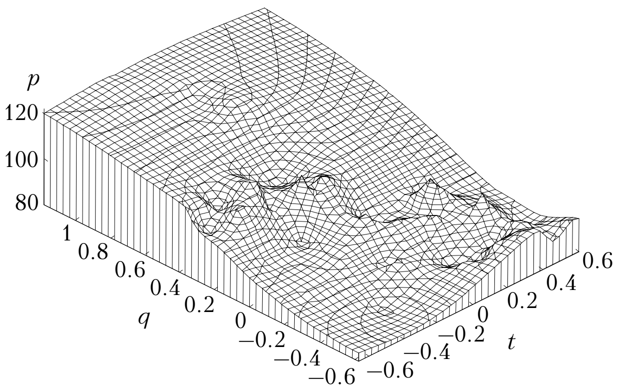

Fig. 1. Accretion of *Pinus sibirica* as a function of the temperature and precipitation sums for the warm period in Yarskoe.

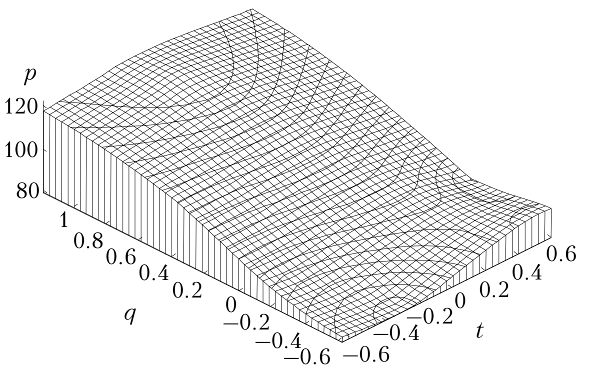

Fig. 2. Polynomial-smoothed dependence of the *Pinus sibirica* accretion index on the temperature and precipitation sums for the warm period in Yarskoe.

Figure 1 shows the actual accretion as a function of the temperature and precipitation sums. The isolines of the accretion index are drawn with the interval of two. The analysis of Fig. 1 suggests that the temperature still influences the radial accretion, which was not revealed earlier with the use of the pair linear correlation. Figure 2 shows the dependence of the accretion index on the “temperature–precipitation” system, smoothed by the polynomial. The high values of the accretion index are observed at the large precipitation amount (360–370 mm) in the whole range of the temperature sum (65–69.7°C). The maximum accretion corresponds to the medium temperature sums (in Fig. 2, to the standardized value of 0.0). At the small precipitation sums, the accretion is low; some increase is observed at the temperature sums higher than 67°C. For other sites, the maximum values of the accretion index (110–120%) are observed at the temperature and precipitation sums in the range of 65–70°C and 350–370 mm, respectively.

For the villages Ipatovo and Koninino, the maximum accretion index is observed at the medium temperatures and maximum precipitation sums, while the minimum accretion is observed at high temperature and low precipitation sums. For the villages Konevo and Petukhovo, the high values of the accretion index correspond to the maximum temperature sums, while the low values correspond to the minimum temperature. In Plotnikovo, at the minimum temperature sum both the increased and decreased accretion indices are observed at the maximum and minimum precipitation sums, respectively.

To reveal the spatiotemporal generality in the accretion indices at the six sites studied, we used the principal-factor method. The study has shown that the correlation between the accretion indices for individual sites and the typical index is high with the correlation coefficient $R = 0.71–0.88$, which is indicative of the high synchronism in the change of the tree ring width regardless of the smoothing period. The application of this method has allowed us to generalize the six series of the accretion index into one (typical) series.

Table 4 and Fig. 3 presents the results of the resolution of the time series of the accretion index into the orthogonal components, the average values of the accretion index, eigenvectors, and correlation coefficients R between the typical accretion indices and actual ones, as well as the time behavior of the index component. These data allow one to calculate the actual values of the accretion indices for each site.

Table 4. Characteristics of the typical accretion for the pine forests under study

Site	Average accretion, %	Eigenvector	R
Ipatovo	98.401	0.470	0.879
Yarskoe	97.877	0.367	0.879
Konevo	98.143	0.331	0.707
Koninino	100.94	0.407	0.871
Petukhovo	98.428	0.470	0.884
Plotnikovo	95.892	0.385	0.866

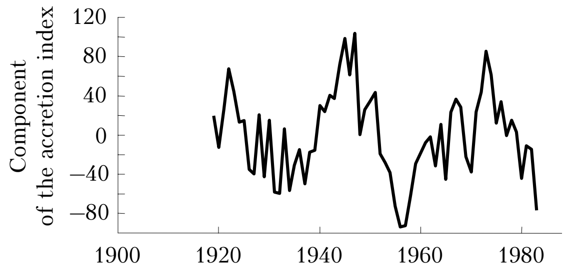

Fig. 3. Time behavior of the component of the accretion index.

Conclusions

Our study of the correlation between the accretion of the Siberian stone pine and the temperature and precipitation sums for the warm period, as well as the synchronism of the accretion at different sites, has revealed that:

– as the smoothing period increases from three to nine years, the correlation coefficient between the accretion index and the total precipitation amount increase from 0.33–0.62 to 0.46–0.84;

– the pair linear correlation between the accretion indices and the temperature sums is virtually absent for both the initial and smoothed series;

– the 3D graphical representation of the accretion of the Siberian stone pine in the temperature–precipitation coordinates has demonstrated that with the increase of the temperature the accretion index at low precipitation increases;

– the approximation of the accretion dependence on the temperature and precipitation by the cubic polynomial has allowed the mathematical description of the obtained empirical dependences with the correlation coefficients between the actual and model values being from 0.77 to 0.89;

– the correlation among the accretions at all the sites is high, the correlation coefficient amounts to 0.85 for the initial data array. The 3 to 7-year smoothing increases the correlation only by 0.04, which is indicative of the high synchronism in the changes of the tree ring width.

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