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Climatic Factors Affecting the Growth of *Larix cajanderi* in the Kamchatka Peninsula, Russia

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Abstract

Tree-ring width chronology of larch (*Larix cajanderi*) was developed in the lowland in the central part of the Kamchatka Peninsula in Russia, and climatic factors affecting the growth of larch were examined by using monthly temperature, precipitation and water deficit [(potential evapotranspiration) – (precipitation)]. Eighteen disks of larch were examined, and a tree-ring index was developed by using five-year moving averages. Tree-ring indexes of sampled trees were positively correlated with each other, suggesting that many trees grew synchronously. A standardized tree-ring index (RI) was developed from A.D. 1840 to 1996 by averaging tree-ring indexes among sampled trees in each year. A correlation test revealed that RI was negatively correlated with precipitation in April in the current year. In addition, RI was positively correlated with precipitation and negatively with water deficit during the growing season (June–September) in the previous year. This was probably due to low precipitation in this region: mean precipitation during the growing season was only 171 mm, and water deficit was 183 mm. Therefore, drought stress during the growing season is an important factor affecting the growth of larch in the lowland of the central Kamchatka.

Key words: Climatic factor; Kamchatka Peninsula; *Larix cajanderi*; Tree ring

Introduction

The regeneration of trees at the timberline or in boreal forests is supposed to be sensitive to climate change, and therefore, tree-ring information there is useful for re-constructing past climates. Many attempts have been conducted to reveal effects of climatic changes on tree growth and to re-construct past climate by analyzing tree rings (e.g., Sweda and Takeda 1993, Yasue *et al.* 1996, Gindl 1999). Several researchers reported that tree growth and recruitment rates increased in ameliorated years than the average in boreal forests or at the timberline (Kullman 1986; Steijlen and Zackrisson 1987; Hofgaard 1993; Kullman 1993; Taylor 1995; Camarero and Gutiérrez 1999). Most of these studies have been conducted in the Scandinavia Peninsula, North America and the northwestern part of Russia. However, there have been few studies in the eastern part of Russia.

Recently, tree-ring chronological studies have been started in the Kamchatka Peninsula in the Russian Far East. In the central part of the Kamchatka Peninsula, larch (*Larix cajanderi* Mayr.) is a long-lived species (> 400 years) and is widely distributed (Hultén, 1972). Therefore, some researchers examined tree-ring chronology of this species in Kamchatka. Gostev *et al.* (1996) and Solomina *et al.* (1999) reported that tree-ring width of larch was positively correlated with early summer temperature and was sometimes reduced by volcanic eruptions. However, sampling sites are still limited in the Kamchatka Peninsula. The sampling sites of these previous studies were located in relatively high elevations or near the timberline. Geography of the Kamchatka Peninsula is unique. The central part of this peninsula is lowland surrounded by mountains (Fig. 1), and precipitation is lower in the lowland in the central part than in the coastal sides. Gervais and MacDonald (2000) reported that tree-ring widths of *Pinus sylvestris* on hill were not correlated with those in valley in northwestern Russia, probably due to the difference in local climatic variations such as temperature and wind speed. Therefore, climatic factors affecting the growth of a given species is expected to be different among sampling sites. Although climatic characteristics are different within the Kamchatka Peninsula, there have been no tree-ring chronological studies in the lowland of the Kamchatka Peninsula. Results presented in this study

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from the lowland of the central part of the Kamchatka Peninsula add to the tree-ring information in the Kamchatka Peninsula. Increased knowledge of larch chronology under different climatic conditions from those of the previous studies contributes to re-constructing comprehensively the past climate of Kamchatka.

In this study, we analyzed larch chronology in the lowland of the central part of Kamchatka. As a first step of re-construction of the past climate of this region, this study aims (1) to reveal what climatic factors affect the growth of larch in the lowland of the central Kamchatka Peninsula, and (2) to compare our results with those of the previous studies conducted at the timberlines and high elevations.

Materials and methods

Study site and sampling

The study site was located in Kozyrevsk in the central part of the Kamchatka Peninsula in Russia (56°04'N, 160°01'E, 70 m above sea level, Fig. 1). The climate of the central part of Kamchatka is characterized primarily by a continental regime with low annual precipitation. In Kozyrevsk, mean annual precipitation during 1950–1983 was 448.2 mm, and mean monthly temperatures in the hottest July and the coldest January were 15.1 and –18.3°C, respectively (Fig. 2). The maritime area is much snowy in winter and the intra-annual difference in temperature is smaller than that in the central part of Kamchatka.

Eighteen trees of larch were cut down for timber production in August 1998, and disks were obtained at a height of 30 cm above the ground. Ages of the sampled trees were approximately 100–150 years. Ring widths along a radius per tree were measured at a precision of 0.01 mm using binocular after sanding the disks.

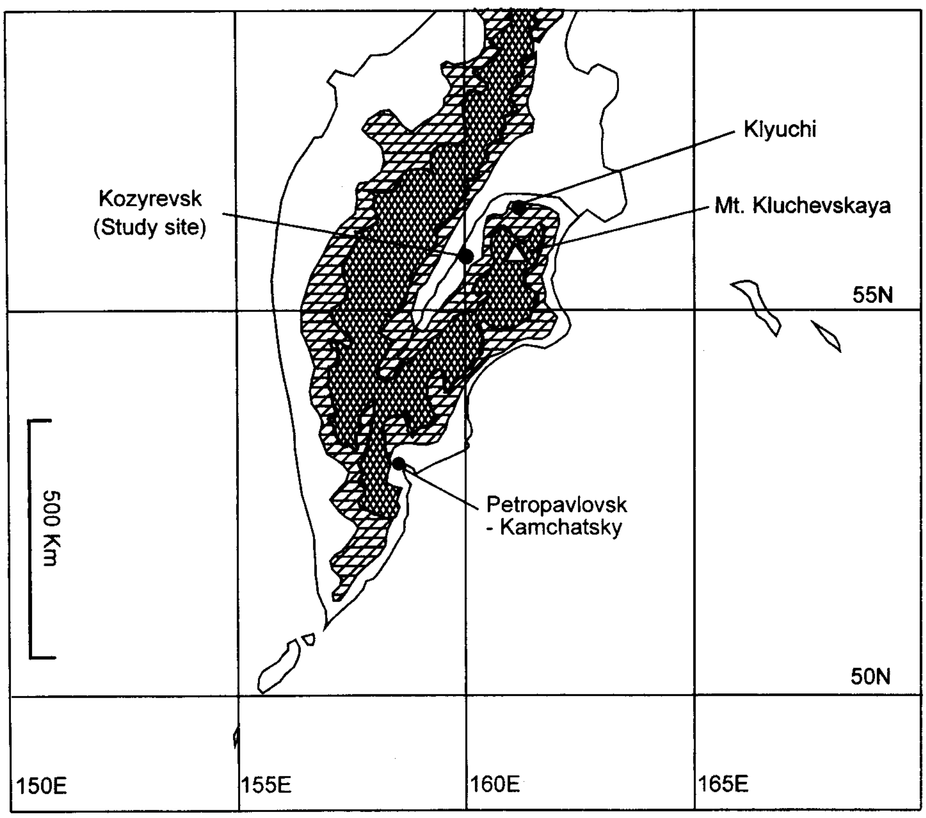

Fig. 1. Location of study site in the central part of the Kamchatka Peninsula in Russia.

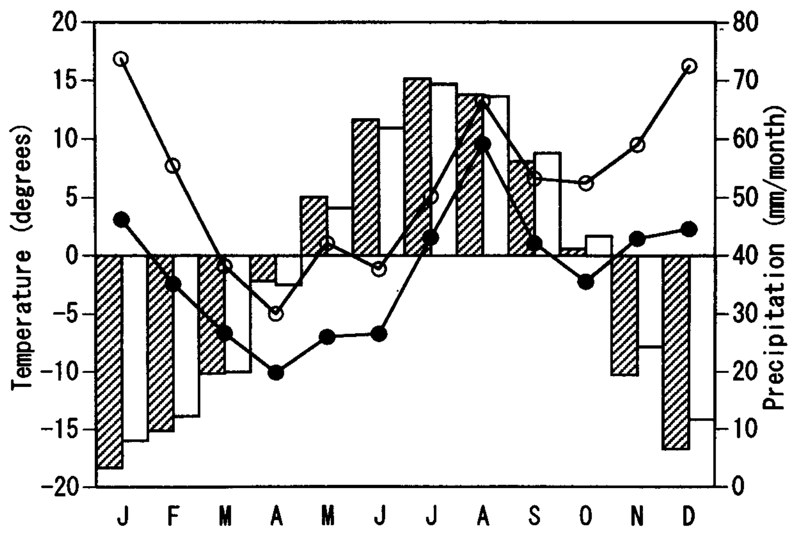

Fig. 2. Mean monthly temperature (bar) and precipitation (circle) during 1950–1983 in Kozyrevsk (shaded bar and solid circle) and in Klyuchi (open bar and open circle).

Tree-ring analysis

The growth of trees is affected not only by climatic factors but also by competition between neighboring trees, i.e., suppression by tall trees and release from suppression. To eliminate such competitive effects and to detect climatic effects on radial growth, a tree-ring index was developed. Tree-ring width in year *t* was divided by a five-year moving average in year *t* for each tree, and was transformed to mean 0 and SD 1 to reduce differences in absolute growth rate among individual trees. After determining the tree-ring index of each tree, the standardized tree-ring index was obtained by averaging the tree-ring indexes of all sampled trees in each year. We used at least four disks for making the standardized tree-ring index in each year (cf. Gostev *et al.* 1996).

Correlation test was employed to compare the standardized tree-ring index and meteorological data. Meteorological data in Kozyrevsk, where our study site was located, were only for 34 years during 1950–1983, but long-term data (1931–1989) of Klyuchi meteorological station were available, except May precipitation during 1941–1960. Although Klyuchi was far away from the study site (ca. 160 km, Fig. 1), mean monthly temperature was similar to Kozyrevsk (Fig. 2). Monthly precipitation in Klyuchi was persistently higher than that in Kozyrevsk throughout the year, but the seasonal pattern of precipitation was similar to that in Kozyrevsk (Fig. 2). Thus, we used the climatic data in Klyuchi for the correlation test between the standardized tree-ring index and climatic data (monthly temperature and precipitation).

During the growing season, temperature and precipitation do not affect plant growth separately, i.e., high temperature sometimes reduces plant growth by decreasing soil moisture available for plants if precipitation is low. Therefore, water deficit is another important factor for plant growth, which is determined by the balance between actual precipitation and potential evapotranspiration (Thornthwaite 1948). Thus, in this study, we tested the correlation of standardized tree-ring index not only with precipitation and temperature but also with water deficit. To estimate monthly water deficit in each year, we adopted Thornthwaite's evapotranspiration equation (Thornthwaite 1948). Willmott *et al.* (1985) summarized this equation as follows. Potential evapotranspiration in month *i* (PE_i, mm/month) without adjustment for day length and daylight duration is computed as:

$$PE_i = 0, \quad (\text{if } T_i < 0\ ^\circ\text{C})$$

$$(1)\ PE_i = 16(10\ T_i / J)^a, \quad (\text{if } 0 \le T_i < 26.5\ ^\circ\text{C})$$

$$PE_i = -415.85 + 32.24\ T_i - 0.43\ T_i^2, \quad (\text{if } T_i \ge 26.5\ ^\circ\text{C})$$

where T_i is the mean monthly temperature (°C) in month *i* and, *J* is the heat index defined in equation (2) below. The exponent *a* in equation (1) is a function of the heat index *J*:

$$(2)\ J = \sum_{i=1}^{n} (T_i / 5)^{1.514}, \text{ and}$$

$$(3)\ a = 6.7\ J^3 / 10^7 - 7.71\ J^2 / 10^5 + 1.79\ J / 10^2 + 0.49.$$

Monthly estimates of potential evapotranspiration calculated by equation (1) need to be adjusted for day length because 30-day months and 12-hour days were assumed when this relationship was developed. The adjusted potential evapotranspiration in month i (APE_i, mm/month) accounting for month length and daylight duration is given by

(4) $APE_i = PE_i\,[(d / 30)\,(h / 12)]$,

where d is the length of month i (days) and h is the duration of daylight (hours) on the fifteenth day of month i. In Kozyrevsk, the durations of daylight were 17, 15, 13 and 11 hours in mid-June, -July, -August and -September, respectively. In this study, water deficit in each month in each year was determined as [(APE_i) – (observed monthly precipitation)]. In this study, we determined the growing season of larch as June–September because mean monthly temperature during this period exceeded 5 °C (as effective heat for plant growth, after Kira 1949) and because snow completely melted by the end of May in Kozyrevsk in 1999 (our unpublished data).

Results

The tree-ring indexes of sampled trees were positively correlated with each other, suggesting that many trees grew synchronously (Table 1). However, the tree-ring indexes of two samples (No. 2 and No. 13) showed considerably weak correlation with those of the other samples (Table 1). Thus, we excluded data of these two samples for making standardized tree-ring index. The standardized tree-ring index is shown in Fig. 3.

A simple correlation test was applied to reveal what climatic factors affected the standardized tree-ring index. The standardized tree-ring index was negatively correlated with the precipitation in April in the current year (Pearson correlation coefficient r = –0.271, $p < 0.05$, Table 2), while the temperature in April in the current year showed a weakly positive correlation with the standardized tree-ring index (r = 0.253, p = 0.053). Mean monthly temperature in April was still below 0 °C in Kozyrevsk (Fig. 2), suggesting that the most of precipitation in April was snow.

During the growing season of larch (June – September), the standardized tree-ring index was positively correlated with the precipitation in August in the previous year (r = 0.286, $p < 0.05$, Table 2) and negatively correlated with the water deficit in August in the previous year (r = 0.301, $p < 0.05$). Same relationships were also detected when total precipitation and the sum of monthly mean temperature during the growing season were analyzed (Table 2). In addition, total water deficit during the growing season showed the highest correlation coefficient among the examined climatic variables (r = 0.327, $p < 0.05$). In Kozyrevsk, mean precipitation during the growing season was only 171 mm (Table 3). In contrast, potential evapotranspiration exceeded precipitation in each month during the growing season and water deficit was 183 mm in total (Table 3).

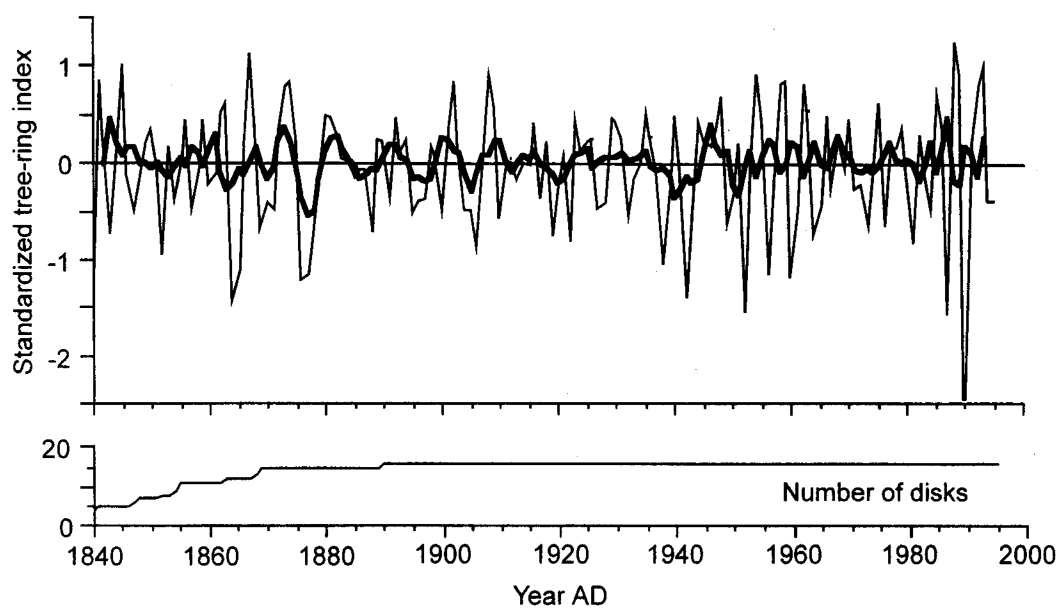

Fig. 3. The standardized tree-ring index for chronology of *Larix cajanderi* in the central Kamchatka Peninsula in Russia. The bold line is a 5-year moving average of the standardized tree-ring index in each year (thin line). The lower figure indicates the number of disks used for the construction of chronology.

Table 1. Pearson correlation coefficients between tree-ring indexes of sampled trees. The values typed in bold face indicate significant correlations ($p < 0.05$).

Tree No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No.9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17
No. 2	0.007																
No. 3	**0.298**	-0.002															
No. 4	0.160	-0.068	**0.208**														
No. 5	**0.417**	-0.098	**0.507**	**0.225**													
No. 6	**0.255**	0.049	**0.278**	**0.388**	**0.456**												
No. 7	**0.382**	-0.033	**0.334**	**0.451**	**0.372**	**0.344**											
No. 8	**0.333**	-0.102	**0.309**	**0.348**	**0.380**	**0.485**	**0.569**										
No. 9	**0.306**	0.020	**0.455**	**0.478**	**0.440**	**0.483**	**0.518**	**0.447**									
No. 10	0.097	0.047	0.131	**0.232**	0.085	**0.163**	**0.272**	**0.264**	**0.331**								
No. 11	**0.252**	-0.038	0.160	**0.247**	**0.193**	**0.534**	**0.285**	**0.453**	**0.302**	0.155							
No. 12	0.159	-0.089	**0.236**	**0.404**	**0.355**	**0.431**	**0.499**	**0.475**	**0.400**	**0.301**	**0.185**						
No. 13	0.007	-0.025	0.138	-0.071	0.113	-0.020	0.047	**0.169**	0.066	-0.008	-0.012	-0.041					
No. 14	**0.410**	0.090	**0.347**	**0.370**	**0.311**	**0.356**	**0.437**	**0.377**	**0.401**	**0.255**	**0.212**	**0.346**	-0.053				
No. 15	0.059	0.097	**0.249**	**0.479**	0.126	**0.309**	**0.343**	**0.343**	**0.406**	0.088	**0.211**	**0.372**	-0.005	**0.210**			
No. 16	**0.353**	0.169	**0.330**	**0.421**	**0.226**	**0.542**	**0.382**	**0.438**	**0.407**	**0.242**	**0.569**	**0.331**	-0.099	**0.353**	**0.277**		
No. 17	**0.196**	0.023	**0.177**	**0.231**	**0.317**	**0.428**	0.161	**0.319**	**0.233**	**0.198**	**0.346**	0.155	0.065	**0.294**	0.186	**0.337**	
No. 18	**0.196**	-0.012	**0.247**	**0.210**	**0.308**	**0.287**	0.166	**0.372**	**0.262**	**0.349**	0.146	**0.204**	0.113	**0.204**	0.111	**0.196**	**0.452**

Table 2. Pearson correlation coefficients between the standardized tree-ring monthly index and climatic variables (precipitation, temperature and water deficit) during 1931 − 1989. Total precipitation and sum of monthly mean temperature during the growing season from June to September were also analyzed. The values in bold indicate significant correlation ($p < 0.05$).

Month	Precipitation	Temperature	Water deficit
Previous year			
June	0.161	0.056	−0.115
July	0.094	−0.179	−0.123
August	**0.286**	−0.204	**−0.301**
September	0.150	0.109	−0.133
October	0.163	0.100	ND
November	0.025	−0.009	ND
December	−0.126	−0.224	ND
Jun. − Sep.	**0.324**	−0.093	**−0.327**
Current year			
January	−0.053	−0.083	ND
February	−0.147	0.045	ND
March	−0.052	−0.036	ND
April	**−0.271**	0.253	ND
May	0.075	0.149	ND
June	0.047	0.038	−0.035
July	−0.077	−0.149	0.032
August	−0.054	0.249	0.083
September	0.140	0.136	−0.129
Jun. − Sep.	0.021	0.085	−0.014

ND: not determined.

Table 3. Water budget during the growing season of larch in Kozyrevsk in the central Kamchatka. Mean monthly temperature and precipitation during 1950 − 1983 were used for the estimation of water deficit.

Month	PR	APE	WD
June	26.5	100.8	74.3
July	43.2	112.9	69.7
August	59.1	90.9	31.8
September	42.2	49.2	7.0
Total	171.1	353.8	182.7

PR: precipitation (mm/month).

APE: adjusted potential evapotranspiration (mm/month).

WD: water deficit (mm/month).

Discussion

In the previous studies in Kamchatka Peninsula, Gostev *et al.* (1996) and Solomina *et al.* (1999) showed that the early summer temperature (May and June) in the current year was positively correlated with the ring width of larch. Their study sites were in relatively high elevations or near the timberline ranging from 600 to 900 m a.s.l., and therefore, the start of the growing season in their study sites was later than that in our study site (70 m a.s.l.). Early summer temperature probably determines the start of growing season in such high elevations or at timberlines, and high temperature is effective for the growth of larch by prolonging the duration of growing season. A similar result was also found in this study, i.e., high temperature in April in the current year showed a positive correlation with the tree-ring index. However, April temperature probably was not so important for the growth of larch in this lowland because April temperature was statistically not significant ($p > 0.05$). Duration of growing season is shorter in higher elevations. It is expected that relative change in the duration of growing season is larger in higher elevations in warm years. Therefore, it is suggested that the importance of high temperature at the beginning of the growing season increases with altitude.

Drought stress was prevailing during the growing season in the lowland of the central part of Kamchatka Peninsula. Low availability of soil moisture reduces the transpiration and photosynthetic rates of plants (Havranek and Benecke 1978). Thus, it is likely that precipitation is a main limiting factor for the growth of larch in the lowland of the central part of the Kamchatka Peninsula. Tadaki *et al.* (1994) reported that radial growth of Japanese larch (*Larix leptolepis*) ceased until the end of early half of the growing season. Kikuzawa (1983) categorized deciduous broad-leaved tree species between two extremes according to leaf phenology: leaf emergence simultaneously during short period or continuously during long period. He also described that the former type of species grows using the photosynthetic products of the previous year, while the latter type of species strongly depends on the current-year's products. In this respect, the growth of larch seems to strongly depend on the previous-year's production. Therefore, drought stress will reduce the growth of larch in the next year. Such a relationship was not found in the previous studies conducted at high elevations or at the timberlines (Gostev *et al.* 1996; Solomina *et al.* 1999). In conclusion, many samples from different sites are needed to understand comprehensively the past climate of the Kamchatka Peninsula because climatic factors affecting the growth of larch are different among sampling sites under different climatic conditions.

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Photo. 1. *Larix cajanderi* forest in the central part of Kamchatka Peninsula, Russia.

Photo. 2. *Larix cajanderi* forest with *Pinus pumila* in the understory.

Photo. 3. *Larix cajanderi* forest damaged by fire. Recently, the forest fires caused by human activities often occur in the central part of the Kamchatka Peninsula.