Eco. Env. & Cons. 28 (3) : 2022; pp. (1252-1261)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i03.023

Radial growth dynamics in Scots pine forests of the Yalutorovsky forest district of Tyumen region

Epishkov A.A.[1], Lipatkin V.A.[1], Frolova V.A.[1], Sidorenkov V. M. [2], Stonozhenko L.V. [3], Vorobyeva N.S.[1] and Rumyantsev D.E. [1*]

[1] Mytischi Branch of Bauman Moscow State Technical University, Mytischi, Moscow Oblast, Russian Federation
[2]All-Russian Research Institute of Silviculture and Mechanization of Forestry, Pushkino, Moscow Oblast, Russian Federation
[3]All-Russia Institute of Improvement of Professional Skill of Executives and Specialists of Forestry, Pushkino, Moscow Oblast, Russian Federation

(Received 1 June, 2021; accepted 4 February, 2022)

ABSTRACT

The investigation of radial growth may be performed in different aspects. The indication significance of this parameter is great, and the potential of its using has not fully exhausted. Different features of radial growth variability in Scots pine stands from Tyumen region (West Siberia, Russia) are present at the article. Chronologies from the Russian Federal Agency Forestry Database of the Dendrochronological Information Characteristics were used for investigation. Climatic influences on radial growth of Scots pine (*Pinus sylvestris* L.) in different forests sites were established. As a result of dendroclimatic analysis, it was found that the distribution of reliable values of correlation coefficients by month in the current year and in the previous year is specific for different chronologies, which reflects the specifics of the environmental conditions of growth in the sample areas. There is drought dependent climatic signal in the chronologies. The using methodological approaches have perspectives for investigations in the sphere of forest science.

Key words : *Scots pine forest, Tyumen Russia*

Introduction

Scots pine (*Pinus sylvestris* L.) is the species which was well investigated by dendrochronological methods. Probably the first investigation of Scots pine tree rings by the climate influence in Russia was performed by Tolsky (1904). But despite long history of this kind investigations, they continue to be relevant both for the territory of Russia and abroad it (Tabakova *et al*., 2020; Matveev *et al.*, 2020; Katjutin *et al*., 2020; Ivanova *et al.*, 2021; Kolar *et al.*, 2020; Zheleznova and Torbatov, 2021; Bose *et al*., 2020; Quan-Wen *et al*., 2020; Gazo *et al.*, 2020; Nagaviciuc *et al*., 2019). The most important results of investigations are related with detail our knowledge about ecophysiological mechanisms of tree ring forming, and first of all, the mechanism of climatic impact to tree ring width. So, the investigation in the forest-steppe ecotone in southern Siberia is characterized by a strong dependence of tree growth on summer drought, which is expected to increase under ongoing climate change, with potential consequences for regional and global water and carbon cycles (Tabakova *et al*., 2020).

One of the insufficiently studied areas in dendroclimatology is the seasonal dynamics of the radial growth of trees in regions with different climatic conditions. The urgency of this problem has increased due to the observed climate changes (Matveev *et al.,* 2020). It has been established that the Scots pine ecotype under the conditions of the forest-steppe zone demonstrates a multi-peaked cyclical dynamics of cell growth rate within the growing season. At the same time, the culmination of growth differs significantly in different calendar years.

The results of investigations are the patterns of radial growth of Scots pine (*Pinus sylvestris* L.) in various top ecological conditions of the Meshchera lowland (Ryazan region, the East European plain) speaks that that the key factor influencing the width of annual tree rings of pine is the amount of the available soil moisture (Zheleznova and Torbatov, 2021).

The study of Scots pine growth in Europe (from southern Spain to northern Germany) showed that the impact of drought on tree level resilience was not dependent on its latitudinal location, but rather on the type of sites trees were growing at and on their growth performances (i.e., magnitude and variability of growth) during the predrought period (Bose *et al*., 2020). It was found significant interactive effects between drought duration and tree growth prior to drought, suggesting that Scots pine trees with higher magnitude and variability of growth in the long term are more vulnerable to long and severe droughts. Moreover, the results indicate that Scots pine trees that experienced more frequent droughts over the long term were less resistant to extreme droughts. Therefore, physiological resilience to extreme droughts might be constrained by their growth prior to drought, and that more frequent and longer drought periods may overstrain their potential for acclimation

In our research, we proceeded from the premise that the range of dendrochronological studies of Scots pine can be methodically much wider than now, especially in the sphere of forestry and forest science. That is why is possible to analyse dendrochronological information by new methodological solutions, which are different from classical methodic using for dendroclimatic reconstructions (Fritts, 1976; Shyatov, 1986; Solomina *et al*., 2017). To this article, we have selected chronologies for the Yalutorovsky Forest District (Tyumen Oblast) from the Russian Federal Forestry Agency Database of the Dendrochronological Information for Conifer Species from Individual Forest Areas with a Higher Risk of Illegal Logging developed by Moscow State Forest University (Palchikov and Rumyantsev, 2009). These chronologies have been used to develop methods to assess qualitative characteristics (forest types) based on tree ring variability.

Methods and Materials

Wood samples were obtained using a Pressler increment borer; cores were taken from each tree at a height of 1.3m with a spot on the stem being chosen at random. The samples were put in paper envelopes of a specific shape. Characteristics of test areas in stands of Scots pine are shown in Table 1. And parameters of testing trees in Table 2.

Then, the selected and labeled samples were sent to the Dendrochronological Laboratory of the Science and Education Center for Wood Investigation, Analysis and Expertise to perform a further analysis with the LINTAB equipment in combination with the TSAP-Win software. Tree ring widths were measured with a resolution of 0.01mm. Cross-dating in TSAP-Win was carried out to verify the measurement results (Matveev and Rumyantsev, 2013; Rumyantsev, 2010). The generalized chronologies from sample areas are shown in Figure 1.

When studying the graphs, a focus should be put on the essential role that tree age plays in the process of tree ring width formation. For example, in the 1980s, the highest rates of the average tree ring width were shown by the youngest forest stand

Table 1. Characteristics of test areas in stands of Scots pine

No.	Fopest type	Age class	Composition of forest stand, percent from growing stock	Undershrub	Underbrush
1	Cladina type	III	100% Scots pine	No	Pine
2	Cladina type	VII	100% Scots pine and admixture of Betula pendula	No	Pine
3	Green moss type	VII	100% Scots pine	No	Pine
4	Green moss type	III	100% Scots pine and admixture of Betula pendula	No	Pine
5	Sphagnum type	IV	100% Scots pine and admixture of Betula pendula	N0	Pine

Table 2. Taxation parameters for testing Scots pine trees

Number	Diameter, cm	Height, mm	Kraft class	Geographic latitude	Geographic longitude
1	2	3	4	5	6
1-1	27	13	I	57 î00.070 ′00 “	066 î 51.147 ′00 “
1-2	31	18,00	I	57 î00.067' 00"	066 î 51. 131' 00"
1-5	24	18,00	II	57 î00.068' 00"	066 î 51. 161' 00"
1-6	24	18,00	I	57 î00. 064' 00"	066 î 51. 156' 00"
1-7	20	18,00	I	57 î00. 062' 00"	066 î 51. 156' 00"
1-9	28	18,00	I	57 î00. 060' 00"	066 î 51. 155' 00"
1-10	20	18,00	I	57 î00. 058' 00"	066 î 51. 152' 00"
1-11	23	18,00	I	57 î00. 056' 00"	066 î 51. 156' 00"
1-12	26	18,00	II	57 î00. 054' 00"	066 î 51. 156' 00"
1-13	36	20,00	I	57 î00. 054' 00"	066 î 51. 152' 00"
1-14	23	18,00	II	57 î00. 054' 00"	066 î 51. 147' 00"
1-15	27	18,00	I	57 î00. 059' 00"	066 î 51. 144' 00"
1-16	21	18,00	II	57 î00. 065' 00"	066 î 51. 144' 00"
1-17	28	19,00	I	57 î00. 065' 00"	066 î 51. 137' 00"
1-18	21	18,00	II	57 î00. 060' 00"	066 î 51. 137' 00"
1-19	27	18,00	I	57 î00. 055' 00"	066 î 51. 136' 00"
1-20	23	18,00	I	57 î00. 053' 00"	066 î 51. 136' 00"
1-4	18	18,00	II	57 î00. 068' 00"	066 î 51. 162' 00"
1-8	24	18,00	I	57 î00.061' 00"	066 î 51. 157' 00"
1-3	32	18,00	I	57 î00. 069' 00"	066 î 51. 152' 00"
2- 1	36	18/00	I	57 î03. 058' 00"	066 î 51. 150' 00"
2- 2	26	20.00	I	57 î03. 059' 00"	066 î 51. 150' 00"
2- 3	31	21.00	I	57 î03. 056' 00"	066 î 51. 147' 00"
2- 4	33	20.00	I	57 î03. 059' 00"	066 î 51. 145' 00"
2- 5	30	21.00	I	57 î03. 058' 00"	066 î 51. 149' 00"
2- 6	20	18.00	I	57 î03. 056' 00"	066 î 51. 140' 00"
2- 7	33	18.00	I	57 î03. 056' 00"	066 î 51. 129' 00"
2- 8	18	16.00	I	57 î03. 057' 00"	066 î 51. 124' 00"
2- 9	33	15.00	I	57 î03. 054' 00"	066 î 51. 122' 00"
2- 11	33	16.00	I	57 î03 .050' 00"	066 î 51. 123' 00"
2- 12	30	16.00	I	57 î03. 046' 00"	066 î 51. 125' 00"
2- 13	29	18.00	I	57 î03. 045' 00"	066 î 51. 124' 00"
2- 14	34	18.00	I	57 î03. 043' 00"	066 î 51. 128' 00"
2- 15	40	17.00	I	57 î03. 041' 00"	066 î 51. 131' 00"
2- 16	40	17.00	I	57 î03. 048' 00"	066 î 51. 136' 00"
2- 17	32	16.00	I	57 î03. 050' 00"	066 î 51. 141' 00"
2- 18	18	16.00	I	57 î03. 051' 00"	066 î 51. 146' 00"
2- 19	13	17.00	II	57 î03. 051' 00"	066 î 51. 145' 00"
2- 20	30	20.00	I	57 î03 054' 00"	066 î 51. 144' 00"
2- 10	34	16.00	I	57 î03. 048' 00"	066 î 51. 123' 00"
3- 2	27	16.00	I	56 î 50. 292' 00"	066 î 46. 909'00 “
3- 3	26	15.00	I	56 î 50. 287'00 “	066 î 46. 908' 00”
3- 5	35	15.00	I	56 î 50. 282' 00"	066 î 46. 912' 00"
3- 6	22	15.00	I	56 î 50. 287' 00"	066 î 46. 913' 00"
3- 8	22	15.00	I	56 î 50. 291' 00"	066 î 46. 918' 00"
3- 7	21	13.00	I	56 î 50. 289' 00"	066 î 46. 916' 00"
3- 9	24	14.00	I	56 î 50. 292' 00"	066 î 46. 922' 00"
3- 10	25	14.00	I	56 î 50. 294' 00"	066 î 46. 916' 00"
3- 11	24	15.00	I	56 î 50. 293' 00"	066 î 46. 918' 00"
3- 12	24	13.00	I	56 î 50. 289' 00"	066 î 46. 918' 00"
3- 13	22	12.00	I	56 î 50. 295' 00"	066 î 46. 918' 00"
3- 14	24	16.00	I	56 î 50. 296' 00"	066 î 46. 916' 00"

Table 2. Continue

Number	Diameter, cm	Height, mm	Kraft class	Geographic latitude	Geographic longitude
3- 15	24	15.00	I	56 î 50. 297' 00"	066 î 46. 915' 00"
3- 16	30	14.00	I	56 î 50. 295' 00"	066 î 46. 913' 00"
3- 17	27	13.00	I	56 î 50. 295' 00"	066 î 46. 907' 00"
3- 18	23	13.00	I	56 î 50. 295' 00"	066 î 46. 903' 00"
3- 19	26	14.00	I	56 î 50. 294' 00"	066 î 46. 901' 00"
3- 20	25	15.00	I	56 î 50. 293' 00"	066 î 46. 901' 00"
3- 1	33	14.00	I	56 î 50. 293' 00"	066 î 46. 911' 00"
3- 4	26	15.00	I	56 î 50. 286' 00"	066 î 46. 910' 00"
4 -1	30	16.00	I	56 î 51.885' 00"	066 î 48. 251' 00"
4 -3	32	22.00	I	56 î 51 884' 00"	066 î 48. 257' 00"
4 -4	27	20.00	I	56 î 51. 885' 00"	066 î 48. 263' 00"
4 -5	25	20.00	I	56 î 51. 887' 00"	066 î 48. 252' 00"
4 -6	25	22.00	I	56 î 58. 880' 00"	066 î 48. 261' 00"
4 -7	35	21.00	I	56 î 51. 889' 00"	066 î 48. 263' 00"
4 -8	53	23.00	I	56 î 51. 889' 00"	066 î 48. 258' 00"
4 -9	36	22.00	I	56 î 51. 891' 00"	066 î 48. 261' 00"
4 -10	29	22.00	I	56 î 51. 878' 00"	066 î 48. 269' 00"
4 -12	18	18.00	I	56 î 51. 885' 00"	066 î 48. 269' 00"
4 -11	35	22.00	I	56 î 51. 892' 00"	066 î 48. 257' 00 “
4 -13	25	20.00	I	56 î 55. 882' 00"	066 î 48. 265' 00"
4 -14	24	20.00	I	56 î 51. 879' 00"	066 î 48. 268' 00"
4 -15	31	22.00	I	56 î 51. 882' 00"	066 î 48. 260' 00"
4 -16	30	22.00	I	56 î 51. 897' 00"	066 î 48. 254' 00"
4 -17	24	22.00	I	56 î 51. 893' 00"	066 î 48. 271' 00"
4 -18	27	22.00	I	56 î 51. 895' 00"	066 î 48. 266' 00"
4 -19	36	22.00	I	56 î 51. 889' 00"	066 î 48. 280' 00"
4 -20	34	22.00	I	56 î 51. 882' 00"	066 î 48. 279' 00"
4 -2	23	20.00	I	56 î 51. 885' 00"	066 î 48. 260' 00"
5-1	47	16.00	I	56 î 47. 940' 00"	066 î 44. 593' 00"
5-3	32	17.00	I	56 î 47. 943' 00"	066 î 44. 600′00"
5-8	30	17.00	I	56 î 47. 934' 00"	066 î 44. 593' 00"
5-9	29	16.00	I	56 î 47. 933' 00"	066 î 44. 587' 00"
5-11	26	16.00	I	56 î 47.930' 00"	066 î 44. 590' 00"
5-14	51	20.00	I	56 î 47. 929' 00"	066 î 44. 598' 00"
5-15	19	16.00	I	56 î 47. 930' 00"	066 î 44. 587' 00"
5-16	19	16.00	I	56 î 47. 930' 00"	066 î 44. 582' 00"
5-19	22	16.00	I	56 î 47. 927' 00"	066 î 44. 585' 00"
5-20	30	16.00	I	56 î 47. 925' 00"	066 î 44. 594' 00"
5-5	33	16.00	I	56 î 47. 943' 00"	066 î 44. 590' 00"
5-6	26	16.00	I	56 î 47. 941' 00"	066 î 44. 589' 00"
5-7	23	14.00	I	56 î 47. 940' 00"	066 î 44. 583' 00"
5-12	38	17.00	I	56 î 47. 935' 00"	066 î 44. 584' 00"
5-13	41	18.00	I	56 î 47. 936' 00"	066 î 44. 591' 00"
Ò5-2	28	16.00	I	56 î 47. 938' 00"	066 î 44. 599' 00"
5-18	29	18.00	I	56 î 47. 926' 00"	066 î 44. 599' 00"
5-4	24	15.00	I	56 î 47. 942' 00"	066 î 44. 596' 00"
5-17	18	16.00	I	56 î 47 .937' 00"	066 î 44. 586' 00"

(sample area (SA) 1) and the lowest rates were shown by one of the oldest stands (SA3). This fact clearly shows a potential of measuring tree age as a biometric parameter based only on the radial growth observed over the last five years. However, a realistic transition to development of a bioinformatics model of this type is feasible only provided that larger databases of empiric materials

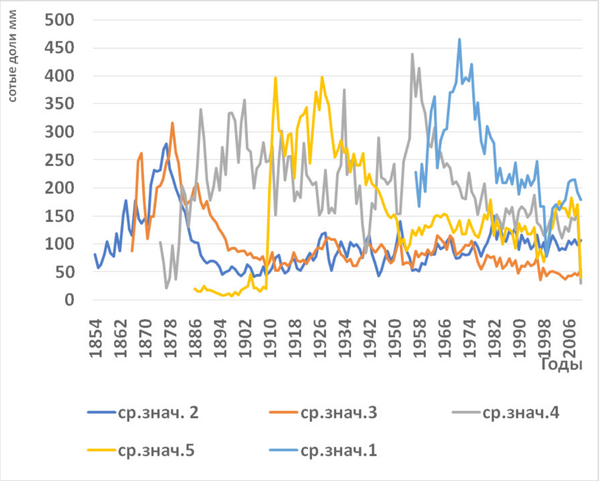

Fig. 1. Radial growth dynamics in tree ring chronologies

are created and processed based on algorithms of bioinformatics matrices functioning.

Results and Discussion

In this respect, while analyzing an impact of a forest type on tree ring variability it is necessary to keep in mind that the forest stands under study are of mixed age. Although forest types (or growing conditions) may differ in soil fertility, soil moisture content, light penetration levels and in other microclimatic parameters, the age factor (a center of auxin formation (tree top) being offset from a point of the cambial activity at the area of core sampling) can have a great formative effect on a tree ring width. There is no connection between these differences and the changes in volume growth and in increment growth observed among forest types. It is just a particular feature of the used method for assessing biometric parameters that should be always kept in mind.

If we pass on to the analysis of the radial growth variability over the latest period of forest stand growth (over the last 29 years), the graphs of growth variability time series will be as presented in Figure 2.

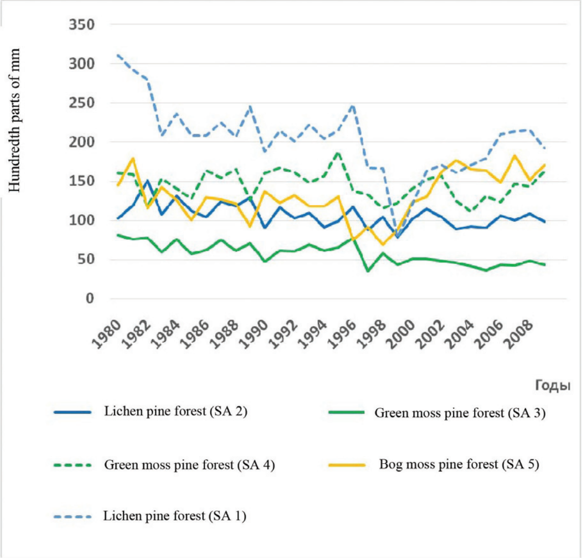

Fig. 2. Radial growth dynamics in tree ring chronologies from pine forests of different types.

While analyzing the graphs we will not take into account the absolute values of a tree ring width, but will focus on a nature of short-time variability (year-to-year growth variations). Chronologies show synchronous variations (concurrent decrease or concurrent increase in growth rates) in some particular years, and anisochronous variations can be observed (one chronology shows an increase in growth and another one shows a decrease in growth as compared with the growth observed last year) in some other years. As long as genotypic parameters are the same for the trees from the forest stands under study, synchronism/asynchrony in growth variations depends on differences in environment conditions between biotopes over the same growing season (or on differences in conditions over preceding growing seasons in rare cases). For example, during a dry year, a biotope with a higher moisture level provides favorable conditions for Scots Pine growth (resulting from improvement of peat moss bog soils) and therefore tree rings are wider this year. At the same time, there is a drastic decrease in moisture content in pine forests of a Myrtillus type during the same dry year resulting in relatively narrow tree rings being produced (as compared to the adjacent tree rings). It should be noted, however, that the differences between the forest types remain unchanged as far as the absolute tree ring widths are concerned – a relatively wide tree ring produced during a dry year in the bog moss pine forest will be much narrower than a relatively narrow tree ring from the pine forest of a Myrtillus type.

The described patterns explain the biologic foundation for development of algorithms to identify such qualitative forest characteristics as a type of growing conditions, forest type and even a certain phytocenosis. Under the forest survey activities, forest plots are allotted based on a phytocenotic principle (with some exceptions),and therefore it seems quite feasible from a biological point of view to identify a specific area of origin of the logged timber based on the dendrochronological information (first of all, based on the synchronism of tree ring width variations, but, in any case, not on the tree ring width itself and, for sure, not on the number of tree rigs as it isoften ascribed to the Dendrochronological method).

It goes without saying that environment conditions differ in a stronger way between different types of growing site conditions (dry, semi-wet and wet) than between different forest types (pine forests of a Myrtillus type and pine forests of a Vaccinium type inside the green moss forest group). Differences in ecological patterns of the specific phytocenoses (forest plots) are even weaker. Depending on the gradient of the ecological variations between different phytocenoses it can be easier or harder to identify such pytocenoses using dendrochronological methods (degree of reliability of the identification algorithm).

In the view of the above, it seems reasonable to study variability of the radial growth time series presented in Figure 2. For this reason, we can review a typical case of 1997 when all the chronologies under study show a decrease in growth rates while the chronology obtained from the bog moss pine forest (yellow line) shows a clear increase. Let us analyze the weather patterns of 1997 using climographs based on the time series of the monthly average precipitation recorded by the meteorological station in the city of Tyumen. The climograph representsthe dynamics of the 1997 monthly precipitation as compared to 1996 and shows what parameters changed in 1997 and therefore caused the above-mentioned growth response (Figure 3).

As we can see in Figure 3, the precipitation is distributed in such a way that its amount is practically the same in some months and differs drastically in the other months. In 1997, we can observe insufficient precipitation in May and June, and there is an especially strong difference between precipitations in July. Thus, 1997 was a dry year - just as in the hypothetical case we have described above – resulting in poor conditions for pine growth in all the forest stands under consideration apart from the bog moss forest where growing conditions improved.

If we investigate the pine chronologies from one forest type (green moss forest) (Figure 4), we can see that there is no significant asynchrony in the growth variations.

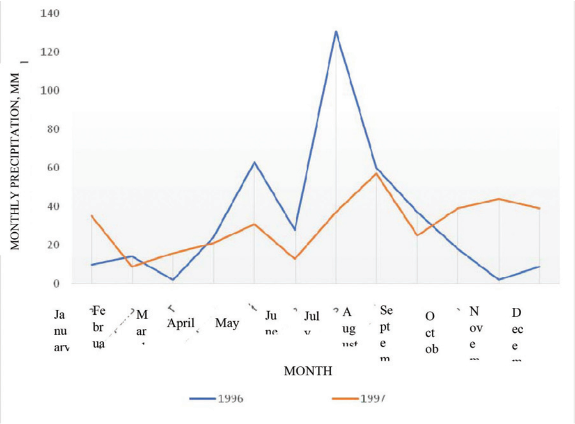

Fig. 3. Dynamics of monthly precipitation

When studying the graphs presented in Figure 4 we should highlight an important (primary) role of the age factor as compared to the forest type factor. Younger trees produce wider tree rings in comparison with old-aged trees. This explains their enhanced capability to sequestrate carbon and produce oxygen. Consequently, this example clearly shows that it is feasible to develop methods to identify such qualitative forest characteristics as ecosystem services based on the dendrochronological information.

Another important issue involves a possibility to reconstruct a growth formation process using lookback methods. Here we can use the following algorithm. Based on the graphs presented in Figures 4 we can identify that from 2000 to 2009 the average growth was 45.3 hundredth parts of a millimeter (0.45 mm) in pine trees of age class VII. It should be noted that the average growth rate does not have a

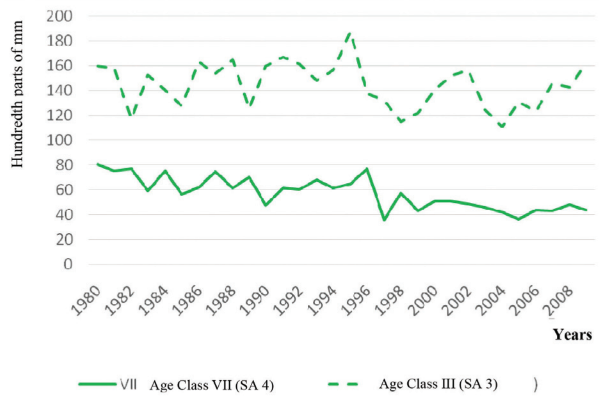

Fig. 4. Dynamics of radial growth in tree ring chronologies from green moss pine forests of mixed age.

component of the climate-based rate variations. For trees of age class III the same rate is 138.8 hundredth parts of a millimeter (1.39 mm). As a result, we can determine the current radial growth rate over 10 years for the other age classes using the extrapolation method: VI – 0.69 mm; V – 0.93 mm; IV – 1.17 mm. The summarized results are shown in Figure 5.

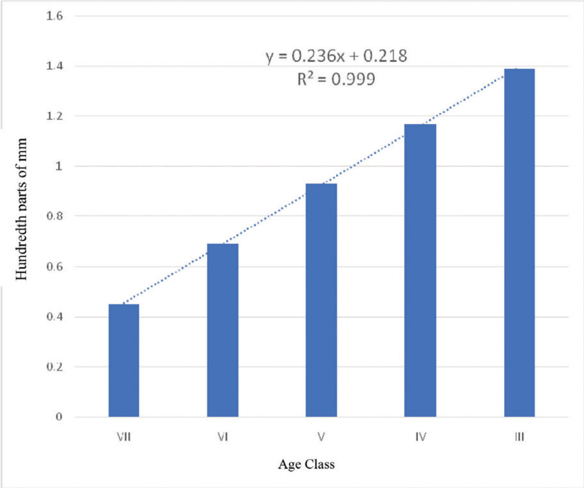

Fig. 5. Average current growthover 10 years in green moss pine forests of mixed age classes.

The linear regression equation allows extending the obtained data to the other age classes. This approach can significantly reduce the cost of initial survey data gathering and contribute to development of bioinformatics models for assessment of specific qualitative and quantitative forest survey factors using dendrochronological information.

Another important issue for consideration involves a possibility to use dendroclimatic information to develop bioinformatics models for assessment of qualitative and quantitative forest characteristics.

As a rule, to reveal a climatic signal in tree ring chronologies it is necessary, first of all, to single out a short-term component of the radial growth variability by removing the effects of the growth variability caused by an age-related trend of phytohormone nature as well as the effects resulted from exposure to the ecological factors which have long-term patterns of changes in exposure rates (interspecies and intraspecific competition; soil fertility; global climate changes, etc.)

For this purpose, dendroclimatology uses a procedure of indexing radial growth time series. One of the simple indexing techniques involves dividing a tree ring width observed in the year X by the average tree ring width observed over five years. First, each individual chronology (for each tree under study) is indexed and then they are used as a basis to calculate the generalized chronology (for a specific sample area). The results of the calculations performed are presented in Figure 6.

Fig. 6. Dynamics of radial growth indexes in the forest stands under study.

The analysis shows that the graphs indeed do not have an age-related trend. Synchronism and asynchrony in the growth variations are visible here even more clearly than in Figure 1. Extremely low growth indexes were observed in 1999 for SA 1 (lichen pine forest) and extremely high indexes were observed in 2000 for SA5 (bog moss pine forest).

A dendroclimatic analysis (one of the possible techniques) involves calculating correlation coefficients between the indexed chronologies (time series of growth indexes) and time series of meteorological parameters. Validity of the obtained correlation coefficients depends on the length of the time series used. The longer they are the lower absolute values are needed to consider a correlation coefficient as reliable at a specific probability level. A confidence level of 0.05 is usually used for biological studies. The results of our calculations are presented in Tables 1-4. To perform the analysis we used the databases available at http://www.pogodaiklimat.ru/history/28367_3.htm. Location of the Tyumen meteorological station (Tyumen region, Russia): 57°12′N 65°43′E; Elevation: 102 m).

When studying the data presented in Tables 1-4 it should be noted that distribution of reliable correlation coefficients is specific for different chronologies, which reflects a specific character of environment features of various growing sites within the sample areas. Mostly, ecophysiological interpretation of the obtained patterns cannot be easy especially in those cases where it involves an impact that the meteorological parameters, which have been in place before the beginning of active cambium division, have on growth rates. However, the fact that we might not understand the mechanism of influence does not change the existence of reliable correlation coefficients though it should be noted that the confidence level of 0.05 means that 5% of reliable correlation coefficients will not have any real biological basis and will be random. In our case, such correlations may appear, for instance, as a result of correlation between individual meteorological parameters. For example, clearly random relations include a relation between the growth index and December temperature in the calendar year of tree ring formation (i.e. influence of the meteorological parameters of the month when tree ring formation has been already completed).

One of the algorithms to identify qualitative characteristics of a forest phytocenosis (differentiated identification) may include analyzing a level of growth dependence on droughts assessed based on the total number of drought-associated signals. In

Table 1. Correlation coefficients between the indexed chronologies and the series of monthly precipitation rates with a one-year-back shift (precipitations of the previous year)

Month	Sample area (SA)				
	SA5	SA4	SA3	SA2	SA1
January	0.31	0.33	0.10	0.04	0.04
February	0.34	0.13	0.03	-0.16	-0.12
March	0.28	0.14	0.30	0.36	0.46
April	-0.14	-0.08	-0.18	-0.01	-0.31
May	0.24	0.19	0.14	0.17	0.25
June	0.14	-0.06	0.05	-0.04	0.20
July	0.02	-0.04	-0.05	0.08	0.10
August	0.25	0.35	0.10	-0.17	0.11
September	0.02	0.31	0.15	0.18	0.02
October	0.17	0.05	-0.39	-0.39	-0.20
November	0.03	0.14	0.22	0.08	0.01
December	-0.06	-0.04	0.10	-0.14	-0.23

Table 2. Correlation coefficients between the indexed chronologies and the series of monthly precipitation rates (precipitations in the year of growth formation)

Month	Sample area (SA)				
	SA5	SA4	SA3	SA2	SA1
January	0.20	0.21	0.01	0.04	-0.17
February	0.18	0.24	-0.01	0.04	-0.09
March	0.48	0.26	-0.10	0.06	0.20
April	-0.27	-0.30	0.06	-0.03	-0.05
May	0.39	0.39	0.06	0.05	0.08
June	0.20	0.05	0.02	0.15	0.20
July	0.02	-0.11	0.17	-0.08	0.05
August	0.15	0.33	-0.03	-0.23	0.02
September	0.13	0.31	0.10	-0.06	-0.18
October	-0.10	-0.40	-0.04	0.21	0.02
November	0.05	0.25	-0.14	-0.14	-0.01
December	-0.17	-0.09	-0.38	-0.29	-0.38

Table 3. Correlation coefficients between the indexed chronologies and the series of monthly average temperature rates with a one-year-back shift (temperatures of the previous year)

Month	Sample area (SA)				
	SA5	SA4	SA3	SA2	SA1
January	-0.21	-0.15	0.14	-0.02	0.13
February	-0.12	-0.20	0.17	0.23	0.13
March	-0.24	0.04	0.13	0.00	0.35
April	-0.16	0.11	0.50	0.31	0.30
May	0.14	0.02	-0.24	-0.20	0.13
June	-0.19	0.15	-0.40	-0.24	-0.19
July	-0.11	0.04	-0.27	-0.16	-0.28
August	-0.28	-0.22	0.11	0.10	0.02
September	0.04	-0.14	0.29	0.20	0.45
October	-0.13	-0.08	0.17	0.11	-0.09
November	0.01	0.00	0.15	0.24	0.42
December	0.11	-0.03	-0.06	0.11	-0.21

Table 4. Correlation coefficients between the indexed chronologies and the series of monthly average temperature rates (temperatures of the current year)

Month	Sample area (SA)				
	SA5	SA4	SA3	SA2	SA1
January	0.23	0.12	-0.03	-0.22	0.05
February	0.29	0.15	-0.17	-0.17	-0.16
March	0.17	0.43	-0.20	-0.13	0.23
April	0.15	0.33	-0.27	-0.22	-0.10
May	-0.01	-0.16	0.18	0.10	0.42
June	-0.39	-0.26	0.20	0.09	0.21
July	-0.16	-0.10	0.15	0.06	-0.03
August	0.14	-0.06	-0.02	0.01	0.05
September	0.26	0.17	-0.29	-0.02	0.18
October	-0.05	0.03	-0.29	-0.41	-0.16
November	0.16	0.19	0.04	0.07	0.36
December	-0.14	-0.36	0.09	0.15	-0.04

this case, by drought-associated signals we mean reliable positive correlations of the growth index with the total monthly precipitation of May, June, July and August as well as reliable negative correlations with the monthly average temperatures over the same period. The calculations preformed for the forest stands under study are presented in Table 5.

Table 5. Distribution of drought-associated signals in chronologies from different sample areas

Parameter	Sample area (SA)				
	SA5	SA4	SA3	SA2	SA1
Number of drought-associated signals	2	2	1	0	0

When looking into the data presented in the Table we can conclude that this method allows us to single out accurately the trees from the lichen forest type (SA2 and SA1). This does not mean, however, that drought does not affect the cambium activity in these forest stands. Ecophysiological mechanisms of the climate impact on growth rates are sophisticated and different methods identify different aspects of this impact. It is reasonable to interpret the obtained result as an example of implementation of the algorithm to identify the lichen forest type within the specific geographical conditions using the bioinformatics potential of the dendroclimatic analysis.

Currently, dendrochronology knows little about a bioinformatics potential of a coefficient of tree ring width variations in forest stands assessed over a number of years. A tree ring width varies in different trees but the nature of these variations differs in different years due to a year-to-year difference in the environment conditions. The time series of this parameter for the forest stands under study are presented in Figure7.

The graphs show that the coefficient under consideration has a clear short-term variability and a clear long-term variability. Its time series have both bottom and top local extreme points. It seems reasonable to do the corresponding follow-up research.

Conclusion

Thus, summarizing the above, we should conclude that the study of the tree ring chronologies of the pine forests from the Yaloturovsky Forest District (Tyumen Oblast) has revealed a potential of the bioinformatics identification of ecological patterns of phytocenosis formation and, in particular, has showed that it is feasible to identify forest types based on different methods.

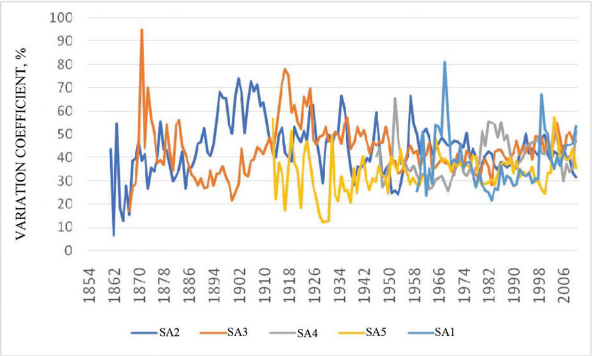

Fig. 7. Dynamics of the coefficients of tree ring width variations in forest stands from different sample areas

References

Bose, A.K., Gessler, A., Bolte, A., Bottero, A., Buras, A., Gailleret, M., Camarerro, J.J., Haeni, M., Heres, A.M., Hevia, A., Levesque, M., Linares, J.C., Martinez-Vilata, J., Matias, L., Menzel, A., Sanchez-Salquero, L., Saures, M., Vennetier, M., Ziche, D. and Rigling, A. 2020. Growth and resistance responses of Scots pine to extreme droughts across Europe depend on pre drought growth conditions. *Global Change Biology.* 26 (8) : 4521- 4537.

Fritts, H. C. 1976. *Tree Rings and Climate.* London, New York, San Francisco: Academic press – 576 p.

Gazo, A., Camarero, J.J., Sansquesa-Barredu, G., Serra-Malaquer, X., Sanderz-Salguero, R., Coll L. and Casals, P. 2020. Tree species are differently impacted by cumulative drought stress and present higher synchrony in dry places. *Frontiers in Forests and Global Change.* 2 : 573346.

Ivanova, Iu, Kovalev, A. and Soukhorolsky, V. 2021. Modelling the radial stem growth of the pine (*Pinus sylvestris* L.) forests using the satellite-derived NDVI and LST (Modis/Aqua) data. *Atmosphere.* 12 (1) : 12010012

Katjutin, P.N., Stavrova, N.I., Gorshkov, V.V., Lyanguzov, A. Yu., Bakkal, I. Ju. and Mikhailov, S.A. 2020. Radial growth of trees differing in their vitality in the middle-aged Scots pine forests in the Kola peninsula. *Silva Fennica.* 54 (3) : 10263.

Kolar, T., Kusbash, A., Cermak, P., Sterha T., Batkhun, E. and Rybnicek, M. 2020. Climate and wildfire effects on radial growth of *Pinus sylvestris* in the Khan Khentii Mountains, north-central Mongolia. *Journal of Arid Environments.* 182 : 104223.

Matveev, S., Tishin D. and Zhuravleva, I. 2020. Seasonal radial growth dynamics of Scots pine (*Pinus sylvestris* L.) in Voronezh region (Russia). *IOP Conference series: Earth and Environmental Science*. 595: 012044.

Matveev, S. and Rumyantsev D. 2013. *Dendrochronology.* Voronezh: Voronezh State Forestry Academy. 140 p. (in Russian).

Nagaviciuc, V., Roibu, C. C., Lonita, M., Mursa, A., Cotos, M.G. and Popa, I. 2019. Different climate response of three tree ring proxies of Pinus sylvestris from the Eastern Carpatians, Romania. *Dendrochronologia.* 54: 56 -63.

Palchikov, S. and Rumyantsev, D. 2009. Timber logging legality control based on tree-ring information. *Sustainable Forest Use.* 2 (2): 12–16 (in Russian).

Quan-Wen, J.I., Cheng-Yang, Zh., Lei Zh and Fa-Xu Zh, 2020. Stem radial growth dynamics of *Pinus sylvestris* var. mongolica and their relationship with meteorological factor in Saihahana, Hebei, China. *Chinese Journal of Plant Ecology.* 44 (3) : 57 – 265.

Rumyantsev, D.E. 2010. History and methodology of forestry dendrochronology. Moscow, Moscow State University of Forestry. 107 p.

Shyatov S. G. 1986. Dendrochronology of highest line of forests in Ural. M.: Science – 136 p. (in Russian).

Solomina, O.N., Bushueva, I.S., Dolgova, E.A., Zolotokrylin, A.N., Kuzneczova, V.V., Lazukova, L.I., Lomakin, N.A., Maczkovskij, V.V., Matveev, S.M., Mihajlov, A.Yu., Mihajlenko, V.N., Pozhidaeva, D.S., Rumyantsev, D.E., Sakulina, G.A., Semenov, V.A., Hasanov, B.F., Cherenkova, E.A. and Chernokulskij, A.V. 2017. Droughts of the Eastern European plain according to hydrometeorological and dendrochronological data. Geography institute of Russia Academy of Sciences, Moscow. 360 p. (in Russian).

Tolsky, A.P. 1904. About temperature and precipitation influence on pine diameter growth. *Forest Journal.* 5: 858-868.

Tabakova, M.A., Arzac, A., Martinez, E. and Kirdyanov, A.V. 2020. Climatic factors controlling *Pinus sylvestris* radial growth along a transect of increasing continentality of southern Siberia. *Dendrochronologia*. 62: 125709

Zheleznova, O.S. and Torbatov, S.A. 2021. Influence of climate on radial growth of Scots pine (*Pinus sylvestris* L.) in different habitats of Meshchera lowland. *Izvestiya RAN. Seriya Geograficheskaya.* 5 : 67 -77. (in Russian).