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DENDROCHRONOLOGICAL ANALYSIS OF SCOTS PINE IN THE BAYANAUL NATIONAL PARK

Radial tree growth is a complex indicator that allows tracking changes in tree condition throughout their lifetime while accounting for climatic factors. Dendrochronological studies of Scots pine (*Pinus sylvestris* L.) provide valuable insights into the relationship between climate and growth, as well as regional differences. In the arid conditions of the forest-steppe zone of Northeastern Kazakhstan, within the Bayanaul State National Natural Park, an analysis of the relationship between the radial growth of Scots pine (Pinus sylvestris L.) and key climatic variables, such as air temperature and precipitation, was conducted. The LINTAB VI device was used to measure the width of annual rings. The calendar year of each ring was determined using the TsapWin computer program using the CrossDating method. The accuracy of the cross-dating was checked using cross-correlation analysis in the specialized COFEHA computer program. It was established that high temperatures in May and June have a limiting effect on the growth of early wood in this species. Additionally, the results of the study showed that pine growth is significantly dependent on the amount of precipitation in the current growing season. Chronological data indicate a low sensitivity of the forests of Bayanaul National Park to external environmental impacts, as evidenced by a sensitivity coefficient of 2,8. A high value of the first-order autocorrelation (≥ 0,50) was also revealed, indicating the influence of climatic conditions of previous years on the annual growth of pine. The research findings can be applied to developing strategies for adapting forest ecosystems to climate change and planning conservation and restoration measures for the forests of Bayanaul National Park.

Key words: scots pine, climate, correlation, radial increment, precipitation, air temperature.

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Баянауыл ұлттық паркі территориясындағы қарағайдың дендрохронологиялық талдауы

Ағаштардың радиалды өсуі – олардың өмір бойы күйінің өзгеруін бақылауға және климаттық факторларды ескеруге мүмкіндік беретін күрделі көрсеткіш. Шотландиялық қарағайдың (Pinus sylvestris L.) дендрохронологиялық зерттеулері климат пен өсу арасындағы байланыстар, сондай-ақ өңірлік ерекшеліктер туралы маңызды мәліметтер береді. Солтүстік-Шығыс Қазақстанның орманды даласының құрғақ жағдайында радиалды өсу мен негізгі климаттық айнымалылар (ауа температурасы мен жауын-шашын) арасындағы байланыстардың талдауы жүргізілді. Жылдық сақиналардың өлшеу үшін LINTAB VI құралы қолданылды. Әр сақинаның күнтізбелік жылы Cross Dating әдісімен TsapWin компьютерлік бағдарламасы арқылы анықталды. Кросс-танысу дәлдігі COFEHA мамандандырылған компьютерлік бағдарламасында корреляциялық талдау арқылы тексерілді. Шотландиялық қарағайдың (Pinus sylvestris L.) ерте ағаштарының өсуіне негізгі шектеуші әсер мамыр-маусым айларындағы жоғары ауа температурасының әсер ететіні анықталды. Шотландиялық қарағайдың өсуі ағымдағы вегетациялық кезеңдегі жауын-шашын мөлшеріне байланысты екендігі көрсетілген. Баянауыл табиғи паркінің хронологиясын сыртқы орта факторларына сезімтал емес деп санауға болады, өйткені сезімталдық коэффициенті 2,8 құрайды. Сондай-ақ бірінші ретті автокорреляцияның жоғары мәні (≥ 0,50) атап өтілді, бұл тық жағдайлар мен қарағайлардың ағымдағы жылдық өсуі арасындағы байланысты көрсетеді. Зерттеу нәтижелері орман экожүйелерін климаттық өзгерістерге бейімдеу стратегияларын әзірлеу, сондай-ақ Баянауыл ұлттық паркінің ормандарын қорғау және қалпына келтіру шараларын жоспарлау үшін пайдаланылуы мүмкін.

Түйін сөздер: шотландиялық қарағай, климат, корреляция, радиалды өсу, жауын-шашын, ауа температурасы.

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Дендрохронологический анализ сосны обыкновенной на территории Баянаульского национального парка

Радиальный прирост деревьев – комплексный показатель, позволяющий проследить изменение их состояния в течение всей жизни и учесть климатическую составляющую. Дендрохронологические исследования сосны обыкновенной (Pinus sylvestris L.) предоставляют ценную информацию о взаимосвязях климата и роста, а также региональных различиях. В засушливых условиях лесостепной зоны Северо-Восточного Казахстана на территории Баянаульского государственного национального природного парка проведен анализ связи радиального роста сосны обыкновенной (Pinus sylvestris L.) с ключевыми климатическими переменными, такими как температура воздуха и осадки. Для измерения ширины годовых колец использовался прибор LINTAB VI. Календарный год каждого кольца определялся с помощью компьютерной программы TsapWin методом CrossDating. Точность перекрестной датировки проверялась с помощью кросс-корреляционного анализа в специализированной компьютерной программе COFEHA. Установлено, что высокие температуры мая и июня оказывают лимитирующее влияние на рост ранней древесины сосны. Кроме того, результаты исследования показали, что рост сосны существенно зависит от количества осадков в текущем вегетационном периоде. Хронологические данные показывают низкую чувствительность лесов Баянаульского национального парка к внешним воздействиям окружающей среды, о чем свидетельствует коэффициент чувствительности 2,8. Выявлено также высокое значение автокорреляции первого порядка (≥ 0,50), что указывает на влияние климатических условий предыдущих лет на годовой прирост сосны. Результаты исследований могут быть использованы для разработки стратегий адаптации лесных экосистем к изменениям климата, а также для планирования мероприятий по охране и восстановлению лесов на территории Баянаульского национального парка.

Ключевые слова: сосна обыкновенная, климат, корреляция, радиальный прирост, количество осадков, температура воздуха.

Introduction

Forest ecosystems are considered self-regulating and capable of maintaining dynamic equilibrium under various conditions [1, 2]. However, anthropogenic factors can disrupt these ecosystems [3, 4]. Forest ecosystems play a key role in ensuring ecological sustainability, performing essential functions such as regulating water resources, carbon sequestration, and preserving biodiversity. Forests are home to a significant portion of the world's terrestrial biodiversity, making them crucial natural areas for conservation and study [5]. Due to their ability to regulate precipitation and evapotranspiration, forest ecosystems have a significant impact on climate and hydrological cycles [6]. Increasing climate variability and growing anthropogenic pressures pose serious threats to these ecosystems [7]. Global warming and climate change are the main causes of wildfires worldwide [8]. These factors lead to disruptions in ecosystem processes, reduced biodiversity, and forest degradation, necessitating detailed studies to understand their resilience and dynamics.

Dendrochronology, a method based on the study of tree rings, plays a key role in investigating the interactions between forest ecosystems and climatic and anthropogenic factors. The width, density, and other characteristics of these rings reflect the climatic conditions in which the tree grew, as well as various natural and anthropogenic impacts. Analysis of dendrochronological data allows for the reconstruction of climatic changes, dating of historical events, estimation of tree and forest ages, and the study of the dynamics of forest ecosystems in response to environmental changes. This method enables highly accurate reconstruction of past climate changes, assessment of the influence of temperature and precipitation on tree growth, and identification of the dynamics of ecosystem processes [9]. Due to its accuracy and versatility, dendrochronology is an indispensable tool for predicting changes in forest ecosystems and developing strategies for their sustainable management.

A study of the annual rings of Scots pine (Pinus sylvestris L.), a dominant tree species in forest-steppe zones, provides an opportunity to assess the impact of temperature and precipitation on radial growth, yielding valuable information on the adaptive capacities of forest ecosystems under changing climate conditions [10]. A number of studies highlight the significance of air temperature for radial growth of pine. It has been shown that temperature conditions at the beginning of the growing season are crucial for the formation of early wood [11]. Extreme summer temperatures can significantly reduce growth, which is associated with increased transpiration and drought stress [12]. Water availability also plays a significant role. In the study by Cedro, A., & Cedro, B. (2018), a direct relationship was found between the amount of precipitation during the growing season and wood growth, especially in arid regions [13]. Similar conclusions are presented in the work of Matveev, S., et al., which shows that precipitation during critical periods can compensate for the negative impact of high temperatures [14]. Climatic features of regions significantly influence pine growth. In northern regions, the temperature factor is more important, while in southern regions, precipitation plays a leading role [15]. The work of Zheleznova, O. S., & Tobratov, S. A. (2019) confirms the significance of the combination of climatic factors for the adaptation of pine in various geographic conditions [16].

Dendrochronological studies of Scots pine allow not only to study the reactions of forest ecosystems to changes in temperature and precipitation but also to predict their adaptive capacities under changing climate conditions. This makes such studies an important tool for developing strategies for sustainable forest management.

Materials and methods

For this study, dendrochronological samples were collected from Scots pine trees growing in the Bayanaul State National Natural Park (BSNNP) in northeastern Kazakhstan, Pavlodar Region. The coordinates of the sampling site and climate data sources are as follows:

- N – 50°49.58’
- E – 75°42.30’
- Height above sea level – 555 m.

The study site in the BSNNP is located on a gentle (up to 10°) southeastern slope of a low hill, within a pine stand on chestnut soils. The soils are stony and poorly developed, with no herbaceous cover. Wood samples (cores) for dendrochronological analysis were collected from Scots pine trees of various ages. Trees for coring were selected in sparse forests in areas of their greatest concentration, and within sample plots in forest stands. Cores were taken at a height of 1.3 m from the root collar. Sample collection and preparation for dating were carried out according to standard dendrochronological methods [17, 18, 19]. Samples were cleaned using blades and a clerical knife. Annual ring boundaries were revealed by rubbing tooth powder into the cleaned surface of the core. The width of annual rings was measured to an accuracy of 0.01 mm using a semi-automatic LINTAB VI instrument. The calendar year of each ring was determined in the TsapWin computer program using the cross-dating method [20, 21]. The accuracy of cross-dating was verified using cross-correlation analysis in the specialized computer program COFEHA [22, 23].

The quality of the dendrochronological material was assessed using the ARSTAN program based on the following indicators: Pearson correlation coefficient, standard deviation, skewness, mean sensitivity coefficient, first-order autocorrelation, and expressed population signal (EPS) of the chronology. A threshold value of 0.85 was adopted for EPS, below which the total variance indicates an unacceptable amount of noise in the chronologies [24].

The climatic response of tree-ring width (TRW) was assessed using correlation coefficients between local chronologies and monthly series of mean, maximum, and minimum temperature and precipitation, interpolated for the corresponding geographic coordinates of the spatially distributed CRU TS field (1901-2020), which is publicly available in the KNMI Climate Explorer database [25]. Correlations were calculated for the period from June of the previous year to September of the current year.

Results and discussion

According to the physico-geographical zoning, the territory of the Bayanaul State National Natural Park belongs to the Yermentau-Karakaralinsk region of the Central Kazakhstan low-hilly region. This region is characterized by a moderately dry and dry steppe climate, as well as a pronounced altitudinal zonation [26]. The uniqueness of the park's natural complex is due to the diversity of plant communities and soil cover, making it an important object for conservation and study [27].

Forest ecosystems, including pine forests, alder groves, birch forests, and aspen groves, are of the greatest value. The main forest-forming species in this area is Scots pine (Pinus sylvestris L.), which occupies about 56% of the park's forest area. These forests play an important role in maintaining the region's biodiversity and ensuring ecological sustainability.

The park is located in the center of the Asian continent, which determines its continental climate. The climatic indicators of the Bayanaul State National Natural Park are presented in Table 1.

Table 1 – Climatic parameters of the Bayanaul State National Natural Park

Climatic parameters	**Value**
Average annual temperature	+3,2 °C
Average January temperature	-13,7 °C
Average July temperature	+14,6 °C
Minimum January temperature	-17,8 °C
Maximum July temperature	+32,6 °C
Annual precipitation	340 mm (190–494 mm)
Precipitation from April to October	213 mm
Duration of frost-free period	140 days

The average duration of the frost-free period is limited to 140 days, which significantly affects the structure and seasonality of biological processes in the park's ecosystems. The annual precipitation is 340 mm, varying from 190 to 494 mm depending on the climatic conditions of a particular year. The greatest amount of precipitation falls from April to October (213 mm), which plays a key role in the formation of vegetation.

The climatic conditions of the Bayanaul National Park, characterized by continentality, significant temperature fluctuations, and limited precipitation, create a specific environment for the growth of woody plants, including Scots pine (*Pinus sylvestris* L.). These features make dendrochronological analysis particularly relevant for studying the response of trees to climate change and anthropogenic factors.

Based on the analysis conducted, high-quality dendrochronological data were obtained for the period from 1852 to 2017, corresponding to a maximum sample age of 166 years. The average tree-ring width is 1.255 mm, with a standard deviation of 0.464. The sensitivity coefficient was calculated at 0.288, indicating moderate variability in annual growth in response to climatic changes.

The inter-series correlation coefficient (r-bar) was 0.525, demonstrating high consistency in radial growth among samples. The first-order autocorrelation value (ar-1) of 0.742 confirms the influence of previous years' climatic conditions on current tree growth. The period suitable for dendrochronological analysis (EPS > 0.85) spans 72 years, from 1946 to 2017.

These statistical findings highlight the reliability of the constructed chronology and its value for analyzing the impact of climatic factors on the radial growth dynamics of Scots pine.

The high inter-series correlation coefficient (0.52) and the value of the standard deviation of radial growth (0.46) make it possible to assess in detail the response of Scots pine to climate change. The individual chronology is characterized by low sensitivity to external environmental factors, as evidenced by a sensitivity coefficient that does not exceed the threshold value of 0.3. Taken together, the statistical data confirm the reliability of the constructed chronologies, emphasizing the influence of abiotic factors on the radial growth of Scots pine.

The generalized dendrochronology for the Bayanaul area is presented in Figure 1.

Table 2 shows the correlation coefficients of the tree-ring width indices (TRW) with monthly climate data.

20 cores were collected in this area, the maximum age of trees was 165 years, while the period suitable for dendroclimatic analysis (EPS> 0.85) covers 72 years. For the region as a whole, there is a tendency for a negative correlation of the radial growth of trees with temperature, especially with its maximum values, and a positive relationship with the amount of precipitation. These dependencies are most pronounced in the summer and autumn months of the previous year, as well as in the spring and summer of the current vegetation season.

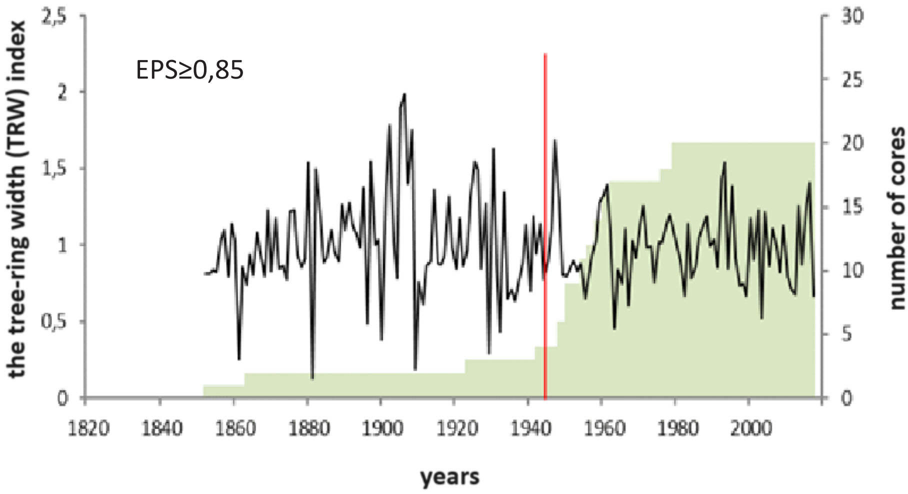

Figure 1 – Growth dynamics of Scots pine. The line represents the standard local chronology; the shaded area represents the sampling depth (number of cores for each year); the vertical red line shows the first year of EPS ≥ 0.85, i.e. the beginning of the period suitable for dendroclimatic analysis

Table 2 – Correlation coefficient of tree-ring chronology with monthly precipitation series, maximum, average and minimum temperatures from June of last year to September of the current year 1946-2017 in Bayanaul State National Natural Park

Parameters	Months															
	June*	July*	August*	September*	October*	November*	December*	January	February	March	April	May	June	July	August	September
Average temperature	-0.18	**-0.29**	**-0.40**	**-0.24**	-0.12	0.06	0.04	0.18	0.17	0.08	0.05	**-0.26**	-0.18	**-0.29**	**-0.23**	-0.08
Minimum temperature	-0.19	**-0.25**	**-0.34**	-0.15	-0.12	0.07	0.04	0.19	0.17	0.08	0.08	-0.22	-0.16	**-0.23**	**-0.27**	-0.07
Maximum temperature	-0.17	**-0.30**	**-0.41**	**-0.27**	-0.10	0.04	0.05	0.18	0.18	0.07	0.03	**-0.27**	-0.19	**-0.32**	-0.19	-0.08
Precipitation	0.12	**0.30**	**0.29**	**0.38**	0.03	-0.13	0.19	0.20	0.06	0.01	0.13	0.12	**0.26**	**0.33**	-0.07	0.10

At the Bayanaul site, a significant negative correlation was found between the radial growth of pine and the average and maximum temperature of the previous year in the period from July to September, and with the minimum temperature in July and August. Temperature indicators of the current year have a significant impact: the average temperature – in May, July, and August; the maximum – in May and July; the minimum – in July and August. A positive relationship between precipitation and pine growth is observed from July to September of the previous year, as well as in June and July of the current year.

Conclusion

Air temperature in May and June plays a key role in determining the radial growth of Scots pine, being one of the leading climatic factors. High temperatures during this period limit the growth of earlywood by 20%, while increased precipitation in the current growing season contributes to growth by 15%. Scots pine wood samples showed high suitability for dendrochronological studies. The chronology constructed on their basis demonstrates a significant correlation with climatic variables (r = 0.74), confirming the reliability of the data. The chronology of radial growth of pine obtained for the territory of the Bayanaul National Natural Park is characterized by moderate sensitivity to external factors. A sensitivity coefficient of 2.8 indicates a stable response of the tree to climate change. At the same time, the high level of first-order autocorrelation (≥ 0.50) indicates a significant influence of climatic conditions of previous years on the current growth of pine, which must be taken into account when modeling future changes. To gain a more complete understanding of the dynamics of pine radial growth, it is recommended to compare sites with different ecological conditions, such as the lower and upper forest boundaries. Such an analysis will allow identifying patterns in tree responses and improving the prediction of the impact of climate change on forest ecosystems. The results of the study have practical value. They can be used to develop strategies for adapting forest ecosystems to climate change, as well as for planning measures to preserve and restore forests in the territory of the Bayanaul National Park.

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Authors’ contributions

Mapitov N.B. – field work, office processing, conducting the research, preparing and editing the text, Aitlessov K.K. – statistical data processing, Klimenko M.Yu. – field work, office processing, conducting the research. Zhumabekova B.K. – conducting the research, approval of the final version of the article.

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