Climate Change and Dynamics of the Forest Area at the Forest Experimental Station of the Timiryazev Agricultural Academy since 1862

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Abstract. In the Forest Experimental Station of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, since 1862, experiments have been carried out to study the methods of planting, the geographical origin of seeds, methods of thinning for forest growth. Over 150 years, significant changes have occurred in the climatic conditions of the Forest Experimental Station. There have been changes in the species composition of the forested area of the Forest Experimental Station. At the time of the first forest inventory in 1862, there were 5.7 units for pine, 1.6 units for birch and 1.4 units for oak. In the subsequent dynamics of the species composition of forest stands, there is a decrease in the share of pine to 3.9 units and an increase in the share of birch (1.6 units), oak (2.3 units) and larch (1.8 units) by 2009.

1. Introduction
Recent studies show that ongoing climatic changes make a significant contribution to the directions of the dynamics of indicators of forest stands and their species composition [1, 2]. In the forests of Central Europe, against the background of climatic changes over the past 100 years, the main forest-forming species show faster growth, an increase in volume and accumulation of standing stock [1]. The results of long-term observations on permanent experimental plots in the central part of European Russia also show the acceleration of forest growth, the intensive emergence of broad-leaved species into the forest canopy [3, 4].

The ongoing changes create new conditions for the forestry, associated with a reduction in cutting ages, an increase in forest productivity, and a change in the species composition of forests, with changes in the areas of pests and pathogens [5]. To prevent the consequences of these changes it is necessary to support initiatives to conserve natural landscapes and promote sustainable forest management. The trajectories from the current state of the forests to the future are unclear, so foresters need to use all the experience to devise suitable adaptive management plans for future forests [6].

2. Methods and materials
The Forest Experimental Station of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy located in the north-west of the city of Moscow. The climate is temperate continental with an average annual temperature of 6.1 °C (for 1987–2016) and average annual precipitation of 700 mm (for 1987–2016). The predominant soils are sod-podzolic. According to the results of the forest inventory in 2009, the area of the forest experimental station is 248.7 ha, including 233.4 ha (93.8%) of the forest-covered land. The area mainly consists of mixed and even-aged forests...
dominated by pine, larch, birch, oak and linden. In the herbaceous layer prevail *Galeobdolon luteum* Huds., *Aegopodium podagraria* L., *Geum urbanum* L., *Stellaria media* (L.) Vill., *S. holostea* L., *Luzula pilosa* (L.) Willd., *Dryopteris carthusiana* (Vill.) H.P. Fuchs, *Calamagrostis arundinacea* (L.) Roth, *Lamium album* L., *Milium effusum* L. and others [7, 8].

The study was based on the results of 10 inventories of the forestry area of the Forest Experimental Station (from 1862 to 2009). To characterize the forest area, such indicators were used as area, volume stock, average age for individual tree species, and average forest stand density. The work uses the results of observations at the Meteorological Observatory named after V.A. Mikhelson RSAU-MTAA, Konstantinovsky Survey Institute, VDNKh meteorological station.

3. Results and discussion

The data of constant meteorological observations indicate that there have been significant climate changes both for the territory of the city of Moscow as a whole and for the Forest Experimental Station, which is part of its borders. During the observed observation period from 1821 to 2020, there is a regular increase in the average annual air temperature (figure 1). The beginning 20th century, the average annual temperature was about 3.5 °C, and in 2020, on average, it was close to 7.0 °C. Against the background of an increase in the average annual air temperature, an increase in the number of natural phenomena (hurricanes, frosts, heat, heavy rains) can be traced, the climate becomes unstable. In recent years, cases of abnormally hot and cold days have become more frequent. In addition, there is a clear tendency to reduce the length of the cold season, winters are becoming milder and warmer. At the end of the 19th century, the duration of winter was about 155 days, and now it averages 120 days.

The change in the annual precipitation from 1881 to 2020 and the trend line are visualized in figure 2. Throughout the entire period of meteorological observations, an increase in the annual precipitation is observed. Analysis of the linear trend equation shows that on average over the year over the observation period, there was an increase in annual precipitation by 1.1 mm per year, and over the past 100 years, on average, the amount of precipitation has increased by 110 mm per year. The previously noted increase in average annual temperatures, especially over the past 20–30 years, is not offset by an
increase in annual precipitation. As a result, against the background of evapotranspiration and increased evaporation, the problem of providing forests with moisture is created.

The previously noted change in the annual amount of precipitation is accompanied by a change in their distribution by seasons. Meteorological observations show that from 1881 to 1900, 16.5% of the annual amount fell in winter, 21.7% in spring, 35.7% in summer and 26.2% in autumn. Over the past decades (from 1997 to 2020), there has been a transformation of the distribution of precipitation by seasons: 20.6% (+4.1%) in winter, 19.2% (-2.5%) in spring, and 33.1% (-2.6%) in summer and 27.1% (+0.9%) in autumn. Thus, there was a decrease in precipitation in the spring and summer periods, and their increase in autumn and winter. It should be noted that in the last decade there has been a tendency to an increase in the number of days in a year with intense precipitation. Thus, the observed climatic changes create new conditions for forestry [9, 10].

In the late 17th - early 18th centuries, the forest cover of the Forest Experimental Station, according to A.R. Vargas de Bedemar, consisted of an oak forest with an admixture of linden, maple and a minor presence of pine, birch and aspen. At the time of the survey in 1763, the forest, located on the territory of the Forest Experimental Station, was dominated by deciduous species and with single inclusions of conifers.

For more than 150 years, the inventory of the forest fund of the Forest Experimental Station was carried out 10 times (the last one was in 2009). According to forest inventories in 1862, the area of the Forest Experimental Station was 257.7 hectares, and after 1902–248.7 hectares. According to the first forest inventory, forested land accounted for 75%. As a result of work on planting forests by 1887, they increased to 92%, and by 2009 – to 94%. After the drought of 1936–1940 and the subsequent destruction of spruce stands, the share of forested areas decreased to 87%.

Figures 3 and 4 visualize the dynamics of the areas of prevailing tree species at the Forest Experimental Station and their volume stock. When conducting the first forest inventory in 1862, A.R. Vargas de Bedemar, the most represented on the territory were plantations with a predominance of pine (115 ha). The area occupied by oak forests (37 hectares), birch forests (27 hectares) and aspen forests (21 hectares) was much smaller. By that time, the stands were very thinned and weakened due to improper forest management. A.R. Vargas de Bedemar developed a forestry plan for the Forest
Experimental Station. They were asked to create mixed forest plantations of pine and birch. He suggested cutting down low-value forest stands. Later on, at the site of felling, forest plantations were created or they were left for natural forest renewal.

**Figure 3.** Dynamics of areas by dominant tree species.

**Figure 4.** Volume stock dynamics for dominant tree species.
Since 1862, large changes have been observed in the types of composition of the forest areas of the Forest Experimental Station. At the first forest inventory in 1862, there were 5.7 units of pine, 1.6 units of birch and 1.4 units of oak. Since 1915, after part of the territory was taken away for the construction of the railway, the forested area remained stable and amounted to 90.4 ± 0.7%. By 1945, the following changes took place in the average species composition of forests: the share of pine increased to 7.1 units, and birch and oak decreased to 0.9 and 1.0 units, respectively, the share of larch was 0.8 units. In the process of species composition dynamics by 2009, against the background of ongoing climatic changes and aging of forest stands, the share of pine decreased to 3.9 units and the share of birch (1.6 units), Oak (2.3 units) and larch (1.8 units).

4. Conclusion
Over 150 years, significant changes have occurred in the climatic conditions of the Forest Experimental Station. Pine stands of natural origin that prevailed on the territory of the Forest Experimental Station have practically collapsed, but at the same time there was a process of increasing the share of the most resistant to the conditions of the city of Moscow tree species: larch, birch and oak. To maintain the ecological, aesthetic, sanitary and hygienic, oxygen-producing functions of Forest Experimental Station stands in the city of Moscow, it is necessary to carry out economic activities aimed at the formation of mixed, uneven-aged coniferous-deciduous forests.

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