Pine radial growth in the Trans-Baikalian steppe and taiga zones as a reflection of the climatic parameters and lake hydrological regime dynamics

I L Vakhnina and L V Zamana

1 Institute of Natural Resources, Ecology and Cryology, SB RAS, Chita, Russia
2 Siberian Federal University, Krasnoyarsk, Russia

E-mail: vahnina_il@mail.ru

Abstract. The paper presents the results of the annual rings width research of the trunk test core sampled from standing common pines. The purpose of the research is the analysis of the ability to use the radial recruitment changes of the trees growing in different natural zones for further reconstruction and prognosis of the climatic variables and lake hydrological regime. It was revealed that the dynamics of annual rings width in the steppe zone is characterized by the maximum values of the standard deviation and sensitivity to environmental factors in comparison with taiga zone trees. The radial growth of trees in the steppe zone shows a significant positive reaction to atmospheric precipitation and a negative reaction to air temperature from May to October. The influence of meteorological parameters on the annual growth of pine in the taiga zone is less considerable. The analysis of the synchronicity of changes in pine increments in the steppe zone with interannual fluctuations in the water level of Lake Barun-Torey due to the climatic conditions dynamics showed the significant correlation; therefore, the maximum correlation is observed with lake reaction lag for 4-5 years. Dendrochronological analysis of trees in the taiga zone (Baikal-Stanovoye Upland) revealed only a weak correlation with the average annual level of Lake Bount in the current year. Thus, the tree-ring chronology based on pines of steppe zone can be used for retrodiction of the hydrometeorologic elements.

1. Introduction
Assessment of current climate changes and development of an adaptation strategy requires not only an analysis of climatic parameters based on meteorological data, but also knowledge of long-term trends that exceed a number of instrumental observations. Tree ring chronologies are used as reliable sources reflecting the dynamics of hydrometeorological parameters over long periods of time (up to several thousand years) with a resolution of up to a year or even a season [1-4]. In different natural zones, radial growth is determined by different limiting factors. In the taiga zone, this is, as a rule, the effect of air temperature [2, 3, 5-7], and for semi-arid and arid forest-steppe and steppe territories - the amount of precipitation [8-12].

The purpose of the research is the analysis of the ability to use the radial recruitment changes of the trees growing in different natural zones for further reconstruction and prognosis of the climatic variables and lake hydrological regime.
2. Materials and methods
The study area is the taiga and steppe natural zones of Transbaikalia. Trunk test core sampled from two growth sites of common pines is the research material. The distance between the sites is approximately 600 km.

In the steppe zone, wood samples were taken in the Tsasuchey steppe pine forest (N 50°45'22", E 115°09'11", 682 m above sea level). The pine forest is located on the Onon-Torey plain in the Trans-Baikal Territory, near the border of Russia and Mongolia. Tsasuchey steppe forest is an outlier up to 40 km long in latitudinal direction with the total area of about 600 km².

Average annual atmospheric precipitation in the studied steppe zone is 300-380 mm. Within the year, it is distributed very unevenly. Mostly it falls in July (about 20%), slightly less – in August. These two months account for more than the half of the annual precipitation. In the cold season from October to April, a little more than 10% of the annual amount falls. The average annual air temperature varies from -1.0 to -2.2°C. The average monthly temperature in January is in the range from -22.5 to -27.0°C, and in July – from 18.2 to 19.4°C.

In the taiga zone cores were taken in the Bauntovsky district of the Republic of Buryatia (N 55°24'49", E 112°88'13", 1140 m above sea level). The territory belongs to the Baikal-Stanovoye Upland. On average, about 400 mm of precipitation falls here per year, and in some years more than 600 mm. The intra-annual distribution of atmospheric precipitation is similar to the steppe zone. The average annual air temperature amounts to -5.5°C and varies from -7.6 to -3.7°C from year to year. The average monthly temperature in January ranges from -37.2 to -21.7°C, and in July – from 13.1 to 18.4 °C.

Old-growth common pine trees (Pinus sylvestris L.) were used as the object of the study. The trunk cores were taken using an age drill presser at a height of 1.3 meters from the north side along one radius. The collection, transport and primary processing of wood cores were performed using conventional dendrochronological techniques. All stages of tree-ring series obtaining (dimensions, cross-dating, and quality control) were performed using a half-automatic tree-ring measuring instrument (LINTAB-6) and the dendrochronological software programs TSAP [13] and COFECHA [14]. Generalized standardized chronology was received via ARSTAN software [15] by approximate curves.

The standard deviation and the sensitivity coefficient were used as statistical parameters, on the basis of which the researchers estimate applicability of chronologies for measuring the reaction on hydrometeorological parameters. The expressed population signal (EPS) was used for estimation of reliability of the received chronologies.

To identify the response of tree growth to climatic characteristics, generalized standardized chronologies and data on the amount of precipitation and air temperatures for the period from 1937 were used.

Dendroclimatic analysis was carried out using a correlation analysis between generalized standardized chronologies and average monthly temperatures and total precipitation for a month and a year according to the data from the meteorological stations located near the study areas. The dendrohydrological analysis used data on the water level in Lake Bount (taiga zone), located less than 5 km from the sampling site, and Lake Barun-Torey (steppe zone), located approximately 20 km from the sampling site.

3. Results and discussion
As a result of the research, 19 individual tree-ring chronologies of the steppe zone and 26 chronologies of the taiga zone were obtained. The duration of individual chronologies in the taiga zone of the region is from 114 to 348 years (202 years in average). The maximum time interval is from 1633 to 2010. The duration of individual chronologies in the steppe zone is from 113 to 213 years (155 years in average). The maximum time interval is from 1797 to 2009.

The synchronicity coefficients between individual series in individual chronologies were 80% and correspond to high and very high levels. The obtained statistical characteristics made it possible to
combine individual tree-ring chronologies into generalized chronologies for each site and to standardize them, i.e. the age trend was removed from the increment series (figures 1 and 2). The maximum duration of the obtained generalized indexed chronologies was 213 for the steppe zone (Onon-Torey plain) and 348 years for the taiga zone (Baikal-Stanovoye Upland).

Figure 1. The generalized measured and standardized tree-ring chronologies and the number of used cores of common pine from the steppe zone (Onon-Torey plain).

The sensitivity coefficient characterizes the degree of influence of external factors of the natural environment by the relative differences in the sizes of adjacent annual rings. The standardized generalized chronologies had a sensitivity coefficient of 0.14 and 0.32. The standard deviation, which characterizes the amplitude of the increment variability caused by environmental conditions in the chronologies, was 0.24 and 0.32. Autocorrelation of the first order in the increments of trees in the taiga zone is 0.63; in the chronologies for the steppe zone it amounts to 0.45. This indicates a significant influence of the growth rate of previous years on the growth of the current year.

The dynamics of the tree ring width in the steppe zone is characterized by the highest values of the standard deviation and sensitivity indices in comparison with trees growing in the taiga zone. This is the evidence of the greater sensitivity of pines in the steppe zone to the effects of external climatic factors of the environment and the presence of a general climatic signal in the rows of increment.

For the charted generalized chronologies for the taiga zone, the EPS ≥ 0.85 value was obtained from 1865, for the steppe zone it was obtained from 1823.

Analysis of the correlation coefficients of the climatic response between the annual ring increments of pines in the steppe zone and meteorological data showed that the radial increment of trees in the steppe zone contains a significant positive response to atmospheric precipitation from May to August and a negative response to air temperature in the same months, as well as in September (table 1). At the same time, the highest correlation coefficients were obtained for June and July, both for precipitation and for air temperature. Both generalized standardized tree-ring chronologies are
characterized by a significant positive correlation with annual precipitation. The influence of meteorological parameters on the annual growth of pine trees in the taiga zone is less significant. Precipitation in June and air temperatures in July and October have a significant positive impact.

![Figure 2.](image)

**Figure 2.** The generalized measured and standardized tree-ring chronologies and the number of used cores of common pine from the taiga zone (Baikal-Stanovoye Upland).

Spectral analysis of the standardized tree-ring chronology for the steppe zone made it possible to identify significant quasi-thirty-year cycles in the formation of tree rings, consistent with the long-term changes in the average annual precipitation and dynamics of Barun-Torey Lake level. No other stable, well-expressed and statistically significant rhythms were found at the chosen level of significance. Determination of the cyclicality in the rows of increments of pines growing in the steppe zone showed the presence of cycles approximately 60 years long, apparently consistent with fluctuations in air temperature.

**Table 1.** Correlation coefficients between changes in the width of pine tree rings and meteorological parameters.

| Period          | V   | VI  | VII | VIII | IX  | X   | I-XII |
|-----------------|-----|-----|-----|------|-----|-----|-------|
| Precipitation   |     |     |     |      |     |     |       |
| Taiga zone      | 0.16| 0.28a| 0.02 | 0.15 | 0.13| -0.14| 0.26a |
| Steppe zone     | 0.19a| 0.31a| 0.44a| 0.22a| 0.08 | 0.17 | 0.54a |
| Air temperature |     |     |     |      |     |     |       |
| Taiga zone      | 0.09| -0.03| 0.34a| -0.02| -0.07| 0.19a| 0.06  |
| Steppe zone     | -0.20a| -0.34a| -0.40a| -0.18a| -0.25a| -0.06| -0.15 |

*a* Significant coefficients are marked in bold (p <0.05).
Analysis of the synchronicity of changes in the indexed tree-ring chronology pines of the steppe zone with interannual fluctuations in the level of Barun-Torey Lake for the period from 1965 to 2009 (figure 3) revealed the presence of a significant correlation, with the closest correlation observed when the lake response was delayed by 4-5 years (table 2).

Dendrochronological analysis of trees in the taiga zone (Baikal-Stanovoye Upland) indicates a reliable, but weak correlation with the average annual level of Lake Bount for the period from 1971 to 2010 (figure 4, table 2). The assessment of the time shift between tree growth and the level of this lake using cross-correlation analysis did not reveal reliable values, which may also be associated with the presence of runoff from it.

Table 2. Correlation coefficients between the tree growth and the level of lakes with a time shift of 1-7 years.

| Cross-correlation order | 0   | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Lake Barun-Torey        | 0.34| 0.42| 0.43| 0.49| 0.61| 0.64| 0.59| 0.54|
| Lake Baunt              | 0.28| 0.12| 0.12| 0.13| -0.17| -0.16| -0.16| -0.02|

* Significant coefficients are marked in bold (p <0.05).

4. Conclusion
The results of the studied dynamics of the width of annual rings in cores of common pines growing in the steppe and taiga zones of Transbaikalia show that the dynamics of the width of annual rings in the steppe zone is characterized by the highest standard deviation and sensitivity to environmental factors compared to trees growing in the taiga zone.

The radial growth of trees in the steppe zone shows a significant positive reaction to atmospheric precipitation and a negative reaction to air temperature from May to October. The influence of
meteorological parameters on the annual growth of pines in the taiga zone is less significant. Precipitation throughout the year and in June, as well as the air temperature in July and October, has a significant positive impact.

Figure 4. The generalized tree-ring chronology for pines of the taiga zone (Baikal-Stanovoe Upland) and interannual water level fluctuation of Lake Baunt for the period from 1971 to 2010.

The analysis of the synchronicity of changes in pine increments in the steppe zone with interannual fluctuations in the water level of Lake Barun-Torey due to the dynamics of climatic conditions showed the significant correlation, while the maximum correlation is observed with lake reaction lag for 4-5 years. Dendrochronological analysis of trees in the taiga zone (Baikal-Stanovoye Upland) revealed a weak correlation with the average annual level of Lake Bount in the current year.

Consequently, the tree-ring chronology based on pines of steppe zone can be used for further reconstruction and prognosis of the climatic variables and lake hydrological regime.

Acknowledgements
Core sampling and lake water level characteristic were carried out under the budgetary research projects of Institute of Natural Resources, Ecology and Cryology, SB RAS; climate data analysis was performed within the Russian Science Foundation support (Project No.19-14-00028).

References
[1] Fritts H C 1976 Tree Rings and Climate (London-New York-San Francisco: Acad Press) p 567
[2] Shiyatov S G 1986 Dendrochronology of Upper Forest Line in the Urals (Moscow: Nauka) p 136
[3] Vaganov E A, Shiyatov S G and Mazepa V S 1996 Dendroclimatic Study in Ural-Siberian Subarctic (Novosibirsk: Nauka) p 246
[4] Schweingruber F H 1996 Tree-Rings and Environment Dendroecology (Birmensdorf: Bern; Stuttgart; Vienna: P. Haupt, Verlag) p 609
[5] Esper J, Cook E R and Schweingruber F H 2002 Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability Science 295 2250-3
[6] Sidorova O V, Siegwolf R, Saurer M, Naurzbaev M M, Shashkin A V and Vaganov E A 2010 Spatial patterns of climatic changes in the eurasian north reflected in siberian larch tree-ring parameters and stable isotopes Global Change Biology 16 1003-18

[7] Hellmann L et al. 2016 Diverse growth trends and climate responses across Eurasia’s boreal forest Environmental Research Letters 11(7) 074021

[8] Andreev S G, Tulokhonov A K and Naurzbaev M M 2001 Regional factors of variability of growth of pines in the steppe zone of Buryatia Geography and Natural Resources 1 49-53

[9] Agafonov L I and Kukarskikh V V 2008 Climate changes in the past century and radial increment of pine in the Southern Ural steppe Russ. J. of Ecol. 39(3) 160-7 doi:10.1134/S1067413608030028

[10] Babushkina E A and Belokopytova L V 2014 Climatic signal in radial increment of conifers in forest-steppe of southern Siberia and its dependence on local growing conditions Russ. J. of Ecol. 45(5) 325-32 doi:10.1134/S1067413614050038

[11] Chen F, Yuan Y, Wei W, Zhang T, Shang H and Zhang R 2014 Precipitation reconstruction for the Southern Altay mountains (China) from tree ring of Siberian Spruce reveals recent wetting trend Dendrochronologia 32 266-72 doi:10.1016/j.dendro.2014.06.003

[12] Vakhnina I L, Obyazov V A and Zamana L V 2018 Dynamics of humidification in the steppe zone of Southeastern Transbaikalia since the beginning of the 19th century evidenced by the cores of common pine Bulletin of Moscow University, Series 5: Geography 2 28-33 doi:10.18411/vmu-2018-02-28

[13] Rinn F 1996 TSAP V3.5. Computer Program for Tree-Ring Analysis and Presentation (Heidelberg: Frank Rinn Distribution) p 264

[14] Holmes R L 1983 Computer-assisted quality control in tree-ring dating and measurement Tree-Ring Bulletin 44 69-75

[15] Cook E R 1985 Time Series Analysis Approach to Tree–Ring Standardization (Tucson, AZ: University of Arizona) p 171

[16] Briffa K R and Jones P D 1990 Measuring the Statistical Quality of a Chronology Methods of Dendrochronology: Applications in Environmental Sciences (Boston, Mass., USA: Kluwer Academic Publishers) p 137