The state of Scots pine plantations in the steppe Voronezh region in drought conditions and under anthropogenic influence

A P Serdyukova
All-Russian Research Institute of Forest Genetics, Breeding and Biotechnology, Voronezh, Russia
E-mail: ali.serdyukova@yandex.ru

Abstract. Monitoring the state of forest tree plantations is an urgent task in today's changing climate conditions. Climate change presents acute challenges for steppe biome: there is a prolonged increase in average daily temperatures, accompanied by a deficit of precipitation, mainly in the spring-summer period, and droughts become more frequent. Also, in addition to climatic factors, the consequences of human economic activity have a negative impact on forest communities. The aim of the study is to assess the indicators of the vital state of Scots pine in the steppe Voronezh region under drought conditions and under anthropogenic influence. To study the state of forest woody plants, we selected two Scots pine plantations growing in contrasting ecological conditions of the steppe zone of the Central Black Earth region. The main indicators of the vital state were assessed: dechromation of needles, defoliation of the crown, the number of new cones, and the total score of the vital state of each plant and the studied plantation as a whole was calculated using the totality of these characteristics. It is found that a plantation under anthropogenic load is subjected to greater stress and has worse performance compared to a plantation from the same climatic zone, but growing on a relatively ecologically clean territory.

1. Introduction

Scots pine is a valuable species: it is widespread, well adaptable and is one of the main forest-forming species of the Voronezh region [1]. Pine plantations help to improve climatic conditions, improve soil fertility, prevent water and wind erosion, filter polluted air and have recreational and aesthetic value. However, this species is able to react sensitively to changes in the environment: climatic conditions, pressure of anthropogenic load [2]. Climatic droughts, lack of moisture and air pollution lead to the weakening of Scots pine plantations, promote the activation of pests, which leads to the drying out and death of trees. In this regard, monitoring the main indicators of the vital state of Scots pine is an urgent problem.

2. Statement of the problem

Voronezh Region is located in the south of the Central Federal District. The southern part of its territory belongs to the steppe region in the Voronezh region. The border between the forest-steppe and steppe regions is still the subject of discussion by many scientists [3]. In the studies of L. S. Berg (1936), the border between the steppe and forest-steppe regions runs along the Valuiki-Liski-Bobrov line, encompasses the Shipov Forest, Kamennaya Steppe, Novokhoporsk and continues to the city of Borisoglebsk [4]. In the studies of F. N. Milkov (1951), the northern boundary of the steppe in the...
Voronezh region runs along the line: from the lower reaches of the Oskol to the lower reaches of the Chernaya Kalitva River, to the Don from the mouth of the Chernaya Kalitva to the Podgornaya River and to Uryupinsk [5]. In the studies of L. P. Parshutina (2012), certain changes in the boundary between the steppe and forest-steppe, proposed by F. N. Milkov, were established: from the lower reaches of the Oskol to the lower reaches of the Black Kalitva, then to the Don to the beginning of the river Kriushi and to the mouth of the Buzuluk river. The north of the region is located in the forest-steppe natural zone [6]. The climate of the steppe zone is characterized by a lack of moisture and high temperatures, which causes difficulties in growing forest vegetation in this region [7, 8]. Therefore, the study of the issue of the ecological features of the growth of Scots pine in the steppe zone of the Voronezh region is an extremely relevant direction for the development of scientific foundations of reforestation in this region.

An increase in the activity of human economic activity carries a lot of negative consequences, manifested in climate change, atmosphere, soil and water quality. All these factors can have a negative effect on living organisms. In plant organisms, under the influence of a polluted natural environment, metabolism is rebuilt, physiological and biochemical processes are disturbed, which manifests itself in a weakening of the general state of the organism, as well as destabilization of the reproductive functions of plants. With prolonged exposure to external negative factors, metabolic disorders persist for a long period, which entails a deviation of external indicators from the norm, in particular, morphological changes in conifers [9].

The aim of the study is a comparative analysis of the main signs of the vital state of Scots pine growing in the steppe zone of the south of the Voronezh region, in the year of the spring-summer drought of 2019 in a relatively ecologically clean area and under the influence of anthropogenic load.

3. Materials and Methods

To study the life state of Scots pine in the steppe zone under drought and anthropogenic load conditions, two stands were selected. The studied plantings grow at the southern limit of Scots pine distribution in the steppe zone of the Voronezh region (Kantemirovsky district).

Plantation No. 1 is Scotch pine forest plantations growing in a relatively ecologically clean area, in the Kantemirovsky district, outside the settlements. Plantation No. 2 is Scotch pine growing in the nursery of the Kantemirovsky forestry enterprise, within the boundaries of the village of Kantemirovka. High-voltage power lines pass through the nursery, on one side it borders on a road connecting two settlements, on the other side on regional power grids. Also, the nursery is surrounded by a cattle farm and an oil factory, which have not been operating in recent years, but had a huge negative impact on the environment in the 1990s-2000s.

To assess the main parameters of the life state of Scots pine in each plantation, a random sample of 30 trees was selected. According to the method of A. S. Bogolyubov studied the following parameters: crown defoliation class, needles dechromation class, number of new cones. The assessment was carried out on a 4-point scale, where 0 is the norm. On the basis of the totality of signs, the total score of the vital state was calculated for each tree [2].

Statistical data processing was performed using the MS Excel-2010 software package.

4. Results and Discussion

4.1. Climatic conditions of the study region

The climate of the Voronezh region is not homogeneous. In the forest-steppe zone of the region, droughts are repeated with a frequency of 4-5 years, and the south of the region, belonging to the steppe zone, is prone to droughts more often - every 3-4 years. In this regard, in the last decades on the territory of the region, there has been a decrease in the level of groundwater, drainage of lands, and an increase in the frequency of droughts [10].

In 2019, anomalously warm weather in the steppe region of the Central Black Earth Region was established from May 26. The region was marked by an extremely high temperature regime and
atmospheric drought: by the end of May, the average temperature rise over the regional norm was 3.4 ° C, and on May 31, a temperature maximum was recorded: 31.9 ° C. The last heavy rain fell on May 26 (29.1 mm) and a long, rainless period began. June was notable for the absence of precipitation and exceeding the average monthly temperature by an average of 3.6 ° C. The first days of June were particularly hot. The temperature rise ranged from 4.6 ° C to 7.6 ° C. The temperature maximum was reached on June 23 and amounted to 35.3 ° C. Atmospheric drought has moved into the "soil and atmospheric" category [11]. July was characterized by normal temperatures and no precipitation during the first two weeks. The first precipitation after the drought took place on July 16 (15.3 mm). Thus, the drought lasted 7 weeks from late May to mid-July. During this entire period, the generative sphere of the pine was under the pressure of hydrothermal stress. The drought of 2019 fell at a drought-sensitive early embryogenesis stage.

4.2. Analysis of the main parameters of the vital state

In plantation No. 1, located on a relatively ecologically clean area, according to the parameter "crown defoliation" 73.3% of plants have the highest class (0 - normal: opal less than 10% of needles) and only 26.7% have weak defoliation, to lower classes 2 and 3 does not apply to any tree. In plantation No. 2, exposed to anthropogenic load, 80% of plants belong to class 1, which corresponds to a weak level of defoliation (10-25%), 13.4% of plants belong to class 2 (opal 25-60% of needles) and 3.3% to 0 (higher) and 3 (lower) classes - strong defoliation (more than 60% of needles fell off) (figure 1).

Comparing the results of assessing the needles discoloration, it was found (figure 2): in plantation No. 1, more than half of the studied trees - 56.7% have a slight yellowing (10-25% needles - class 1), 26.6% average (25-60% needles - class 2) and 16.7% - the norm (less than 10% needles - 0 grade). In planting No. 2, 43.3% of trees belong to 1 and 2 class of discoloration, and 10% to 3, which corresponds to a strong loss of color of needles (more than 60%), while in a plantation on an ecologically clean area, there are no trees belonging to 3 class.

The yellowing of the needles is a consequence of the persistent negative impact of the environment and occurs as a result of internal disturbances in the physiological and biochemical processes of the tree.
With prolonged exposure to polluting environmental factors, there is a decrease in the weight of needles, a decrease in the size of needles in length, and a decrease in their life expectancy [12].

**Figure 2.** Dechromation class of needles in the studied plantations in the year of spring-summer drought.

The number of new cones was estimated (figure 3). The graph shows that the pine growing in the nursery of the Kantemirovsky forestry enterprise has three times fewer plants belonging to the higher class (0 - a lot of cones) than pine forest crops growing in relatively ecologically clean conditions. Most of the individuals of plantation no. 2 (56.7%) belong to class 2 (several cones) and 40% to class 1 (there are many cones). Note that not a single tree in both studied samples belongs to the lowest class 3 (there are practically no cones).

**Figure 3.** The number of new cones in the studied plantings in the year of spring-summer drought.
It is known that under the influence of negative environmental factors, the reproductive system of conifers is weakened: the fertility of seeds decreases, the sterility of pollen grains increases, the frequency of cytological disorders increases, and the number of “empty” seeds increases [13].

From the totality of the assessed traits, we determine the class of the general life state of each tree in the studied plantations (figure 4). Most of the pines of plantation No. 1 (63.3%) belong to the highest class 0 (more than 20 years before the tree completely dies off), the rest of the plants are almost evenly distributed in 1 (20% - 10-20 years before complete dying off) and 2 (16.7% - 3-9 years before the tree completely dies off) classes. Not a single tree in planting No. 1 belongs to the lowest class 3. In plantation 2, 13.4% of trees belong to the lowest class 3 of life state (less than 3 years before complete withering away), to classes 1 and 2, 40% and 43.3% of trees, respectively, and to the highest class 0 (more than 20 years before complete death of the tree), only 3.3% of the studied sample applies.

![Figure 4. Class of the general life state of the studied plantations in the year of spring-summer drought.](image)

If we talk about the average value of the general life state for a sample of 30 trees, then in planting no. 1, growing in relatively ecologically clean conditions, this parameter is 0.5 ± 0.1, and in planting no. 2, 1.7 ± 0.1, which is 3.4 times higher. This fact suggests that the level of damage to Scots pine under the influence of unfavorable natural factors is more than three times higher than in a plantation with a more favorable ecological situation.

Thus, the most significant differences were revealed in terms of needles dechromation and crown defoliation. This indicates tissue damage and the development of chlorosis and necrosis of needles in a plantation exposed to anthropogenic impact, due to the long-term influence of pollutants.

5. Conclusion

After analyzing all the studied parameters of the general life state of plantings in the year of the spring-summer drought, it was found that planting No. 2 growing in an urban environment is in a weaker state. An increase in the degree of dechromation of needles and defoliation of the crown under the influence of atmospheric pollution was recorded, which is a consequence of the accumulation of heavy metals in the needles, a decrease in the number of new cones. The average score of the vital state of Scots pine growing in a nursery within the village is 3.4 times higher than in pine forest plantations outside of settlements and economic enterprises. This suggests that the ecological situation
in the territory of the village of Kantemirovka is unfavorable and Scotch pine, as an indicator species, reacts to the anthropogenic load of the study area. The main sources of negative impact in this area are the exhaust gases of cars, including agricultural machinery, constant exposure to electromagnetic radiation, high recreational load.

Thus, it was found that the spring-summer drought of 2019 had a serious impact on all the assessed signs of the vital state of Scots pine. The pine tree growing in the nursery of the Kantemirovsky forestry enterprise experiences a double load: these are the climatic conditions of the steppe zone, aggravated in 2019 by the spring-summer drought, which fell on sensitive periods of embryogenesis, as well as the pressure of anthropogenic load in the place of growth.

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