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Reconstruction of grain yield in the steppe zone of the Altai territory (south of Western Siberia) in the XIX-XX centuries on the basis of tree-ring chronologies of tape burs

N V Rygalova^{1*}, E V Rygalov¹ and N I Bykov¹

¹ Altai State University, 61 Lenina prosp., Barnaul 656049 Russia

E-mail: natalia.ml@mail.ru

Abstract. The article presents the results of the reconstruction of the yield of grain crops of the economy of the Volchikhinsky district of the Altai Territory (south of Western Siberia) on the basis of an extended tree-ring chronology until 1822. Based on the restored series, the cyclical nature of cereal productivity was analyzed. In particular, the 22-, 25-, and 27-year cycles are highlighted as the most significant. The increase in the amplitude of variability of the yield series was noted by year from the middle of the 19th century to the end of the 20th century.

1. Introduction

Analysis of the dynamics of yields over a long period (several centuries) is necessary for understanding long-term trends in the production of main food crops (in particular, cereals). Grain crops are grown mainly in the steppe belt, which is also represented on the territory of the Altai Territory. This makes the region the main producer of food beyond the Urals. At the same time, the region is characterized by significant annual fluctuations in the volumes of crop production, which is caused by the frequency of occurrence of droughts (of varying intensity) on its territory. Thus, we can say that the grain yield in the Altai Territory is predetermined by the climatic conditions of the growing season.

To obtain a long series of yields, tree-ring chronology (TRC) tape burs were used. The growth of Scots pine (*Pinus sylvestris* L.) along the radius (formation of the annual ring) is the result of the productivity of the woody plant as well as the yield is an indicator of the productivity of the agrocenosis. The basis for comparing these indicators was the presence of climate as a common determining factor. It was previously established [1] that the chronology of the width of the Scots pine's annual rings are indicators of the climatic conditions of the vegetation period, which makes them suitable for the reconstruction of the climate-mediated component of the yield dynamics. Studies in this direction were previously conducted in Russia and in foreign countries [2-7].

2. Materials and Methods

The research material is represented by a series of yields (a volume of harvested grain per unit of sown area) of grain crops of farms of Volchikhinsky district (steppe zone) for the period from 1976 to 2000. The choice of a region is predetermined by its location in the steppe zone and its proximity to the belt forests. ThVolchikhinsky district specializes mainly in the production of crop products, primarily grain. Traditionally, grain crops are not irrigated in the district. There is no information about the facts of fertilization in the field at the same time. The average yield in the farms of the Volchikhinsky district



for this period was 9.4 c / ha (the standard deviation of the indicator for the farms of the district varies from 2.4 to 3.5).

Tree-ring chronologies of the region's forest belt (Aleutian, Kulunda, Barnaul, Kasmalinskaya) were taken as the basis for the reconstruction. They are the generic, standardized (arstan-chronology) ranks of the width of tree rings. This type of standardization (arstan) allows eliminating the age component in the dynamics of tree growth, minimizing autocorrelation noise, while maintaining long-period fluctuations (unlike residual chronologies). The mean value of the TRC is 1 (since the growth indices are used in the analysis), with the standard deviation in chronologies ranging from 0.14 to 0.27. The TRC with a high standard deviation are considered sensitive, their use in dendroclimatic analysis is the most promising (these mainly include chronologies of pine obtained for the steppe zone).

The main methods used were dendrochronological and statistical. All tree-ring chronologies of pine forests were obtained by the standard technique [8]. The work used extended chronologies to increase the retrospective range of yields. The chronology of Uglovskoe-42 (1844-1997), on the basis of which a number of grain crops was reconstructed, was extended to the past for 22 years (it allowed to increase the replication of individual series at the beginning of the TRC, which increases the accuracy of reconstruction). For the extension of the DKH, samples of historic wood were used, taken from the logs of the old wooden houses in the villages of the region, located near the forests. The "floating" (relative) chronologies obtained for them were dated according to the TRC of the belt forests. In cases where TRC houses covered an earlier period of time than chronologies of forests, the latter extended into the past for this period. To extend the chronology of Uglovskoe-42, the TRC of two wooden houses, the village "Laptevo Log" (Uglovsky district) were used. The cumulative duration of historical wood chronologies was from 1973 to 1822.

Restoration of yield series was carried out using the Pearson correlation method (pair correlation) and regression. The first method allowed us to identify the most significant links between the yields and the TRC, the second allowed us to reconstruct a number of yields on the basis of the obtained statistically significant links. Obtaining and processing of tree-ring series are performed in the TSAP programs and DPL software package. Statistical calculations carried out in Statistica 13.

3. Results

As a result of the correlation analysis of the grain yield series in the farms of the Volchikhinsky district with TRC tape burs, some significant connections (0.4-0.47) were identified. There are no clear geographic dependencies in the manifestation of a mediated relationship between pine growth and grain yield both in the farms and in the region average. The highest correlation coefficient (0.47, significant at $p < 0.05$) was obtained for a series of crop yields of the farm "Za vlast' Sovetov" (Vostrovo), adjacent to the Kasmalinsky forest, Uglovskoe-42 (a dry steppe zone, southern part of the Barnaul belt forest). This chronology was used as an indication basis for the retrospective recovery of yield data. The linear regression equation (1), which underlies the reconstruction, has the following form:

$$Y_i = 4,749 * X_i + 4,9855 \quad (1)$$

where Y_i is the yield value in year i ; X_i is the index of the annual increase in a year of i .

The reconstructed yield values have a smaller variation compared to the actual yield range (standard deviation is 1.4 and 3.0, respectively), which is characterized by significant annual fluctuation amplitudes. For greater clarity, the graph (Fig. 1) presents the averaged values of the observed yield (a five-year smoothing is used).

The recovered grain yield range has a well pronounced cyclical nature. Using the Fourier spectral analysis, several groups of significant cycles of the series were allocated: 22-25-29 years, 35-44 years, 88 years, also a group of 9-12-year cycles and a cycle of 170 years is allocated. The 22-25-29-year cycle is of the greatest importance (Fig.2). It is clearly manifested in the following periodicity of dry years (which determine the decline in the productivity of phytocenoses): 1963/1967, 1990/1991, and 2012.

The last year was not included in the analysis presented but was noted as a year with low grain yield throughout the region [9] and the formation of narrow rings in Scots pine.

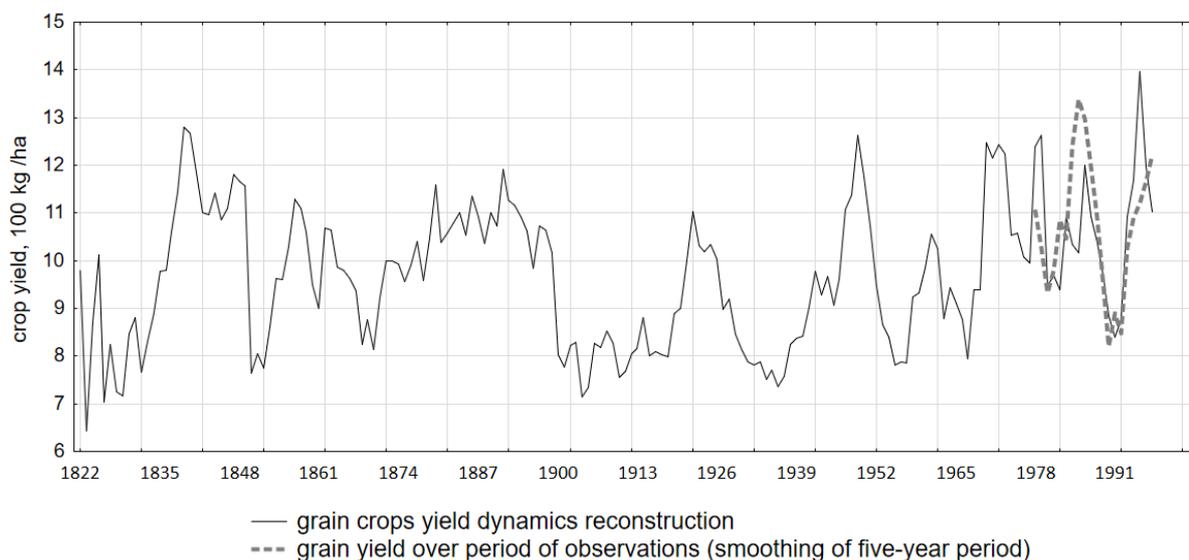


Figure 1. Reconstruction of the yield of grain crops for the economy of the Volchikhinsky district of the Altai Territory based on the tree-ring chronology.

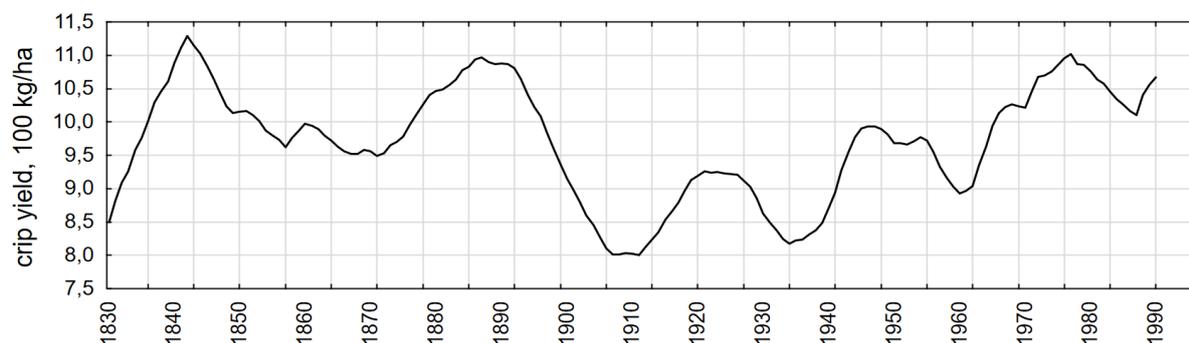


Figure 2. Smoothed (15-year averaging) recovered grain yield series.

In general, we can say that there is an increase in the amplitudes of fluctuations in the value of the yield of grain crops (Table 1) during the analyzed period. This indicates an increase in climatic instability over time, which is a sign of climate change.

Table 1. Statistical estimates of the amplitude of variation of grain yield over time.

Time period	Standard deviation value
1850-1899	1.0
1900-1949	1.18
1950-1997	1.48

4. Discussion

The study of the reconstruction of the productivity of crops based on the use of indicator data is a promising direction, especially in conjunction with the study of long-term climate dynamics. However, several points remain debatable.

- Significant correlations are important for establishing an adequate regression model for reconstructing retrospective values. In the case under consideration, the grain yield series on average showed low values with all TRC (in some cases, the correlation coefficient was higher

than 0.4 with $p < 0.05$). Most likely, this is due to the fact that for the analysis, the yield values for the enlarged group of crops were taken, namely grain. Different grain crops (wheat, buckwheat, oats) show a different connection with an increase (for example, there is a weak connection between the TRC of tape forests and the buckwheat yield in the steppe districts of the region [4]), which introduces heterogeneous noise and leads to a decrease in the correlation values.

- Also, the contribution of the anthropogenic component (application of fertilizers, measures of land reclamation) to the formation of the yield volume is rather difficult to determine. But despite this, the limiting importance of climate for the productivity of agrocenoses is decisive; therefore, the reconstruction of crop yields through the climate component seems possible (in this case, the anthropogenic component will be defined as noise).

5. Conclusion

In the course of the work performed, a number of grain crops yields of the Volchikhinsky district (a steppe zone of the Altai Territory) were reconstructed on the basis of the dendrochronological method until 1822. The restored yield values are characterized by the presence of cycles of various duration. 22-29-year cycles, which are manifested in the frequency of strong droughts, are most significant. Also, there is an increase in the variation (fluctuations) of the yield values over the years from the middle of the 19th century to the end of the 20th century. In general, over the course of the 20th century, there was a general trend towards an increase in the climatic potential of the productivity of agrocenoses (with negative fluctuations local in time). To clarify long-period cycles in the reconstructed rows, further research on the extension of the tree-ring rows is necessary. This will allow you to get the most complete picture of different-period cycles of climate change of the territory and climate-dependent processes and make it possible to forecast them.

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References

- [1] Malysheva (Rygalova) N V, and Bykov N I 2011 *Dendrochronological studies of tape burs in the south of Western Siberia* (Moscow: Russia, Azbuka)
- [2] Bitvinskas T T, and Brukshtus V I 1990 Radial growth of trees, climate extremes and crop yields In *Problems of dendrochronology and dendroclimatology* (pp 20-21) (Sverdlovsk, USSR: Publishing House of the UB of the USSR Academy of Sciences)
- [3] Vaganov E A 1989 Method for predicting grain yield using dendrochronological data *Ecology* **3** pp 15-23
- [4] Rygalova N V, Bykov N I, and Plutalova T G 2014 Retrospective study of the dynamics of crop yields in Altai Territory by the method of dendrochronology *Vestnik of the Altai State Agrarian University* **10**(120) pp 43-49
- [5] Babushkina E, Belokopytova L, Shah S, and Zhirnova D 2018 Past crops yield dynamics reconstruction from tree-ring chronologies in the forest-steppe zone based on low- and high-frequency components *International Journal of Biometeorology* **62**(5) pp 861-871
- [6] Huhtamaa H, Helama S, Holopainen J, Rethorn C, and Rohr C 2015 Crop yield responses to temperature fluctuations in 19th century Finland: provincial variation in relation to climate and tree-rings *Boreal Environ Res* **20** pp 707-723
- [7] Huhtamaa H, and Helama S 2017 Reconstructing crop yield variability in Finland: long-term perspective of the cultivation history on the agricultural periphery since AD 760 *The Holocene* **27**(1) pp 3-11
- [8] Shiyatov S G, and Vaganov E A *et al* 2000 *Methods of dendrochronology (vol 1)* (Krasnoyarsk, Russia: KrasSU)
- [9] Rozova M A, and Ziborov A I 2016 Correlations between the yield of spring durum wheat and the elements of its structure depending on the level of genotype productivity and weather conditions in the priobskaya forest steppe of the Altai Territory *Vestnik of the Altai State Agrarian University* **2**(136) pp 44-49