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Analysis of climate changes in the forest fund lands of Boyarka Forest Research Station

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Abstract. The relevance of the study is conditioned upon the predicted changes in the area, as well as the significant narrowing of the zone of optimal growth of Scots pine. These forecasts are based on obtaining data on the ongoing climate changes. A constant decrease in precipitation, along with a gradual increase in temperature levels, will lead to consequences such as uncontrolled changes in ecosystems. Such a substantial change in abiotic factors caused by human activity plays a key role in the formation of forest coenoses. The main purpose of this study was to analyse the change in the average annual temperature, as well as the monthly amount of precipitation observed in the forest communities in the Separated Subdivision of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forest Research Station". The analysis is performed over decades to obtain data on the level of temperature change in relation to the previous period. This also includes a comparison of monthly precipitation for 2021 relative to 1991-2020, which is set as normal. To obtain indicators of the average annual temperature, the average value method is used, followed by calculating the value of the average annual temperature for each decade. To find the deviation in total precipitation, the method of estimating the moisture conditions according to total precipitation is used. Therewith, the value of a substantial deviation is taken at 20% relative to the precipitation rate. According to the study results, it was established that in 2001-2010 the average annual temperature changed by 0.83°C relative to the previous decade, and in 2011-2020 by 0.74°C relative to the previous period. Such dynamics indicate a gradual increase in the average annual temperature, which is reflected in the forecasts of the world community. During the estimation of moisture conditions, separate months of 2021 with a critical level of precipitation in relation to the normal period were selected. In March, the amount of precipitation was 43% of normal, in June – 32%, in September – 40%, and in October – only 4.3% of normal. The value in November was observed at 63% of the norm. Such a decrease in the amount of precipitation in relation to a gradual increase in the average annual temperature poses a threat of a decrease in the hydrological level of moisture. This leads to a decrease in the radial increment of tree stands, and a gradual shift in the growing area of Scots pine. The obtained analysis results will further be used to conduct dendrochronological studies of tree rings of Scots pine (*Pinus sylvestris L.*) in the tree stands of the Separated Subdivision of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forest Research Station"

Keywords: forest plant community, annual temperature, Scots pine, precipitation, forest fund lands

Introduction

Scots pine is the main forest-forming species in Ukraine. Its main distribution is in Polissia and the northern part of the Forest Steppe. However, since the beginning of the 21st century, the degradation of pine stands has gained considerable momentum not only on the territory of Ukraine, but also on all continents. This is especially noticeable in the forest biocenoses of the temperate climate of the Northern Hemisphere. The loss of one of the main forest-forming species is unacceptable for Ukraine. The mechanisms of investigating the degradation should include the study of its course, as well as the causes and factors of its emergence in forest coenoses. The main reason for this

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phenomenon, as a result, is anthropogenic load, diseases and pests of arboreal plants combined with a set of ecological and climatic factors. Climate fluctuations observed over comparable periods of time, which are directly or indirectly caused by the activities of people on the planet and changes in the climatic conditions of the global atmosphere and are defined as climate change [1].

A substantial change in abiotic factors, because of human activity, plays a major, in some situations, a key role in the formation of forest coenoses. The number, productivity, and distribution of animal and plant communities primarily depends on limiting factors. The global community is on a trajectory that corresponds to a temperature increase of about +4°C by 2100 [2]. This level of temperature increase is catastrophic and will mean the emergence of uncontrolled changes in ecosystems [3]. However, there is also another claim: according to the United Nations, warming by 2100 is projected at 3.2°C [4]. According to the report of the Intergovernmental Group of Experts on Climate Change, scientific studies indicate that since the end of the 19th century, two-thirds of the anthropogenic impact is caused by human activity, namely the increase in the concentration of greenhouse gases in the planet's atmosphere. On the territory of Ukraine, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, the average annual temperature has increased by almost 2°C since the beginning of the 20th century, including by 1.2°C in the past 30 years alone [5]. Based on the results of the World Bank research, the main theses regarding the impact of climate change on the state of forest stands in Ukraine are highlighted. Thus, it was established that the total precipitation will increase annually, but the distribution of precipitation within the year will be uneven. The main increase in precipitation is predicted for the winter period. Prolonged droughts during the growing season will lead to the deterioration of the sanitary condition of forest biocenoses, which in turn will adversely affect the significant increase in the area of forest fires [6]. When investigating the resistance of Scots pine to climatic stress, as well as the reaction to increment in the pine regions of the Czech Republic, the following results of the impact of climate change on stands were obtained: a considerable negative impact of droughts on radial increment over a 30-year period was confirmed, while a positive impact was observed in spring temperatures in February and March, which were higher than normal [7]. Understanding the response of forests to current changes in climate factors is crucial for the implementation of forest management strategies, especially under conditions of expected negative, and even critical climate change [8]. The issue of forest adaptation, as well as its use as an effective means of mitigating global climate change, draws the attention of the scientific community to the key role of forests as one of the most accessible tools for stabilizing the climate and preserving the ecological balance on the planet [9]. According to the authors in [10], the wide ecological range of Scots pine unequivocally demonstrates its ability to adapt to variable environments. The originality of the study lies in the calculation of moisture conditions by the total precipitation using the method of deviation from the norm to determine the months that have deviations from the norm of precipitation.

The purpose of this study was to investigate the issue of changes in the average annual temperature and average annual precipitation in the forest fund of the Separated Subdivision of the National University of Life and Environmental Sciences "Boyarka Forest Research Station".

Materials and Methods

To analyse the general trends, as well as climate patterns in the forest area, the authors used the Separated Subdivision of the National University of Life and Environmental Sciences of Ukraine "Boyarka Forest Research Station" (hereinafter SS NULES of Ukraine "Boyarka FRS").

The forest massifs of SS NULES of Ukraine "Boyarka FRS" are located in the central part of Kyiv region between four administrative districts. Forest stands are in a wide strip, limited to the right bank of the Irpin River – tributaries of the Dnipro and stretch from west to east for 50 km, and from north to south for 35 km [11]. The main type of soil is sod and low-podzolic. According to the forest vegetation zoning of Ukraine, the forest areas of the enterprise, which are located in its northern, western, and eastern parts, belong to the southern zone of the Ukrainian Polissia, the Kyiv-Chernihiv Polissia forestry district, and the forest areas of the southern part of the enterprise belong to the Forest-Steppe zone of the Dniester-Dnipro forest-steppe management district. There are areas that are typical outwash plains of Polissia, as well as clearly defined eroded landforms inherent in the Forest Steppe.

The area of SS NULES of Ukraine "Boyarka FRS" is 17,835 hectares, of which 16,161.5 hectares (92.4%) are forest plots covered with forest vegetation. Of the total amount, the share of Scots pine (*Pinus sylvestris* L.) is 81.6% of forest areas covered with forest vegetation, the share of common oak (*Quercus robur* L.) and common alder (*Almus glutinosa* (L.) *Gaertn*.) is 13.5% and 2.0%, respectively [11]. According to the age indicator, one of the most important forest inventory indicators that characterizes the structure of tree stands [12], medieval plantations predominate and occupy a share of 51.3%. According to the site index classes of forest plots covered with forest vegetation, the share of class I and higher site index classes by age group is 85.5%. Thus, it can be stated that the tree stands of the Boyarka FRS are highly productive. Fresh sudibrovas (mixed oakerys) and subors (mixed pine forests) make up 74.3% and 24.5% of forest areas, respectively. The share of pine forests is 0.7%, and oakerys – 0.5% of forest areas covered with forest vegetation. The most favourable conditions for the growth of highly productive Scots pine stands, as the main forest-forming species, are fresh sudibrova and subor conditions. The forest fund of the enterprise is mainly represented by tree stands with a background portion of Scots pine in the first tier and admixture of common oak in the second tier. In general, the tree stands at the enterprise have a composition of 9Ps1Qr, the average age of the plantations is 74 years, the average site index class is I^a, and the average stand density is 0.63. The distribution of forest land by category was also analysed. Of the total area of the forest fund, 98.1% are forest plots, of which:

– 71.2% – artificial stands;
– 21.2% – natural stands;
– 4.1% – open forest cultures;

– 0.5% – forest nurseries and plantations;
– 0.1% – sparse forests.

Based on the analysis of the distribution of forest fund lands, almost a third of the area comprises artificial tree stands, namely 71.2% of the total amount. The data of the Borys Sreznevsky Central Geophysical Observatory in Kyiv [13] were used. The period 1881-2020 was used to simulate changes in average annual temperatures over a multi-year period. The average annual temperature for each year was determined according to the method of determining the average value, and these data were compiled by decade. For each decade, the average annual temperature was calculated using the method of determining the average value. A graph was drawn based on the obtained values, which made it possible to ascertain the change in the average annual temperature. The value of the temperature change relative to the previous period for each decade was calculated. Data for 1991-2020, which is considered normal, are used to determine the change in precipitation. The estimation of moisture conditions by total precipitation was analysed according to the method of deviation from the norm, and the obtained data are expressed in percentages (%). Indicators are determined for 2021 in relation to the norm period. During the estimation of the moisture conditions according to the amount of precipitation by the method of deviation from the norm, the months that have a substantial deviation from the norm will be determined. A significant deviation is taken at 20% relative to the precipitation norm.

Results and Discussion

Dynamics of changes in the average annual temperature by decade

The factors affecting the radial increment of pine stands were investigated and identified. One of the tasks is the analysis of data on regional climate changes, as one of the possible reasons for the loss of productivity of pine stands [14]. Conducting a retrospective analysis to establish the mechanism, as well as the degree of influence of climate change, to identify the sustainability of Scots pine (*Pinus sylvestris* L.) in the future.

It is necessary to ensure continuous and reliable monitoring of climate impacts, considering special threats to forest ecosystems, to observe changes in the productivity of forests. It is also important to state that an essential component is the monitoring of growth reduction, degradation of stands and soils, as well as loss of biodiversity, and as a result, degradation of coenoses [15].

Data from the B. Sreznevsky Central Geophysical Laboratory in Kyiv were used to analyse changes in general trends, as well as general patterns of changes in the temperature regime and the amount of precipitation in forest areas [13]. Based on data from the Central Geophysical Laboratory, the average monthly air temperatures over a prolonged period were analysed. According to the available monthly average temperature data, the average temperatures over the decade were analysed starting in 1881, which is presented in Figure 1. According to the analysis presented in Figure 1, since 1881 there has been a constant increase in temperature for decades. Using the data of the results obtained during the analysis of archival data, it is also possible to follow the linear trend shown on the graph. The obtained information allows ascertaining that the tendency of the temperature of the environment to increase will only persist in the future.

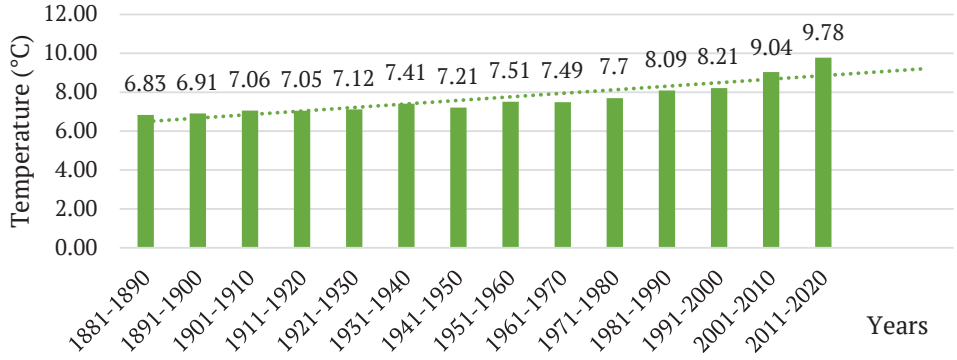

Figure 1. Average annual air temperature by decade (°C) in Kyiv

This was highlighted during the Paris climate agreement [16]. According to the given forecast, it was determined that in 2080-2100 there will be a considerable narrowing of the zone of optimal growth according to the climate humidity indicator [9]. Thus, if one analyses the changes in temperature relative to previous periods, which is presented in the table according to the data of the Central Geophysical Laboratory [13], changes in the average temperature relative to the previous period can be observed.

Table 1. Dynamics of average temperature (t) over decades

Observation period, decades	1881-1890	1891-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950
Indicator t (°C)	6.83	6.91	7.06	7.05	7.12	7.41	7.21
Difference t (°C)	–	0.08	0.15	-0.01	0.07	0.29	-0.2

Table 1, Continued

Observation period, decades	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2020
Indicator t (°C)	7.51	7.49	7.7	8.09	8.21	9.04	9.78
Difference t (°C)	0.3	-0.02	0.21	0.39	0.12	0.83	0.74

Having obtained the results, one can ascertain that an increase in the average annual temperature was observed in different specific periods. Thus, temperature increase was recorded in 1891-1900, 1901-1910, 1921-1930, 1931-1940, 1951-1960, 1971-1990, 1981-1990, 1991-2000, 2001-2010, and 2011-2020. A decrease in the average annual temperature was recorded in 1911-1920, 1941-1950, 1961, and 1961-1970. The largest decrease in temperature was recorded in 1941-1950, and was -0.2°C. Since 1971, the average annual temperature has gradually increased in each decade, except for 1991-2000, when the increase was recorded at 0.12°C, but in observations starting from 2001, a significant increase in the average annual temperature was recorded to 0.83°C in 2001-2010 and 0.74°C in 2011-2020.

Considering the obtained indicators, and the research carried out by the scientific community [17], in recent years, in the territory of the forest fund of the SS NULES of Ukraine "Boyarka FRS", atmospheric maximum temperatures have been observed, which can lead to changes in the hydrological level of soil water. Such a scenario can only be considered if the amount of precipitation for the year is studied, as well as for the growing season (April-September). The analysis of average monthly temperatures during the growing season plays one of the key roles in determining the radial increment of trees per year when conducting dendrochronological studies. The radial increment can also be affected by the temperature regime, not only during the growing season, but also during the rest period.

Deviation of climate indicators in 2021 to normal (1991-2020)

The deviation of the indicators of the average monthly temperature and the monthly amount of precipitation in 2021 was analysed according to the accepted norm of indicators of the period of 1991-2020 [13], which is presented in Figure 2.

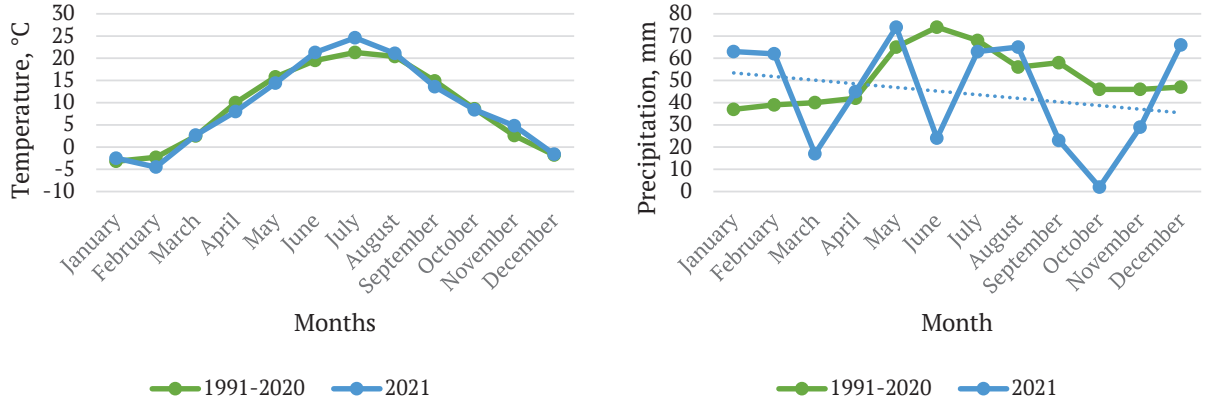

Figure 2. Comparison of average monthly temperature and precipitation in 2021 according to the norm (1991-2020)

It was established that the structure of annual temperatures during 1991-2020 is expressed by smooth changes during the period under study. However, the indicators of 2021 are characterized by lower temperatures at the end of winter and at the beginning of spring, as well as higher indicators in the summer period, respectively. Most of the elevated temperature indicators fall directly on the growing season, namely in June, July and August, an increase in the average temperature by almost 2°C was observed. It is also possible to single out an increase in temperature in October and November, relative to the normal period. However, there is also a decrease in the temperature regime in February, April, and May. The above data on the graph clearly show that in 2021, the period of low temperatures in February-March received a small amount of precipitation – only 17 mm compared to the norm (40 mm). During the following months of the growing season, until June 2021, the amount of precipitation gradually increased and corresponded to the normal indicators, but in June-July, the indicators of precipitation decreased sharply. A significant decrease in precipitation can be observed in June 2021, which was only 24 mm compared to the norm (74 mm). This situation was accompanied by an average temperature of 21.3°C, which is 1.8°C more than in the normal period. This period closely correlated with high summer temperatures that were more in line with the normal period. Such indicators can lead to a violation of the hydrological regime, which can lead to drying out of the forest litter, as well as dehydration of the soil root layers. A decrease in precipitation was observed in September, October, and November against the background of near-normal temperatures. Precipitation indicators during the autumn months amounted to 23 mm for September – 35 mm less than the norm; 2 mm for October, which is less than the norm by 44 mm; and for November – at 29 mm, the difference between the indicators of the normal period was 17 mm. However, the situation improved in December, and the amount of precipitation was 66 mm compared to the normal value of 47 mm. The dependence of radial increment is closely related to the decrease in precipitation during the growing season and is also correlated with fluctuations in average monthly temperatures, high indicators

of which, combined with insufficient precipitation, can lead to a decrease in the width of the annual ring.

Estimation of moistening conditions by the total precipitation
Using the data [13], during the research, the moisture conditions were estimated based on the amount of precipitation in 2021 by the method of deviation from the norm (1991-2020). Calculation results are presented in Table 2. Special attention is paid to the estimation of moisture conditions, in line with the statement that the main limiting factor in Ukraine is the hydrological conditions for the existence of living organisms.

The calculations results presented in Table 2 suggest that, in general, during the year, precipitation fell not significantly below the norm, the indicator is 86% of the norm. The significance of the deviation can be asserted only when it exceeds 20%. When analysing individual months of the year, it can be seen that the amount of precipitation was within the normal range in April, May, July, and August; in January, February, and December, their number was significantly higher than normal; however, in March, June, September, October, and November, the amount of precipitation was significantly below normal. The lowest extreme for precipitation was October – 4.3% of the norm, which is catastrophically insufficient for the normal functioning of coenoses. Such indicators, even when the temperature level is close to normal, demonstrate an increase in the expendable part of the water balance in forest areas. And even an increase in precipitation cannot level the moisture supply of coenoses, considering the indicator of the annual amount of precipitation, which is 14% below the norm.

Table 2. Estimation of moistening conditions by the total precipitation in 2021 by the method of deviation from the norm (1991-2020)

Indicator	Period (month)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Average long-term precipitation (1991-2020), mm	37	39	40	42	65	74	68	56	58	46	46	47	618
Total precipitation for 2021, mm	63	63	17	45	74	24	63	65	23	2	29	66	533
Precipitation as a percentage of the norm, %	170	159	43	107	114	32	93	116	40	4.3	63	140	86

Having obtained the value of the estimation of the moisture conditions by the total precipitation according to the method of deviation from the norm, where the values of the average multi-year total precipitation were used [13], and considering the earlier studies [18; 19] regarding the influence of temperatures and the hydrological regime, it was determined that with a negative trend of such indicators as a decrease in precipitation, extremely high temperatures during the growing season and low temperature indicators in winter and early spring directly affect the radial increment of tree stands. Furthermore, the limitation of the radial increment of pine in Zhytomyr Polissia is caused by precipitation, relative humidity during the growing season, as well as winter and early spring temperatures. Therewith, it is important to note that different dynamics of dependence of radial growth on precipitation were observed in different periods. With an increase in precipitation, there was an increase in radial growth without a limitation in the form of extreme temperatures during the growing season. It is also worth noting the regression of the radial increment with a decrease in the amount of precipitation and the presence of temperature extremes during the growing season [20].

The data obtained in the study allows comparing it with the research conducted in the territory of Ukraine in the corresponding area. When studying and determining the causes of dieback of pine forests of Volyn Polissia, it was found that there was a moisture deficit in the second half of the growing season. This period was accompanied by the withering and premature termination of vegetation of herbaceous vegetation, and premature shedding of older needles was also observed. Considering the indicators obtained during the research, one can observe an increase in temperature in the middle of the growing season relative to the norm, as well as a large decrease in the amount of precipitation, only 32% relative to the norm in June 2021. Due to such deterioration of the hydrological regime, as one of the phenomena, it is also possible to observe the activation of stem pests. In the forest-steppe zone, temperatures rose especially quickly during the cold period [21]. This led to a decrease in the radial increment of pine due to the disruption of winter rest in trees, while the minimum values of the radial increment are characterized by periods with a considerable decrease in precipitation and an increase in temperatures at the beginning of the growing season, as well as in its second half. When investigating the reaction of the radial increment of Scots pine to climate changes in the stands of the Left-Bank Steppe [22], it was established that the minimum radial increment was found in years characterized by high average annual temperatures and low winter temperatures. The maximum increment was observed at the optimal ratio of precipitation and temperature. However, the increase in temperature with a small amount of received moisture negatively affected the radial increment. The droughts during the growing season, which were accompanied by high early spring temperatures, lead to the weakening of tree stands. The greatest limitation of radial increment is caused by high temperatures during the vegetation period, early spring periods and in winter, as well as an increase in the amount of precipitation during the cold period, which does not contribute to the accumulation of moisture in the soil [23]. A similar increase in precipitation since the winter period is also noted in 2021, in January – 170% relative to the norm, in February – 159%, and in December – 140%, respectively. In the specified months, a considerable deviation from the norm was observed.

Analysing the results obtained during the study, it can be assumed that the reaction of the radial increment

in Scots pine stands in the SS NULES of Ukraine "Boyarka FRS" will have a similar value.

Conclusions

The performed analysis suggests that the main limiting factors of the functioning of forest coenoses are the average annual temperature, considering the minimum and maximum temperature extremes during the growing season (April-September). According to the analysis, over the last two decades, the average annual temperature has increased by 0.83°C and 0.74°C, respectively. The average amount of precipitation for a multi-year period, including the precipitation that falls during the growing season, as well as the assessment of moisture conditions by the total precipitation of the specified period according to the method of deviation from the established norm. During the calculation and analysis of the obtained temperatures, it was found that in 2021, in some months of the growing season, there was a significant deviation, and it amounted to a minimum of 39% compared to the period that was considered the norm. The months of 2021 that had a significant deviation from the normal period were noted, some of the lowest indicators were observed at 43% in October, 40% in September, and 43% in March relative to the normal period. In general, based on the assessment of the moisture conditions by the total precipitation using the method of deviation from the norm, it was calculated that in 2021, relative to the normal period, the amount of precipitation amounted to 86%. Such an indicator does not have a significant deviation, but it is an indicator of the occurrence of a climatic signal of the violation of the hydrological conditions in the forest fund of the SS NULES of Ukraine "Boyarka FRS". It has been established that the arid phenomena observed on the territory of the forest fund are undoubtedly of thermal origin. The obtained results will be further used to conduct dendrochronological studies of annual rings of Scots pine trees (*Pinus sylvestris* L.) in the tree stands of the SS NULES of Ukraine "Boyarka FRS".

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Аналіз кліматичних змін на території лісового фонду Боярської лісової дослідної станції

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Анотація. Актуальність дослідження зумовлена прогнозованими змінами ареалу, а також значним звуженням зони оптимального росту сосни звичайної. Дані прогнози ґрунтуються на отриманні даних щодо змін клімату які зараз відбуваються. Постійне зменшення кількості опадів разом із поступовим збільшенням рівня температури призведе до таких наслідків як некеровані зміни у екосистемах. Така істотна зміна абіотичних факторів причиною яких є діяльність людини становить ключову роль у формуванні лісових ценозів. Основною метою дослідження було проведення аналізу зміни середньорічної температури, а також місячної кількості опадів, що спостерігались в лісових угрупуваннях у Відокремленому підрозділі Національного університету біоресурсів та природокористування України «Боярська лісова дослідна станція». Аналіз проводиться по десятиріччях для отримання даних щодо рівня зміни температури по відношенню до попереднього періоду. А також співставлення кількості опадів по місяцях за 2021 рік відносно до періоду 1991–2020 років, який встановлений за норму. Для отримання показників середньої річної температури використовується метод середнього значення, з подальшим обрахуванням значення середньої річної температури для кожного десятиріччя. Для визначення відхилення сум опадів використовується метод оцінки умов зволоження за сумою опадів. При цьому за значення суттєвого відхилення приймається на рівні 20 % відносно показника норми опадів. За результатами отриманих даних в ході проведення дослідження, встановлено, що за період 2001–2010 років середня річна температура відносно попереднього десятиріччя змінилась на 0,83 градуси за Цельсієм, а за період 2011–2020 років на 0,74 градуси відповідно до попереднього періоду. Така динаміка свідчить про поступове збільшення середньої річної температури, що і відображено в прогнозах світової спільноти. Під час проведення оцінки умов зволоження виділено окремі місяці 2021 року з критичним рівнем опадів по відношенню до періоду норми. В березні кількість опадів становила 43 % до норми, червень – 32 %, вересень – 40 % та жовтень лише 4,3 % до норми. Значення у листопаді спостерігалось на рівні 63 % до норми. Таке зменшення кількості опадів у співвідношенні із поступовим підвищенням рівня середньої річної температури становить загрозу зменшення гідрологічного рівня вологи, і як наслідок зменшення радіального приросту деревостанів, та поступове зміщення ареалу сосни звичайної. Отримані результати аналізу в подальшому будуть використані для проведення дендрохронологічних досліджень деревних кілець дерев сосни звичайної (*Pinus sylvestris* L.) в насадженнях Відокремленого підрозділу Національного університету біоресурсів та природокористування України «Боярська лісова дослідна станція»

Ключові слова: лісове угруповання, річна температура, сосна звичайна, опади, землі лісового фонду