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Impact of Climate Change on Scots Pine Plantations: State, Problems, Challenges

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Abstract. It is identified that since the beginning of the 19th century, the degradation of pine stands has acquired a huge scale on all continents. In Ukraine, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, the average annual temperature has increased by more than 2°C since the beginning of the 20th century, in particular, by 1.2°C for the last 30 years. In recent years, the number of days with maximum summer temperatures is more than 35°C and 40°C has almost doubled, meaning the extreme weather events are intensifying. In most parts of Ukraine, there is already a tendency to increase droughts and fire danger, repeating the years during which plantings will be exposed to water stress, pest damage, and degradation of forest ecosystems in general due to the increase in the number and duration of hot periods.

It was determined that dendrochronological methods are used to investigate the relationship between climate change and radial pine growth. The main methods for investigating radial increment are to take cores at a height of 1.3 m from two opposite radii, to exclude the influence of random factors on the radial increment. The width of year rings is determined using installations for dendrochronological studies, with automatic data recording. These values of annual rings are processed according to the programmes of the International Tree Ring Data Bank (ITRDB). A specialised COFECHA programme is used to synchronise the series with setting the calendar year of formation of each year's growth. It was identified that the growth of Scots pine is limited by the humidification of the climate and the presence of sufficient moisture in the soil, but in the case of extreme temperatures, a negative trend towards drying out of plantings still remains

Keywords: dendrochronology, pathological processes of the forest, climate changes, pine, radial growth

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Introduction

The biggest global problem today is the increase in the concentration of greenhouse gases in the atmosphere, in particular, carbon dioxide, which is the main cause of global climate change. Due to the anthropogenic impact of human activity, the impact of the greenhouse effect is constantly increasing, as a result of the burning of fossil fuels, and their less absorption due to deforestation. Human activity can substantially change abiotic factors that play a key role in the formation of forest phytocenoses, because the number, distribution, and productivity of plant and animal communities depend on limiting factors. Since the beginning of the 21st century, the phenomenon of previously unheard-of degradation of pine stands, which is gaining a huge scale on all continents, has already been an indisputable fact. It is necessary to know not only the mechanism of its course but also the factors and causes of its appearance in forest phytocenoses to successfully resist the phenomenon. A vision of the most dangerous manifestations and a professional interpretation of the essence of the processes will allow determining the mechanism of influence on these factors, and the principle of forestry management that will be most suitable for the new transformed conditions. A specific feature of the lowland part of Ukraine is the presence of a transition zone between the forest and steppe, in which the vulnerability of forests is extremely high, and there is a high probability that climate change can cause irreversible loss of forests here. Forest vulnerability can be substantially reduced by developing and implementing systematic actions aimed at adapting Ukraine's forests to climate change. The basic imperative is to understand that Ukrainian forests are not just a source of renewable resources, but one of the main factors for levelling the anthropogenic load and creating comfortable conditions for humans. The adaptive potential of Ukrainian forests and the regional sensitivity of forests have not been sufficiently investigated, which actualises the urgent need for research to prevent disruption of the balance of environmental components, loss of environmental sustainability, and destruction of the natural environment.

Climate change, which has taken on a global character, has attracted the attention of all mankind as one of the most pressing environmental problems. According to the World Meteorological Organisation, the warmest years on record were the last three. According to the report of the Intergovernmental Panel on Climate Change, studies show that since the end of the 19th century, anthropogenic impact on two-thirds is due to human activity, namely, an increase in the concentration of greenhouse gases in the planet's atmosphere (Ivaniuta et al., 2020). In 2015, during the preparation for the signing of the Paris Climate Agreement (Conference on Climate Change in Paris, 2015), it was planned to limit the global temperature rise below 2oC by the end of the century. However, at the moment, according to the United Nations, the world is heading for warming at the level of 3.2oC until 2100 (UN Environment programme, 2019).

In Ukraine, according to the Ministry of Environmental Protection and Natural Resources of Ukraine, the average annual temperature has increased by more than 2°C since the beginning of the 20th century, in particular, by 1.2°C for the last 30 years (How the climate, 2020). In recent years, the number of days with maximum summer temperatures is more than 35°C and 40°C has almost doubled, meaning the extreme weather events are intensifying. In most of Ukraine, there is already a tendency to increase droughts and fire danger due to an increase in the number and duration of hot periods. An increase in summer temperature extremes leads to the threat of extinction of certain species and the emergence of new and invasive species. Such changes pose a threat to reducing forest areas and changing the species composition. In particular, the study provides a forecast for Scots pine (Buksha et al., 2017). According to the study, it was determined that according to the forecast, in the period 2080-2100, there will be a substantial narrowing of the optimal growth zone in terms of climate humidity. Due to climate change, it is expected that by the end of the 21st century, there will be quite substantial areas with unfavourable climatic conditions for the growth of Scots pine.

Materials and Methods

The study is based on the analysis of papers that consider the impact of regional and national climate changes on the radial growth of Scots pine stands. The dependence of the radial growth of pine trees on the action of climatic factors, such as precipitation, temperature, humidity, and deep deformations, and depressions of the hydrological regime is determined.

Results and Discussion

Trees respond to any fluctuations in the external environment, which is manifested in changes in the width of year rings – well-defined and easily accessible anatomical features. Trees affected by various factors have the same order of alternation of wide and narrow rings, with narrow rings indicating years of drought and other limiting growth factors, and wide rings indicating favourable years (Bitvinskas, 1974).

As A.I. Getmanchuk notes in his work, based on departmental materials of forestry enterprises of the Polesia zone, which are subordinate to the Volyn Regional Department of Forestry and Hunting (Volyn RDFH), in relation to the foci of acute drying of pine forests over the past two years, a hypothesis was put forward about the climatic origin of its root causes (Getmanchuk et al., 2017). Archival data from meteorological observations of the Kovel weather station for the period from 1946 to 2015 were used to analyse general climate trends and patterns in the forest area. According to the results of research, it was identified that drying of a new type, which is based on the defeat of pine trees by aggressive stem pests and pathogenic fungi, in the territory of the Volyn region in substantial sizes began to manifest themselves over the past 2 years. As of October 3, 2016, according to experts of the Volyn RDFH, 8861 foci of characteristic acute drying with a total area of 3708.7 hectares were identified. Such activity of aggressive stem pests, which manifested itself during the dry period, according to the study conducted by A.I. Getmanchuk, can also be associated with a decrease in productive moisture in the soil; this relationship is described below in the materials of this study. During the survey of pine stands, it was identified that recently they have been functioning in radically changed forest conditions. Analysis of the complex of characteristics of habitats and vegetation conditions showed that there are atypically deep deformations and depressions of the hydrological regime in forest areas. They are characterised by a sharp character and a powerful negative impact on forests, but until now the details of the mechanism of their formation and action remained uncertain. The climate of the area where enterprises of the Volyn RDFH are located in the materials of previous forest management is described as moderate, humid, with mild winters, unstable frosts, thaws, mild summers, substantial precipitation, and prolonged spring and autumn. The territory of the main woodlands was characterised by a close occurrence of ground water levels. Turf-podzolic soils are common, mainly of light mechanical composition. This is worth noting, because such soils are characterised by high water permeability and low moisture lifting capacity (capillarity). These circumstances contribute to the rapid formation of a crisis hydrological regime during droughts. In particular, in the acute drying year 2015, forest vegetation began to signal a lack of productive moisture in the second half of the growing season. Characteristic reactions were manifested in the form of wilting and early completion of vegetation of grass and tree-shrub flora, partial loss of leaves by individual species (birch, linden, sorbus, etc.), termination of growth processes, early discharge of older needles, defective fruiting, etc. The general mass weakening of the main stand was also accompanied by numerous thermal lesions of the leaf surface in the regrowth and the undergrowth.

In the course of this study, drying out of waterlogged and swampy areas was identified in plantings, and drying out of forest wells and digs due to an increase in the dry period. There was a drop in the water level in reservoirs inside woodlands and tracts, and a lack of water in land reclamation systems in forest and adjacent territories. A characteristic manifestation of the crisis hydrological regime is also the complete disappearance of typical surface water objects in various deepenings, cavities, etc. Considering all the aspects

that were highlighted during the study, it can be argued that there is a direct link between dry periods and depressions of the hydrological regime in plantings. In turn, this affects the wilting and early cessation of vegetation of shrubby vegetation and partial loss of leaves of individual tree species. Due to the deterioration of the hydrological regime in the plantings, the activation of stem pests was observed, which is also associated with the weakening of plantings due to droughts.

The purpose of the study by I.M. Koval et al., "Dendroclimatological studies of Scots pine in the planting of the Left-Bank forest-steppe of Ukraine", was to identify the impact of climate change on the radial growth of pine in the left-bank steppe on the example of a 100-year-old pine plantation of the SE "Kharkiv Forest Research Station" (Koval et al., 2017). Dendrochronological methods were used. Based on the results, tree-ring chronologies were created, which helped to establish links between climatic factors and radial growth of pine trees for two periods: 1960-1988 and 1988-2016.

Correlation analysis and the response function for two periods showed that due to the increase in temperatures and precipitation (with the exception of winter precipitation), the response of forest ecosystems to climate change changed, in particular: in the first period (1960-1988), there was a positive effect of summer temperatures on radial growth, but the increase in radial rings was limited by April temperatures, in the second period (1988-2016), June temperatures already negatively affected the growth. With a positive spring temperature and hydrological regime, a radial increase can be observed that is not limited by these indicators, but it is levelled due to high July temperatures. Therewith, a slight increase in precipitation during the growing season could not mitigate the impact of the high temperatures of the growing season on radial growth.

The responses of radial growth of Scots pine to climate change and recreational load in the forest-steppe zone of Ukraine were also investigated (Koval, 2011). Generally accepted methods in forestry and forest taxation, methods of comparative ecology, and dendrochronological methods are applied. The cores were selected at a height of 1.3 m of pine trunks by a Presler drill from the biogroups of trees. The values of summer wood layers were measured on a Henson digital instrument with an accuracy of 0.01 mm. The obtained series of individual values of tree rings are averaged for each plantation. Data on annual ring values were processed according to the programmes of the International Tree Ring Data Bank (ITRDB).

Data from the Komsomol weather station were used to analyse the influence of climate on the formation of tree rings. The calculation of growth change indices (GGt) for the year of damage (t), which are universal for all types of breeds and growing conditions is performed to identify violations in plantings under the influence of stress factors. As a result of the analysis of the dynamics of radial pine growth, three periods of stand development were identified for the periods 1967-2008. In the forest-steppe zone, warming and increased precipitation began to accelerate during 1989-2008. Temperatures rose particularly rapidly during the cold period, which led to a decrease in the trend of radial growth of pine trees due to a violation of the winter dormancy of trees in 1999-2008. Therewith, precipitation to a lesser extent began to limit the formation of rings in pines. Periods of stand development based on the dynamics of radial pine growth are identified: 1967-1975, 1976-1989, and 1990-2008, and years of minimal radial tree growth (1975, 1983, 1984, 1987, 1990, 1994, 1996, 2002, and 2007), which are characterised by droughts and low temperatures in winter and early spring, with the exception of 2007 with extremely warm winters and early spring. Pine radial growth maxima were established in 1980, 1989, 1997, and 2004 with a favourable heat-to-moisture ratio for tree growth.

In the course of the study, it was determined that the violation of winter dormancy of trees due to a rapid increase in temperature during the winter period in 1999-2008 led to a decrease in the trend of radial growth of pine trees. In addition, in years characterised by reduced precipitation, droughts, and low temperatures in winter and spring, minimal radial tree growth was determined. The maxima of radial growth were in years with a favourable ratio of temperature and hydrological conditions.

In their study, O.V. Zhukovskiy and O.V. Zborovska (Zhukovskiy & Zborovska, 2015) analysed the relationship between the radial growth indices of pine and climate for plantings of 61-80 years of age, which grow in fresh forest conditions on moraine and water-glacial deposits. For 1945-1976, a positive effect of precipitation on the radial growth of pine trees was identified for fresh pinewood plantings in places of water-glacial deposits, that is, in poor conditions and with low soil moisture capacity for the year and during the growing season In 1977-2008, these connections decreased, which is explained by an increase in precipitation. Comparing the periods 1945-1976 and 1977-2008, it was identified that the amount of precipitation during the growing season increased by 5%, and for the year – by7 %. However, in 2001-2010, the amount of precipitation during the growing season, on the contrary, decreased by 10%. Precipitation had a positive effect on the radial growth of trees in fresh forest stands in places of water-glacial deposits.

The negative influence of growing season temperatures on the formation of wood layers was identified for plantings growing in the fresh forest on water-glacial deposits for 1945-1976. Later, in 1977-2008, this restriction was relaxed due to the fact that the temperature increased by 1.3% (0.21°C) compared to the previous period of 1945-1976. The rate of warming accelerated during 1999-2008 when the average annual temperature increased by 6 % (by 0.9°C). March temperatures in the second period (1977-2008) increased the impact on the radial growth of pine trees for all plantings of fresh pine barrens and fresh su-barrens on moraine and water-glacial deposits due to their increase by 62% (1.8°C) compared to 1945-1976. Winter temperatures rose by 66% (1.5°C) in 1977-2008 compared to 1946-1976. A positive effect on the radial increase in winter temperatures was identified for planting fresh pinewood on moraine for 1977-2008 and in plantings that grew on water-glacial deposits for 1946-1976. It is established that plantings in fresh forest conditions on water-glacial deposits are the most sensitive to climate. Radial growth in all plantings is limited by climatic factors such as precipitation, relative humidity during the growing season, and winter and early spring temperatures. For 1977-2008, compared to 1945-1976, the dependence of radial growth of Pine on precipitation decreased, the amount of which increased by 7% during the growing season, but in 2001-2010, the opposite process occurred – a decrease in precipitation during the growing season and an increase in the dependence of radial growth on temperatures, which increased by 1.3% and 62%, respectively.

V.P. Ivanov in his study (Ivanov et al., 2021) proposed an approach for analysing the causes of a sharp decline in the radial growth trend under the influence of temperature and precipitation. The research was conducted on the territory of the Bryansk administrative district in the Educational-experimental forestry of the Bryansk State Engineering-Technological Academy. The climate situation was analysed for five years before the decline in growth and five years after that. Notably, the radial increase in the five years before the recession was not the same. During the study, it was identified that a more informative picture of the features of radial growth is given by detailing the influence of temperature at the level of the average monthly temperatures of the current and previous growing season and using indicators of the average monthly precipitation. Thus, the radial growth of Scots pine in the Bryansk region in dry and fresh forests occurs in years with cold January, warmer May, and August of this year, provided that January of last year is warmer. There was no substantial influence of the average monthly precipitation in conditions of violation of the hydrological regime.

Conclusions

The impact of climate change on the forests of Ukraine varies, depending on the geographical location, geomorphology, and topography of forest types and the forest management regime. The state and dynamics of forest ecosystems are the results of a complex interaction of environmental factors. Trend changes in the main climate indicators within the current and expected values are less dangerous than climate variability, frequency, and severity of extreme situations (heat waves or droughts). The growth of Scots pine in Ukraine is limited by climate humidification. In terms of humidity, favourable

conditions are very poorly represented, satisfactory conditions for pine trees in the West and to a small extent in the North, and in the rest of the territory – unsatisfactory and extreme. Unsuitable conditions are observed in the South of Ukraine.

The main limiting factors influencing the radial growth of Scots pine are the amount of precipitation, soil moisture, its capillarity, and the temperature regime at the beginning of the growing season of stands. The influence of summer temperatures also makes its adjustments to the development of plantings. Extreme summer temperatures can cause early leaf fall from woody and shrubby vegetation due to changes in the hydrological regime.

A change in the climatological situation can lead to a substantial transformation of forest covers, including a shift in the boundaries of pine ranges. It is climate change that is one of the most dangerous factors for the further destruction of forest covers and destabilisation of forestry.

It is necessary to know the mechanism of identification of changes in the types of plantings and stability of Scots pine in the future and conduct a retrospective analysis to establish the degree and mechanism of impact of climate change in the context of the progressive spread of depressions and digressions of plantings to successfully resist a negative phenomenon.

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Вплив змін клімату на насадження сосни звичайної: стан, проблеми, виклики

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Анотація. Досліджено, що з початку XIX ст. деградація соснових деревостанів набуває величезного масштабу на всіх континентах. В Україні за даними Міністерства захисту довкілля та природних ресурсів України середня річна температура з початку XX ст. зросла більш ніж на 2°C, зокрема на 1,2°C за останні 30 років. Останніми роками кількість днів із максимальними температурами влітку понад 35°C та 40°C зросла майже вдвічі, тобто йдеться про екстремальні погодні явища. На більшій частині України вже спостерігається тенденція до посилення посух, збільшення пожежної небезпеки, повторюваності років, упродовж яких насадження зазнаватимуть водного стресу, ураження шкідниками, а також деградації лісових екосистем загалом унаслідок збільшення кількості та тривалості спекотних періодів.

Визначено, що при дослідженні зв'язку між зміною клімату і радіальним приростом сосни використовують дендрохронологічні методи. Основними методами дослідження радіального приросту є взяття кернів на висоті 1,3 м із двох протилежних радіусів, для унеможливлення впливу на радіальний приріст випадкових факторів. Ширину річних кілець визначають за допомогою установок для дендрохронологічних досліджень, з автоматичною реєстрацією даних. Дані величин річних кілець обробляють за програмами Міжнародного банку даних деревних кілець (ITRDB). Для синхронізації рядів зі встановленням календарного року утворення кожного річного приросту використовують спеціалізовану програму COFECHA. Виявлено, що ріст сосни звичайної лімітується зволоженням клімату та наявністю достатньої кількості вологи у ґрунті, проте у разі екстремальних температур все одно зберігається негативний тренд щодо всихання насаджень

Ключові слова: кдендрохронологія, патологічні процеси лісу, кліматичні зміни, сосна, радіальний приріст