ECOLOGY OF PLANTS AND MICROORGANISMS

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CLIMATIC FACTORS IN TREE-RING CHRONOLOGIES OF TYUMEN

SUMMARY. To find out the climatic determination of annual wood gain in the conditions of the southern forest zone, generalized tree-ring chronology (TRC) of Pinus silvestris from sites of environmental monitoring of Tyumen and its vicinity (from 1900 (1936) to 2012) is studied. In STATISTICA program multiple regression of indexes of width of rings by parameters of air and ground temperatures, and precipitation in the year of formation of the ring and the previous year (annual and monthly, including winter) is calculated. In different cases 26 to 40 parameters are applied. The level of multiple correlation and determination of width of a ring by a two-year complex of monthly parameters of temperature and precipitation, systemically characterizing atmospheric circulation is revealed high (close to functional for some TRC (R→1.0)). High level of correlation of width of rings with a number of particular climatic parameters is revealed. To solve the inverse problem, factorial regression of climatic parameters of a set of separate TRC from different soil and hydrological conditions is calculated. The level of correlation depends on the number of applied TRC: 7 chronologies of indexed width of a ring are enough to provide functional relation (R=1.0) with average annual air temperature in the year of formation of a ring and the previous year as dependent variable. The results disprove the limited suitability of TRC of the subtaiga area in dendroclimatological reconstruction and prognosis.

KEY WORDS. Tree rings, climate, environmental monitoring, West Siberia.

Analysis of tree-ring chronologies (TRC) is widely used to assess the condition of environmental components and to monitor its long-term anthropogenic changes and climatic tendencies. Dendroclimatology usually analyses TRCs from areas with strictly limited climatic factors – normally temperature and precipitation [1]. Extensive dendroclimatic studies have been conducted in the hypoarctic zone [2], impact zones of some river flows, and coniferous forests [3] of the West Siberian Plain. The most reliable and evident correlation between forest accretion and climatic and hydrologic factors is found in the northern part of the region (with correlation index up to 0.7–0.8); for the southern part, it is less reliable. The climate warming of the 20th century is best seen in TRCs of the north taiga zone of West Siberia [4]. The climate warming causes the timber-line move to the north [5], phenological changes [6], and augmentation of variability of crops in southern regions [7].

The aim of this study is to reveal the distinctive features of forest accretion in the conditions of the south of forest zone and to assess Tyumen TRCs' relevance for dendroclimatic reconstruction and forecast.

Materials and methodology:

In 2001, four ecologic monitoring reference sites (1 ha) have been defined in Tyumen plantations and greenbelt, with the description of biogeocenosis components [8]: in natural (TSU biostation "Kuchak" – MK, control) and athropogenically transformed pine-birch plantations (Gagarin forest park – MG, Plekhanov forest park – MP) and in the Tekutyev cemetery plantation in the centre of the city – MT. During re-examination of the sites in 2012, representative dendrochronological samples of pine-trees and birches were taken:

TRC	MK	MG	MP	MT
Pine-tree: duration	1931–2012	1926–2012	1936–2012	1900–2000
average ring width (mm)	2.0	2.5	1.8	3.3
Birch: duration	1908–2012	1949–2012	1947–2012	1900–2000
average ring width (mm)	1.5	2.0	2.0	2.1

The absolute width of tree-ring (mm) as the indicator of productivity and climate has limited applicability, because it depends on the age of the tree and some other factors. TRC indexing, eliminating the influence of these factors, is conducted by negative exponential smoothing [9], acknowledged as the best method to assess long-term climatic tendencies [1, 4]. Sensivity indexes [10] (centered) have also been calculated; their absolute values are viewed as stress indexes of plantations [11]. We have analyzed the multiple regressions of the chronologies of tree ring width indexes (accretion indexes) and stress indexes by monthly average air temperature and monthly precipitation in Tyumen in the year of ring formation and the previous year from 1966 to 2008 (variant A, 40 parameters) and by monthly average temperature of the ground at the depth of 0.4 m and annual precipitation in the year of ring formation and the previous year from 1937 to 1990 (variant B, 26 parameters). Two programs have been used: EXCEL and STATISTICA.

Results

The best results have been derived from pine TRCs analysis. A very high level of multiple correlation between tree-ring width index chronologies and monthly temperature and precipitation parameters for two years (variant A), which explains the variability of accretion indexes, has been detected (Fig. 1). Similar level of multiple correlation has been found in stress indexes, reflecting the influence of climate-depending pathologic factors: biotic (infestants and diseases) and hydrologic (subsoil waterlogging at MP in 2004) (Fig. 2). The results disprove the inapplicability of poorly limited by climatic factors TRCs of the subtaiga zone for reliable dendroclimatologic assessment.

Fig. 1. Tree-ring index. Actual and reconstructed (cursive).

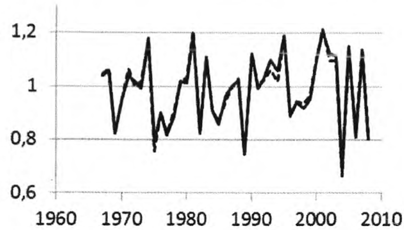
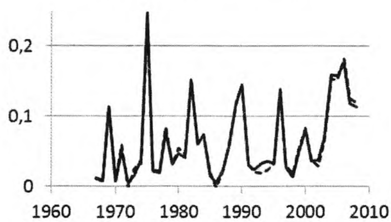


Fig. 2. Stress index. Actual and reconstructed (cursive).



Tree-ring width index multiple regression calculation showed a high level of partial correlation (*β*) with ground temperature (Fig. 3) and precipitation (Fig. 4) in different months of the ring-formation year and the previous one. And this correlation was found not only for climatic parameters of vegetation period, but also for temperature and precipitation of winter months, when trees do not grow.

Fig. 3. The correlation (β) of ring-width indexes with monthly average ground (0.4 m) temperatures in current and previous years

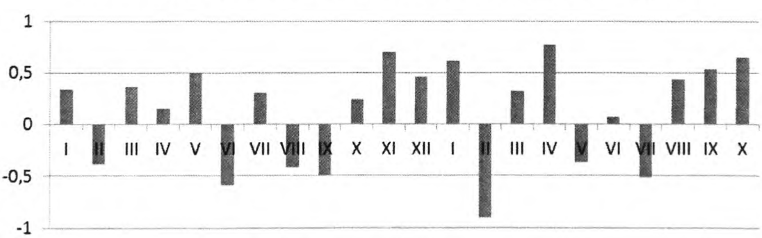
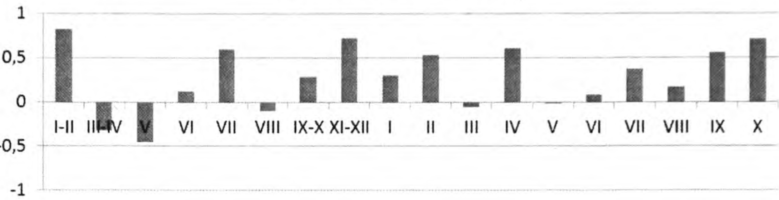


Fig. 4. The correlation (β) of ring-width indexes with precipitations in current and previous years



It can be caused by mediated climate influence on wood accretion (harmful insects dying in cold and dry winters), as well as by climatic factors formation consistency, occurring in the viewed two-year period and characterizing a certain type of atmospheric circulation.

In contrast to the correlation between tree-ring width and temperature (which is frequently negative, as for July this year), the correlation with precipitation is normally positive, which indicates humidity deficit in Tyumen (Fig. 3, 4).

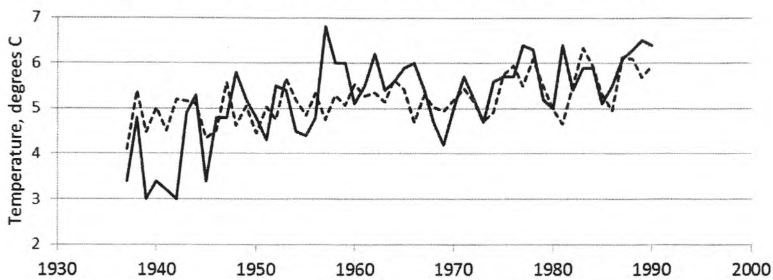
A high level of multiple correlation of accretion and stress indexes chronologies with climatic parameters has as well been detected in the simplified variant B, which shows 0.85 for MK site, and 0.76–0.78 for other sites. At that the major components of regression are diverse for different sites: MK – this year June temperature (negative), MG – previous year May temperature (+), MP – previous year January temperature (–), MT – December temperature (–). Partial correlation of TRC indexes of different sites with annual climatic parameters is low. For the precipitation in the year, prior to the year of ring formation, the correlation is 0.48, for the solar radiation in the year of formation it is 0.35, for the temperature parameters – up to 0.2.

The possibility of inverse estimation of climatic parameters by the tree-ring width is crucial. The possibility to derive these parameters from the totality of separate TRCs from different ground-hydrological conditions has been considered. To achieve this, TRCs from moss-lichen (near Krivodanova village), sphagnous-ledum (near Karaganda village), and grass pine forests, apart from TRCs from the previously mentioned sites, have been used.

STATISTICA offers different variants of regression models as a part of such an approach, in particular: multiple, polynomial, and factor models. Even within a common multiple regression model, which does not operate with interacting predictors, the level of correlation of annual climatic parameters with indexed width of three-rings by the totality of TRCs turned out to be significantly higher than by separate TRCs or one generalized TRC, averaging TRC values from different sites. For the ring formation year, by annual average air temperature, the level of correlation is 0.44, by annual precipitation – 0.53, by annual average ground temperature at the depth of 0.4 m – 0.53. The level of such correlation with average ground temperature in some months is even higher, for example with the temperature in November in the ring formation year – 0.56 (though ring formation stops no later than September!). The main components of the multiple regression indicate that for most months of current year (except May, July, and August), while tree-ring width indexes decrease, monthly average ground temperatures increase in Tyumen (and vice versa).

Though most TRCs created with usual methods are too short-termed for long-term climatic trends analysis, the described method of dendroclimatic reconstruction proves annual average ground temperatures (0.4 m deep) to rise in Tyumen in the second half of the 20th century, which agrees with weather observation data (Fig. 5).

Fig. 5. Ground temperature at the depth of 0.4 m.
Actual and multiple regression reconstruction (stipple line) data.



When using the polynomial regression model, the coefficient of multiple correlation of climatic parameters with tree-ring width indexes for the seven TRCs gets even higher: for average air temperature in the year of ring formation, it is 0.61, for the previous year – 0.49.

Finally, when using the factor regression model, which implies the most thorough analysis of the effects of the interaction of several regressands and regressors, the multiple correlation of tree-ring width with average air temperatures of the tree-ring formation year and the previous year reaches the functional level (R=1.0) for the seven TRCs, which means quite accurate dendroclimatic reconstruction and forecast in Tyumen. When decreasing the number of TRCs used (fewer than seven), the level of such multiple correlation also gradually decreases. For example, for different combinations of six TRCs, it was in the range from 0.95 to 0.99 for ring-formation year average air temperature and 0.85–0.95 for previous year average air temperature.

Conclusion

Thus, despite the absence of strict climatic limitation of tree growth in Tyumen, the tree-ring chronologies of Pinus silvestris indicate a very high level of climatic conditionality, where the most influential factors are temperature and precipitation. It is revealed by multiple regressions of wood accretion parameters by monthly air and ground average temperatures and monthly precipitation (in the year of tree-ring formation and in the previous year, including wintertime). In such continuous long-term meteorological data body, we can see consistency of formation of climatic parameters, which are defined by the type of atmospheric circulation, and their systematic influence on radial wood accretion.

The tree-ring width (index) is more closely related to ground temperature than to air temperature, as the former is a more complex bioclimatic indicator, which is significantly influenced by atmospheric precipitations.

For climatic parameters reconstruction, average annual temperatures in particular, factor regression model for combinations of TRCs from different ground-hydrological conditions is the most appropriate. The functional level of multiple correlation between regressands (average annual air temperatures) and predictors (index TRCs) was achieved by applying seven TRCs, covering a large range of Tyumen pine plantations.

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