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The effects of limiting climate factors on the increment of native tree species (*Pinus sylvestris* L., *Quercus robur* L.) of the Voronezh region

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Abstract

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The article considers the Voronezh region climate dynamics over a 30-year period in comparison with the previous climate normal. Mathematical analysis of the relationships of cyclic changes in radial increment of native tree species of the south of the Russian Plain – Scots pine (*Pinus sylvestris* Linnaeus) and English oak (*Quercus robur* Linnaeus) – with climate factors (air temperature, amount of precipitation) is done. The greatest importance of April and, especially, May sums of precipitation for the formation of radial increment of native species (*P. sylvestris* and *Q. robur*) was confirmed. The forecast of changes in stand growth and productivity of the studied species is presented.

Keywords: climate dynamics; air temperature; precipitation; radial increment; Scots pine; English oak

Studies conducted by constructing predictive models show that climatic conditions change significantly, including in the territory of the central forest steppe. Ongoing climate change is characterized by a significant increase in temperature (particularly of cold seasons), reduction of atmospheric precipitation for the warm period of the year, and, consequently, increasing frequency of droughts. According to hydrometeorological studies and environmental monitoring, these trends are likely to continue at least over the next 5–10 years (Matveev, Matthews 2009; Katsov et al. 2011).

To preserve the valuable forest resources it is necessary to have knowledge not only of their current status, but also of the changes that have occurred over a longer period. Trees are the living bearers and custodians of information recorded in the annual rings. Its interpretation using dendroclimatological methods allows identifying the factors that affect the wood growth in particular conditions (Douglass 1919; Bitvinskas 1974).

Tree-ring based (dendroclimatic) studies are becoming increasingly important and they can be used to predict the growth of forest stands in connection with climate change (Elling et al. 2009; Sensuła et al. 2015; Solomina et al. 2017).

The main forest-forming tree species in the South East European forest-steppe zone, including the Voronezh region, are English oak (*Quercus robur* Linnaeus) and Scots pine (*Pinus sylvestris* Linnaeus).

Sustainable livelihood of tree species depends not only on their biological properties but also on environmental factors. Therefore, the analysis of

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fluctuations of climatic conditions is very important in the evaluation of tree radial increment in the region and their resistance to adverse environmental conditions (Matveev et al. 2017).

The aim of the study was to identify the effect of temperature and precipitation distribution in the particular months of the year on the increment of Scots pine and English oak in the Voronezh region under conditions of changing climate and make a forecast of changes in stand growth and productivity until 2024.

MATERIAL AND METHODS

Study area. The study was conducted in two permanent research plots (PRP) that are situated in the plantations of the Russian Plain. The objects of research are natural pine stands of Usmansky pine forest, located in the territory of the Somovskoe forest area (PRP 1), coordinates of this research plot: 51°78'N, 39°34'E; plantations of English oak are growing in Pravoberezhnoe forest of the Scientific and Experimental Forest of Voronezh State University of Forestry and Technologies (PRP 2), coordinates of this research plot: 51°42'N, 39°12'E (Fig. 1).

PRP 1 is located in 100-year-old Scots pine stand of natural origin, in the type of forest growth conditions (FGC) "pine forest on moderately moist sandy loamy soils" (B_2 symbol on Pogrebnyak's scale) (Migunova 2017).

PRP 2 – artificial stand of English oak, age of 57 years, (a form of trees with late disbanded leafing) is located in optimal growing conditions, in the type of FGC "oak forest on moderately moist clay soils" (symbol D_2 on the scale of Pogrebnyak). The characteristics of stands determined by the authors are documented in Table 1. The analysis of stands was provided in the year 2015.

Data sampling and analysis. The cores for dendrochronological analysis were selected in accordance with the generally accepted method (Drápela, Zach 1995; Shiyatov et al. 2000; Matveev 2001): cores were collected from 15 trees (2 cores per tree). After visual inspection, cores were excluded from further measurements (were rejected) if damaged, with defects that passed far from the centre.

As a result of the selection, 24 cores were selected and analysed on PRP 1 (Scots pine) and 22 cores were measured and analysed on PRP 2 (English oak).

Dating and tree ring width measurement were carried out on a LINTAB-6 table (RINNTECH, Germany) using the specialized software package TSAP-Win (Version 3.0, 1996). Calculation of the tree-ring indices of increment was done in the TREND program (2012).

Programs STADIA (Version 6.2, 1999) and STATISTICA (Version 6.0, 2001) were used for performing calculations of the basic statistical characteristics of tree-ring series, width of annual rings, indices of radial increment, and hydrothermal coefficient. Statistical characteristics of tree-ring series included annual values of the coefficient of variation, standard deviation, the limit possible error in determining the average radial increment of stands for each year.

Correlation analysis and analysis of variance were carried out to determine the strength of relationships and calculation strength of the influence of climate factors on the radial increment of species under consideration. Using the Microsoft

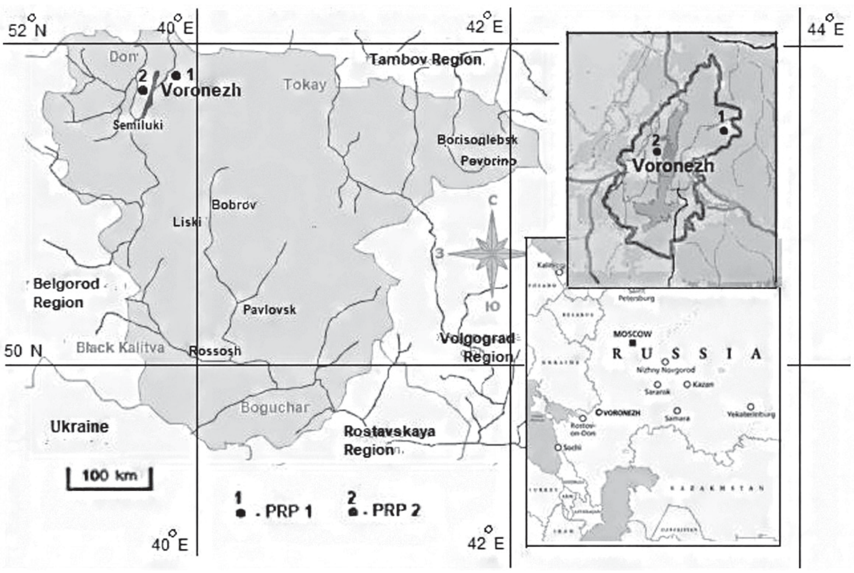

Fig. 1. Geographical position of the objects of study

PRP – permanent research plot

Table 1. Dendrometry characteristics of studied stands determined by the authors (2015)

PRP	Composition of tree species	FGC	Age (yr)	Growth class	h (m)	Mean DBH (cm)	f	V ($m^3 \cdot ha^{-1}$)
1	Scots pine (100%)	B_2	100	I	27	38	0.73	358
2	English oak (90%), linden (10%)	D_2	57	I	23	24	0.76	241

PRP – permanent research plot, FGC – forest growth conditions, B_2 – pine forest on moderately moist sandy loamy soils, D_2 – oak forest on moderately moist clay soils, h – mean height, f – density of tree stationing in PRP (corresponds to canopy density), V – stand volume

Excel program (Version 11.8404.8405, 2003) the dynamics of radial increment of Scots pine and English oak was modelled.

Standard statistical characteristics of tree-ring series include a signal-to-noise ratio (SNR) – it is an indicator of the intercorrelation of individual chronologies used to build a generalized chronology (Eq. 1):

$$\mathrm{SNR} = \frac{N \times r}{1 - r} \quad (1)$$

where:
N – number of individual chronologies in the series,
r – average interseries correlation coefficient.

Climate indicators were taken by us in accordance with observations of weather station No. 34123 "Voronezh", geographical coordinates 51°40'N, 39°13'E, 149 m a.s.l. – http://meteo.ru/data (All-Russia Research Institute of Hydrometeorological Information – World Data Centre), http://www.pogodaiklimat.ru/monitor.php?id=34123, during the 30-year period of averaging adopted in climatology (1987–2016) in comparison with the climatic norm (1961–1990), adopted on the recommendation of the World Meteorological Organization (Bulygina et al. 2010).

An important characteristic of the frequency of atmospheric droughts is the hydrothermal coefficient (HTC) which was proposed for the first time by the climatologist G.T. Selyaninov (Selyaninov 1928; Strashnaja 2011). This index demonstrates the relationship between air temperature and precipitation during the period with active plant growth, and it was calculated using Eq. 2:

$$\mathrm{HTC} = \frac{\sum P}{0.1 \sum T^*} \quad (2)$$

where:
P – precipitation (mm),
T^* – mean temperature for the months with daily temperature above 10°C.

In the city of Voronezh and in the Voronezh region, the period with average monthly temperature above 10°C extends from the May to September, which was used for HTC calculations here.

Coefficient of the strength of the influence (η^2) of climate factors on radial increment was calculated as the ratio of factorial dispersion (D_f) to random variance (D_c) according to Eq. 3 (STATISTICA):

$$\eta^2 = \frac{D_f}{D_c} \quad (3)$$

To model and predict the radial increment, we constructed an additive model described by a sinusoidal function, using a polynomial trend instead of a linear one, which allows to significantly reduce the model error. The function is described by Eq. 4:

$$y(x) = \sum_{k=1}^{k=m_1} \left[a_k \times \cos\left(2\pi k \left(\frac{x-1}{T}\right)\right) + b_k \times \times \sin\left(2\pi k \left(\frac{x-1}{T}\right)\right)\right] + \sum_{k=0}^{k=m_2} c_k \left(\frac{x-1}{T}\right)^k \quad (4)$$

where:
k – autocorrelation coefficient of initial time series,
m_1 – degree of trigonometrical series,
T – period (yr),
m_2 – polynomial (trend) degree,
a_k, b_k, c_k – regression coefficients.

RESULTS

Statistical characteristics of the studied generalized tree-ring series

In assessing the validity of measurement data on the width of annual rings (t_a) for each calendar year by Student's t-test (t), the actual values of Student's criterion exceed the standard value (t_{st} = 2.18) for a confidence level of 0.95, i.e. the average value of the width of annual rings is measured reliably.

Statistical characteristics of the studied generalized tree-ring series are shown in Table 2.

The coefficient of variation of radial increment of all the studied samples varies in separate years between 8.9 to 58.1%. The probable error of determination of the average increment (width of annual rings) does not exceed 10%.

Table 2. Statistical characteristics of the studied generalized tree-ring series

Species	Quantity of measured cores	Period	Length of series (yr)	i_{sr} (mm)	SD	CV	P_{sr}	SNR
Scots pine	24	1915–2015	101	1.67 ± 0.09	0.910	40.6	9.1	127
English oak	22	1959–2015	57	2.03 ± 0.10	0.710	35.2	4.7	47

i_{sr} – average annual increment, SD – standard deviation, CV – average value of the variability of individual chronology, P_{sr} – limit possible error in determining the average radial increment of stands for each year, SNR – signal-to-noise ratio

The calculated SNR for pine was 127, and 47 for oak, i.e., generalized chronologies contain high variability due to the influence of climate factors (studied trees are sensitive to changing climatic conditions).

Analysis of the dynamics of climatic parameters

The average annual values of average ($T_{avg.}$), minimum ($T_{min.}$) and maximum ($T_{max.}$) air temperatures, amount of precipitation ($P_{sum\ of\ avg.}$) according to the "Voronezh" weather station for 1961–1990 are: $T_{avg.}$ = 6.1°C, $T_{min.}$ = 1.9°C, $T_{max.}$ = 10.6°C, $P_{sum\ of\ avg.}$ = 580 mm; for 1987–2016: $T_{avg.}$ = 7.2°C, $T_{min.}$ = 2.9°C, $T_{max.}$ = 11.5°C, $P_{sum\ of\ avg.}$ = 603 mm.

Dynamics of the average sum of precipitation for the April-September period shows the same trends as the average annual amount: it is 337 mm for 1961–1990, and 353 mm for 1987–2016.

In the studied region there is a continuous intensive increment of mean annual air temperature, mostly due to increasing winter temperatures, and a relatively small increase in the average annual amount of precipitation in the background of their cyclical fluctuations.

The dynamics of average annual air temperatures shows an increasing amplitude from 1961 to 1989 and reaches a maximum in 1987–1989 (3.7–8.2°C), whereas since 1989 the amplitude has decreased, but an intense uptrend is manifested (Fig. 2a). Since 2007 the average annual temperature did not fall below 7°C and in 2015 the record value of 8.7°C was observed.

It should be noted that there is a significant variation in rainfall by calendar year in the Voronezh region for the whole period of observations at the "Voronezh" weather station: from 263 mm in 1891 to 874 mm in 2012. Irregularity in rainfall is also characteristic of the warm period. Total precipitation for April-September in 2009 was 182 mm, in 2012 – 556 mm (64% of the anomalous annual amount), and in 2014 – only 227 mm again.

Fig. 2b represents comparative development of the absolute values of Selyaninov's HTC for the 30-year period of climate normal (1961–1990) and present time (1987–2016).

As the graph shows, there is a weak upward trend of HTC on the background of a high amplitude of absolute values from 1961 to 1990 (especially in 1979–1981). To date, from 1987 to 2016, the trend is a weak pull-down, the amplitude of absolute values is below, but there is an increase in the amplitude of the values after 2010, characterizing the instability of climate in general. The absolute range of HTC values in the Voronezh region from 1961 to 2016 varies from 0.52 to 2.24, which also indicates the instability of climatic conditions in the region.

Influence of limiting climate factors on radial increment of wood

Correlations of the tree-ring indices of Scots pine with climate factors (air temperature and total precipitation at the "Voronezh" weather station) over the months of the year are shown in Fig. 3a.

Fig. 3a shows that the increment of pine has the closest relationship with precipitation in April-August. Precipitation of winter and spring months also has a positive effect on annual increment that is caused by the limiting value of moisture supply for the spring period. In 1961–1990, the limiting value of the air temperature had a large influence on the increment of pine, especially in February-March. Currently, the role of precipitation has increased and this is confirmed by higher correlation coefficients of April-May for 1987–2014. In these two months the relationship reached its maximum and was 0.32 and 0.42 in 1961–1990, and it was 0.36 and 0.49 in 1987–2014, respectively.

The decrease in the values of correlation coefficients (both positive and negative) with temperature indicates the optimization of temperature regime in the last 30 years, particularly the increase in temperature for January-March, and the decline in their limiting role in the increment of pine in the region.

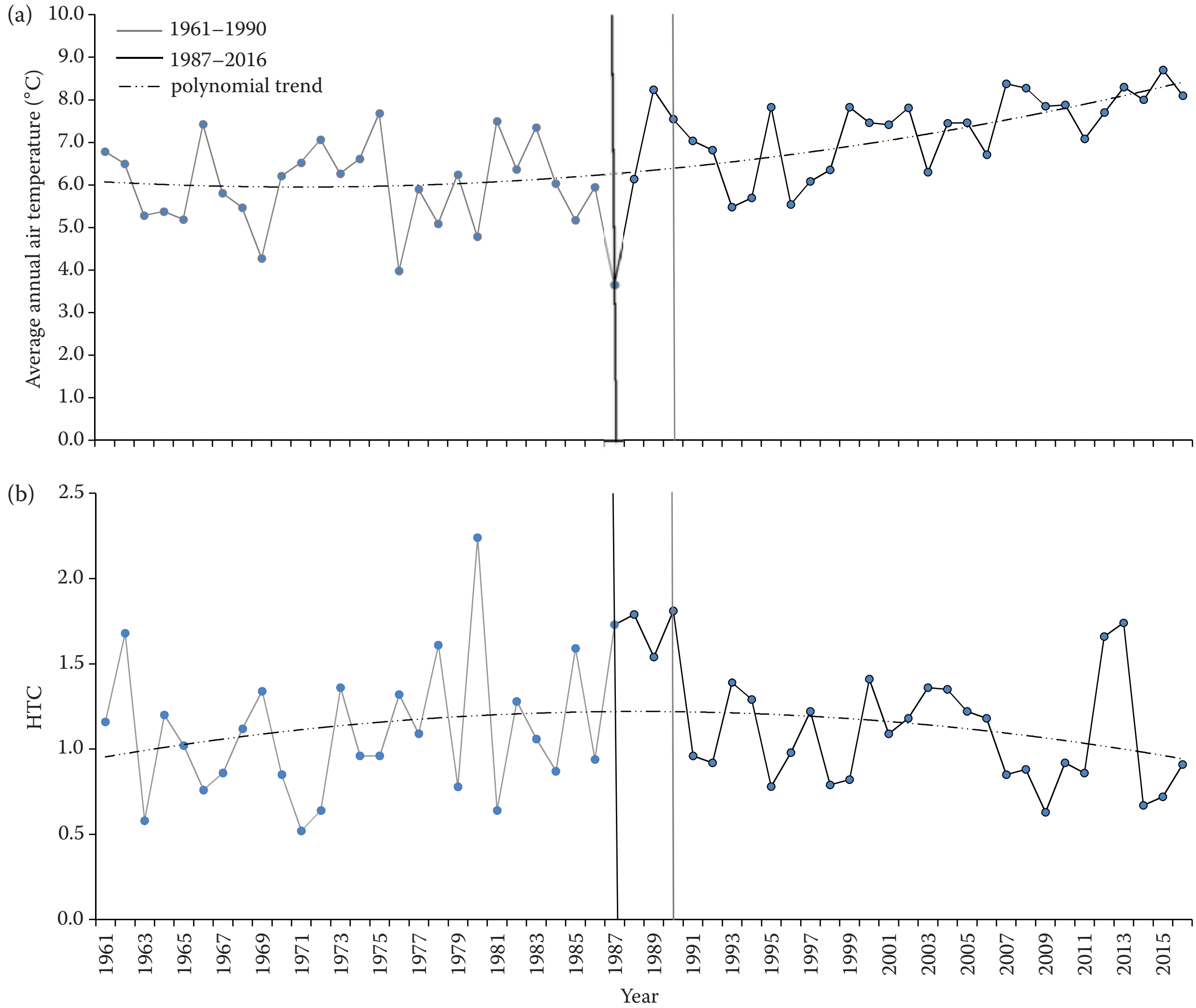

Fig. 2. Dynamics of average annual air temperatures (a), absolute values of Selyaninov's hydrothermal coefficient – HTC (b) for the 30-year period of the climate normal (1961–1990) and present time (1987–2016)

Cyclical fluctuations in radial increment of English oak in the Voronezh region are also associated with response to climate conditions. A significant decrease in the overall increment was identified in 1962, 1971, 1972, 1983, 1985, 1999, and 2010. Higher values of the tree-ring indices were noted in the following years: 1961, 1978, 1992, and 2006. Increment depression is mainly due to summer drought with temperatures above average standards and rainfalls which are less than average annual norms. Periods with high radial increment were noted in the years with low air temperatures and average annual rainfall, exceeding regular amounts.

The precipitation of the autumn-winter period and weather conditions at the beginning of the active growing season in April and May were of great importance for the radial increment of oak on PRP 2 (Fig. 3b).

In 1961–1990, the limiting influence of air temperature on oak increment was great, especially in March. In 1987–2014, tree-ring indices of oak showed a significantly lower correlation with March temperatures (the difference between the correlation coefficients was statistically significant for a confidence level of 0.95), but a slightly higher correlation with temperatures of February and July.

As the analysis of variance has shown, considered factors are in the following order according to the force of the influence on radial increment of pine and oak: HTC, precipitation for April-September, temperature, i.e., combined effects of temperature and rainfall are higher than the effects of each factor separately (Table 3).

Since the actual values of Fischer's criterion for all the considered factors are higher than for the standard (critical) one ($F_f > F_{st}$), for a confidence level of *P*-value < 0.05, it can be argued that the influence of climate factors (precipitation for April-September; HTC) on radial increment is significant. Consequently, the radial increment of stem wood is an integral indicator of the response of tree species to limiting climate factors.

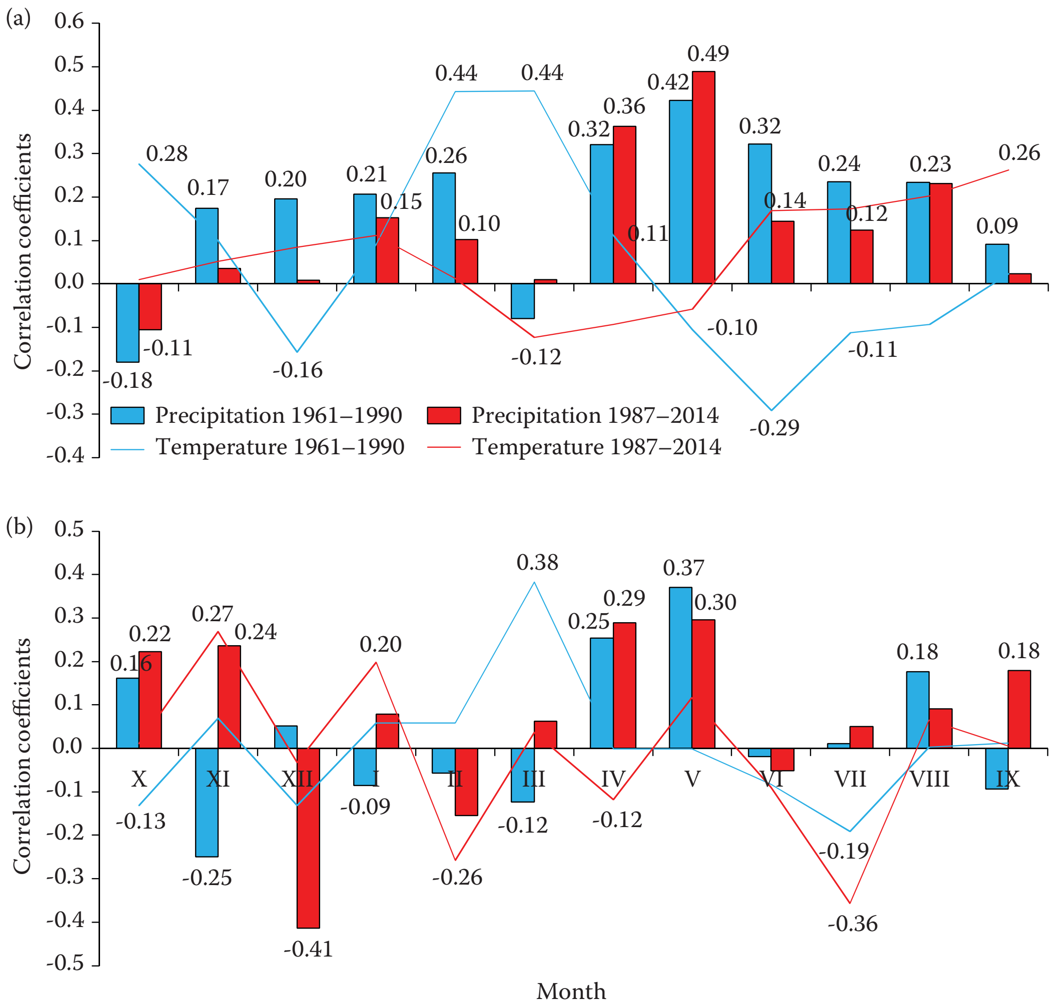

Fig. 3. Correlations of the tree-ring indices of Scots pine (a) and English oak (b) with average air temperatures and sums of atmospheric precipitation in 1961–1990 and in the years 1987–2014 for the months of the year

Table 3. Analysis of variance of the influence of climate factors on increment of Scots pine and English oak

Factor of influence on increment	Coefficient of the strength of influence on increment ± *m*	
	Scots pine	English oak
Hydrothermal coefficient	0.52 ± 0.053	0.38 ± 0.036
Precipitation in April-September	0.49 ± 0. 019	0.32 ± 0.029
Temperature	0.15 ± 0.046	0.20 ± 0.055

m – error of the representativeness of the main indicator of the strength of influence

Modelling and forecasting

The prediction of biological processes is an important actual area of ecological research. Tree-ring chronologies are used both in intrasystem prediction, when we forecast only increment of wood, and in intersystem prediction, when the tree-ring chronology, together with other solar and geophysical data is used for reconstruction and prediction of climate, ecological and other natural processes (Comin 1990).

To forecast the radial increment of Scots pine and English oak for a 10-year period (until 2024), we built an additive model of time series. We applied the 11-year cyclical component in the construction of the combined mathematical model. The constructed models of increment and the increment forecast are presented on the charts for Scots pine and English oak (Fig. 4).

DISCUSSION

Studies of the response of radial increment of trees to climate factors were carried out in different climatic regions (Agafonov, Kukarskikh 2008; Novák et al. 2010; Matveev, Chebotaryov 2012;

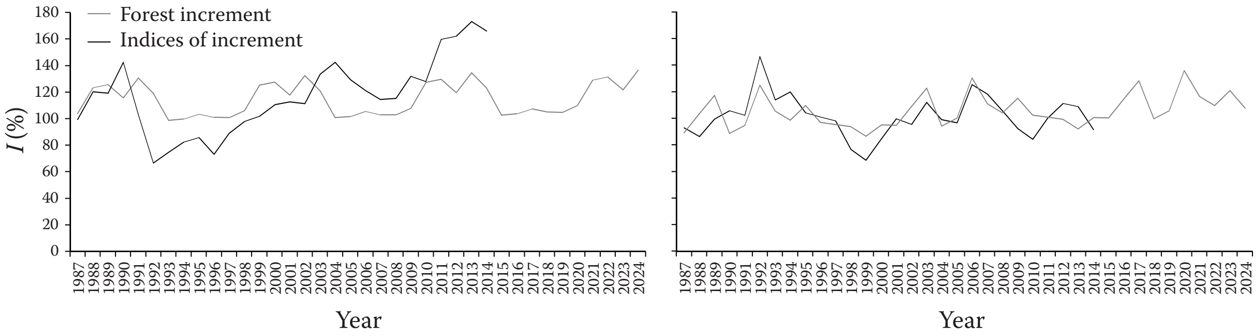

Fig. 4. Modelling and prediction of Scots pine (a) and English oak (b) increment – *I*

Rohner et al. 2016; Králíček et al. 2017; Vacek et al. 2017). Studies of Scots pine and English oak revealed a predominant influence of precipitation on the dynamics of their increment (Zhang et al. 1994; Rubtsov, Utkina 1995; Matveev, Chebotaryov 2012, Milenin 2012) and a joint impact of temperature and precipitation on it (Glyzin, Dorganova 1999; Magda, Vaganov 2006) was revealed. It should be noted that Bitvinskas (1974) in the context of Lithuania did not find a correlation between the increment of pine and average temperatures for May-August. Lazurenko (2002), in the Voronezh region, observed a moderate effect of June temperature (the correlation coefficient was –0.18). Our research has shown an even more significant value of June temperature for the climate normal period (1961 to 1990) (the correlation coefficient is –0,29), but for the period 1987–2014 the correlation of Scots pine increment with May-August temperatures has significantly decreased, with an increasing influence of precipitation.

CONCLUSIONS

As the conducted studies showed, radial increment of native tree species of the Voronezh region (Scots pine and English oak) depends not only on the amount of precipitation for the year, but also on the nature of their distribution by seasons and separate months. The closest relationship was observed with precipitation for April-May in the increment of pine and oak. The correlation with summer rainfall is less significant, especially for oak. Winter precipitation also has some positive impact on annual increment, due to the limiting value of moisture supply for the spring period. In 1961–1990, the limiting influence of air temperature was great for pine and oak growth, especially in February-March. In 1987–2014 the correlation coefficients of pine growth with air temperatures were considerably reduced. The values of correlation coefficients of oak growth with March temperatures declined significantly, but the values of the negative correlation with temperatures of February and July increased.

The decrease in the values of the correlation (both positive and negative) of pine increment with the air temperature indicates optimization of temperature regime in the last 30 years, particularly the increase in temperatures for January-March and reduction of their limiting role. Currently, the role of precipitation, particularly in April and May, has increased in the increment of stem wood of native tree species of the Voronezh region, which is confirmed by higher correlation coefficients for 1987 to 2014. As it is shown by the analysis of variance, the joint effect of temperature and precipitation on radial increment of pine and oak is higher than the influence of each of these factors separately.

The simulation results of radial increment of native tree species of the Voronezh region (Scots pine and English oak) have identified the following. If the observed trends persist in the climatic regime of the East European forest-steppe (significant increase in winter and annual average air temperatures, weak increase of precipitation on the background of their cyclical fluctuations) the response of the studied tree species in 2017–2024 will be different. Probably, radial increment of the stem wood of English oak will remain at the same level, whereas fluctuations in the increment of Scotch pine will occur at a lower level.

References

Agafonov L.I., Kukarskikh V.V. (2008): Climate changes of the last century and pine radial growth in the steppe of Southern Urals. Ecology, 3: 173–180. (in Russian)

Bitvinskas T.T. (1974): Dendroclimatic Research. Leningrad, Gidrometeoizdan: 172. (in Russian)

Bulygina O.N., Korshunova N.N., Razuvaev V.N. (2010): The weather on the territory of the Russian Federation in 2010. Available at http://www.meteo.ru/climate_var/sp.phpid_article=18

Comin G.E. (1990): The use of dendrochronological methods in environmental monitoring of forests. Silviculture, No. 2: 3–11. (in Russian)

Douglass A.E. (1919): Climatic Cycles and Tree-growth: A Study of the Annual Rings of Trees in Relation to Climate and Solar Activity. Washington, Carnegie Institution of Washington: 171.

Drápela K., Zach J. (1995): Dendrometrie (Dendrochronologie). Brno, MZLU: 149.

Elling W., Dittmar C., Pfaffelmoser K., Rötzer T. (2009): Dendroecological assessment of the complex causes of decline and recovery of the growth of silver fir (*Abies alba* Mill.) in Southern Germany. Forest Ecology and Management, 257: 1175–1187.

Glyzin A.V., Dorganova M.G. (1999): Dendro-climatic research in the forests of Northern Mongolia. Sibirskii Ekologicheskii Zhurnal, 2: 131–134. (in Russian)

Katsov V.M., Kobysheva N.V., Meleshko V.P., Porfiryev B.N., Revich B.A., Sirotenko O.D., Stadnik V.V., Khlebnikova V.I., Chicherin S.S., Shalygin A.L. (2011): Assessment of the Macroeconomic Consequences of Climate Change in the Territory of the Russian Federation for the Period up to 2030 and Beyond. Moscow, Federal Service for Hydrometeorology and Environmental Monitoring, D'ART: The Main Geophysical Observatory: 252. (in Russian)

Králíček I., Vacek Z., Vacek S., Remeš J., Bulušek D., Král J., Štefančík I., Putalová T. (2017): Dynamics and structure of mountain autochthonous spruce-beech forests: Impact of hilltop phenomenon, air pollutants and climate. Dendrobiology, 77: 119–137.

Lazurenko L.B. (2002): Dendroclimatology of Scots pine (*Pinus sylvestris* L.) in the conditions of the Central forest-steppe. [Ph.D. Thesis.] Voronezh, VGLTU: 183. (in Russian)

Magda V.N., Vaganov E.A. (2006): Climatic response of the mountain forest-steppes of Altai-Sayany region. Izvestiya RAN. Geographical Series, 5: 92–100. (in Russian)

Matveev A., Matthews H.D. (2009): Transient simulations of historical climate change including interactive carbon emissions from land-use change. Geophysical Research Abstracts, 11: 1104-1.

Matveev S.M. (2001): Dendrochronology, Tutorial. Voronezh, VGLTA: 88. (in Russian)

Matveev S.M., Chebotaryov V.V. (2012): Cyclic climate fluctuations in Central partially wooded steppe, fire seasons repeatability, the weather conditions of summer 2010. Analysis of observational data of weather station "Voronezh" and dendroclimatic data. In: Heat 2010 in the Central Black Earth: Implications, Reasons, Forecasts. Voronezh, Central-Black Earth Publishing House: 74–93. (in Russian)

Matveev S.M., Chendev Y.G., Lupo, A.R., Hubbart J.A., Timashchuk D.A. (2017): Climatic changes in the East-European forest-steppe and effects on Scots pine productivity. Pure and Applied Geophysics, 174: 427–443.

Migunova E.S. (2017): Forest typology by G.F. Morozova-A.A. Krudenera-P.S. Pogrebnyak is theoretical basis of forestry. Forestry Bulletin, 21: 52–63. (in Russian)

Milenin A.I. (2012): Effect of air temperature on the radial increment of pedunculate oak in the Shipov forest. Forestry Journal, 2: 65–69. (in Russian)

Novák J., Slodičák M., Kacálek D., Dušek D. (2010): The effect of different stand density on diameter growth response in Scots pine stands in relation to climate situations. Journal of Forest Science, 56: 461–473.

Rohner B., Weber P., Thürig E. (2016): Bridging tree rings and forest inventories: How climate effects on spruce and beech growth aggregate over time. Forest Ecology and Management, 360: 159–169.

Rubtsov V.V., Utkina I.A. (1995): Influence of meteorological factors on the growth of English oak wood. Silviculture, No. 1: 24–34. (in Russian)

Selyaninov G.T. (1928): On agricultural climate valuation. Proceedings of Agricultural Meteorology, 20: 165–177. (in Russian)

Sensuła B., Wilczyński S., Opała M. (2015): Tree growth and climate relationship: Dynamics of scots pine (*Pinus sylvestris* L.) growing in the near-source region of the combined heat and power plant during the development of the pro-ecological strategy in Poland. Water, Air, and Soil Pollution, 226: 220.

Shiyatov S.G., Vaganov E.A., Kirdyanov A.V., Kruglov V.B., Mazepa V.S., Naurzbaev M.M., Khantemirov R.M. (2000): Methods of Dendrochronology. Krasnoyarsk, KrasGU: 80. (in Russian)

Solomina O.N., Bushueva I.S., Dolgova E.A., Zolotokrylin A.N., Kuznetsova V.V., Kuznetsova T.O., Kukhta A.E., Lazukova L.I., Lomakin N.A., Matskovsky V.V., Matveev S.M., Mikhailov A.Y., Mikhalenko V.N., Pozhidaeva D.S., Rumyantsev D.E., Sakulina G.A., Semenov V.A., Khasanov B.F., Cherenkova E.A., Chernokulsky A.V. (2017): Droughts of the East European Plain in Hydrometeorological and Dendrochronological Data. St. Petersburg, Nestor-Historia: 360. (in Russian)

Strashnaja A.I. (2011): Agrometeorological characteristics of the drought in 2010 in Russia compared to the previous drought years. Proceedings of the Hydrometeorological Center of Russia, 345: 171–188.

Vacek Z., Vacek S., Bulušek D., Podrázský V., Remeš J., Král J., Putalová T. (2017): Effect of fungal pathogens and climatic factors on production, biodiversity and health status of ash mountain forests. Dendrobiology, 77: 161–175.

Zhang S.Y., Nepveu G., Eyono Owoundi R. (1994): Intratree and intertree variation in selected wood quality characteristics of European oak (*Quercus petraea* and *Quercus robur*). Canadian Journal of Forest Research, 24: 1818–1823.

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