Research paper

Changes in the forest structure of the Bashkortostan Republic over two decades

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Abstract. This paper aimed to study the distribution of the main tree species in the Republic of Bashkortostan (RB) in a transforming climate and compare the results for the last decades. The analysis was based on the forest fund data, forest management documents, route surveys and field studies, and conducted by generally established forestry methods. The trial plots had identical soil conditions. The paper considers the impact of climate on the forest resources of the RB located at the junction of the Urals with the West Siberian Lowland, the Cis-Ural plain and steppe belt with diverse vegetation. The floristic composition of the republic is varied and includes about 1700 species of higher plants. Comprehensive research was followed by field results comparison. In 1998–2018, the area of soft-leaved species, primarily *Betula pendula* Roth and *Tilia cordata* Mill. increased by 70.8 (39%) and 74.2 thousand hectares (32%), respectively; the share of coniferous *Picea* and *Abies* declined by 57.9 thousand hectares – 15%, short-trunk *Quercus robur* L. lowered by 34% and the high-trunk one decreased by 6% and Acer by 8%. The conducted study suggests a significant increase in destructive insects. Spruce forests will suffer, because there is a reduction in the area by 20% over 20 years. Thus, there has been a gradual displacement of forest species. Forestry challenges and the sustainable ecological balance both in the republic and the planet as a whole require further joint efforts of scientific and environmental organisations and authorities for forecasting transformational processes and developing measures to address them.

Key words: average annual temperature and precipitation, climate changes, forest growers of the Republic of Bashkortostan, forest stands, Russia.

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Introduction

There is a close relationship between climate change on Earth and the state of forests. Extreme weather conditions, changes in the average annual temperature, and precipitation adversely affect forests (FAO, 2021; ShareAmerica, 2020; WWF, 2018). Since 1990, the Earth has suffered from the loss of 420 million hectares of forest lands due to logging for the needs of farmers, miners, and industrialists. The equatorial forests have been destroyed the fastest. Brazil, Bolivia, and Indonesia were

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the most affected countries by forest loss due to commercial logging and frequent fires. Academicians of the University of Southampton (England) and George Mason University (Virginia, USA) claim that the Amazon forests will disappear in the next fifty years if the current rate of deforestation continues. Europe has not escaped the worse fate either. Half of its territory is still covered by forests, which absorb almost 10% of all carbon dioxide (CO_2) emissions in The Old World. The dry summer in 2019 and 2020 caused terrible forest fires and large-scale tree diseases. Over the past half-century, the composition of European forests has changed, and their ability to absorb carbon dioxide has decreased. The European Commission indicates that increased demand for timber and frequent fires prevent trees from reaching the age when they absorb the maximum CO_2 (FAO, 2021; IPCC, 2001, 2013; Itter *et al.*, 2017; Sultanova *et al.*, 2018; UPM, 2021).

Increasing weather phenomena that pose a danger for forests on the territory of Russia are recorded by forestry statistics (from two hundred to four hundred manifestations from 1990 to 2010). For example, weather patterns destroyed 21 thousand hectares of forests in the 1990s; at the end of the 2000s, 53 thousand hectares were depleted. Adverse weather is likely to affect the Russian economy and the forest sector in the future (FAO, 2020; ShareAmerica, 2020; WWF, 2018). In turn, plants, depositing carbon dioxide, make an invaluable contribution to mitigating the effects of global warming. Trees play an essential role in fighting against climate change, as they absorb and store carbon dioxide throughout their lives. The United States takes part in the the Trillion Tree Campaign (ShareAmerica, 2020) to ensure the absorption of 25% of the total carbon dioxide emissions caused by human activity. According to the campaign company Plant-for-the-Planet, this will combat global warming at the level of two degrees Celsius (ShareAmerica, 2020). However, logging and forest fires are a source of carbon dioxide (CO2), contributing to the greenhouse effect (IPCC, 2013; USGCRP, 2017). Therefore, there is a need for a comprehensive approach to solving these urgent issues.

Academia to date has not got across a common point of view about the apparent relationship between the causes and consequences of increased CO_2 and global warming. In 1992, many countries joined the United Nations Framework Convention on climate change to reduce industrial emissions of all greenhouse gases into the atmosphere. The 2015 Paris Agreement provides measures to reduce CO_2. The International Group on Climate Change claims that the global average temperature is more likely to increase by 1.4–5.8°C until 2100 (Bobrik, 2015), and change the composition and structure of the vegetation cover (Ministry of Forestry of the Republic of Bashkortostan, 2019; VNIIGMI-MCD, 2021; WWF, 2018).

To date, the study and making the observed climate transformations relevant for forest ecosystems is one of the significant issues both at the level of fundamental research and at the level of socio-economic development of the country's regions (Cortés *et al.*, 2020; Yousefpour *et al.*, 2017). Plants acting as indicators witness the tree species displacement resulting from the ongoing temperature change, water and human activity factors (Duveneck & Thompson, 2017). The type of forest depends on climatic, orographic, and soil conditions (FAO, 2020; Itter *et al.*, 2017; Sommerfeld *et al.*, 2020; Yanbaev *et al.*, 2020), and its dynamics determines the climate forecast for a particular region.

This study aimed to analyse and compare the forest species placement in the RB over the last decades in climate change conditions.

To achieve this goal, the research examined the impact of climatic transformations on forest composition. It developed recommendations and measures to reduce

losses in the forest sector from the emerging changes and preserve the biodiversity of the forest ecosystem.

The RB is among the leading regions of the Russian Federation with a high resource and environmental potential. The current climate change affects urban and forest ecosystems in one way or another (Isyanyulova *et al.*, 2019). Therefore, studying these processes is necessary to predict transformations and develop recommendations for managing the economy both in one republic and globally.

Materials and Methods

The research target is the entire territory of the RB (Figure 1). Its flora is mainly determined by its location at the junction of the Urals with the West Siberian Lowland, the Cis-Ural Plain and steppes. The republic's vegetation is a multi-species diversity, numbering more than one thousand seven hundred plants (City District Council Ufa City of the Republic of Bashkortostan, 2019). Forests in Bashkortostan until the 19th century occupied more than 70% of the total area of the current region, with a predominance of conifers and hardwoods (Muldashev, 2020). *Pinus* and *Larix* were the dominant species in the forest composition. The Diurtiulinskii, Kaltasinskii, Krasnokamskii and Ianaulskii districts have been known for indigenous coniferous forests for several centuries. The forest distribution in the region is heterogeneous. The percentage of the forest area ranges from six in the south-western districts up to sixty in the eastern and north-eastern districts (Acting Head of the Republic of Bashkortostan, 2018; Ministry of Forestry of the Republic of Bashkortostan, 2019). The region is covered by forest, forest-steppe and steppe zones.

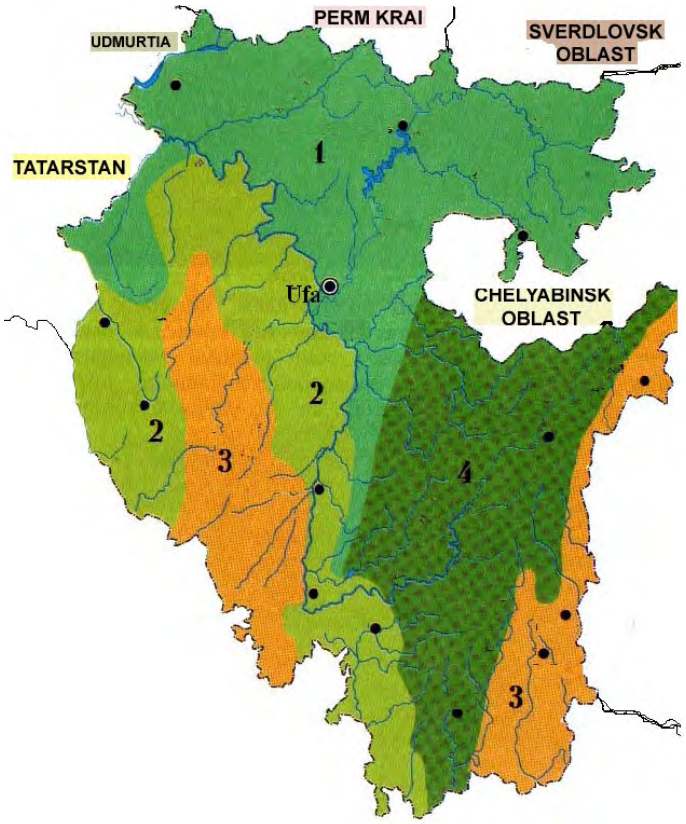

Figure 1.

Natural zoning of the Republic of Bashkortostan. Natural zones: 1 – coniferous and broad-leaved forests; 2 – forest-steppe; 3 – steppe zone; 4 – mountain-forest zone.

Changes in climatic patterns (average temperature and precipitation during the year) were estimated over the last fifty years (VNIIGMI-MCD, 2021). Forest characteristics rely on the forest fund data, forest management documents (Acting Head of the Republic of Bashkortostan, 2018; City District Council Ufa City of the Republic of Bashkortostan, 2019; Ministry of Forestry of the Republic of Bashkortostan, 2019) for a comparative analysis of the forest species placement, materials of route surveys and field studies conducted by generally established forestry methods (Verkhunov & Chernykh, 2007). Our research covered areas with the main forest-forming tree species in the region. Tree species were identified and analysed according to the reporting documents of the state forest register. Trial plots are set to study the ongoing processes in the forest during the entire observation period in the same soil conditions under the Russian forestry standard OST 56-69-83 "Trial plots in forestry. Sampling establishment". In the corners of the trial plots, mine shafts were installed with a compass according to industry standards 56-44-80 "Field signs for forest management and forestry. Types, sizes and general technical requirements". The tree trunk diameter was measured at the height of 1.3 metres in two directions using a measuring fork (with an accuracy of 0.5 centimetres). The tree height was estimated with a SUUNTO RM-5/1520 altimeter (accuracy 1–2%). The stand vital condition was assessed according to the VA Alekseev's method: healthy, damaged (weakened), severely damaged (severely weakened), dying trees, newly and long-ago dead stands (Alekseev, 1989). In some cases, in addition to assessing the vital state of the stand, it is rational to find its damage. This examination takes into account weakened, severely weakened and destroyed trunks. The comprehensive research ended with an analysis of the findings using Microsoft Excel 2019.

Results and Discussion

According to forecasts based on different scenarios for the future development of the Earth's climate, carbon dioxide concentrations and the average temperature will increase by 2100. The carbon content in the atmosphere will vary from 10 to 30%. The planet's average temperature from the early 1990s to 2100 will be rising by 1.4–5.8°C. Warming rates are likely to be very high over the last hundred thousand years. From 1990 to 2025 and 2050, the predicted growth will be 0.4–1.1°C and 0.8–2.6°C, respectively (Gil & Zajączkowski, 2014; Hemery *et al*., 2010).

Both around the world and on the territory of Russia, the warming rate continues to exceed the global average. The Institute of Global Climate and Ecology, named after Academic YA. Israel (IGKE) recorded the average air temperature increase in the Russian Federation in 1976–2019, which was 0.47°C for ten years. The Hadley Centre for Climate Prediction and Research and the University of East Anglia (UEA) found that this indicator was more than two and a half times higher than the global temperature increase (0.18°C) over the decade and one and a half times more than the surface air warming (0.28°C). The temperature value of each decade since 1980 has exceeded the previous indicator. The Northern Polar region faced the most drastic temperature rise. The Arctic and Antarctic Research Institute (AARI) analysed the average annual temperature from 1990 to 2019 and revealed its rise to 0.81°C for ten years, that is 2.43°C (Glaesaer, 2006; IPCC, 2001). The rapid reduction of the Arctic ice cover indicates accelerated warming.

The high concentration of carbon dioxide released during fuel combustion into the atmosphere leads also to global warming and, consequently, the planet's climate change. Forests can deposit carbon from the atmosphere, which is "stored" in the form of wood and vegetation (Khanova *et al.*, 2020; Lozhkin & Anderson, 2020), there-

by mitigating the effects of climate change. As a rule, the main part of trees consists of 20% carbon. In addition, forest biomass is also a "carbon storage. Forest stands retain a huge amount of carbon". FAO and World Food Programme (WFP) studies confirm that the world's forests and forest soils hold over one trillion tons of carbon (twice as high as atmospheric carbon). Still the CO^2 level increases by six billion tons every year due to reduced forest territories. The United Nations representatives suggest preserving the carbon balance by preventing its entry into the atmosphere and focusing on preserving the environment (Ministry of Forestry of the Republic of Belarus, 2011).

Current attempts of the world community to cut greenhouse gas emissions fail to reduce their concentration and prevent the temperature increase.

The Federal Hydrometeorological Service (northern background stations) indicates the constant growth of carbon dioxide by an average of 2.26 million^{-1}/year. In 2019, this indicator reached the maximum level; the average annual value was 414 million^{-1}. There is also an increase in methane fixation.

According to observations, 2019 became the warmest for Russia since 1936: the average annual temperature exceeded the norm by 2.07 degrees Celsius (the average for 1961–1990) and there were abnormal climate manifestations. Spring witnessed an average temperature index of 2.86 degrees Celsius above normal. High temperatures were observed in the south of the European part during June: in the North Caucasus Federal District (4.26 degrees Celsius above normal) and the Southern Federal District (4.29 degrees Celsius above normal), while the precipitation deficit exceeded the norm by 46%, resulting in an inevitable drought. December in 2019 was extremely warm in the European part of Russia.

It was very warm in the Northern Polar region with an abnormal temperature of +2.5 degrees Celsius (after 1936). Since the nineties of the last century, the rapid increase in Arctic temperatures has reduced sea ice in the Arctic Ocean (its area amounted to one hundred thousand square kilometres in 2019).

Temperature changes resulted in the troposphere warming (the warmest values were observed from 2015 to 2019) and cooling of the stratospheric layer (for example, 2019 was the most abnormally cold with -1.01°C for last years) (Roshydromet, 2019).

The study of the annual temperature transformations over the last century revealed a certain tendency to increase (Bahna, 2020; Isyanyulova *et al.,* 2019). The average air temperature on the territory of the Bashkortostan Republic raised by 0.7 degrees Celsius for the last thirty years. This corresponds to global trends. According to meteorological data, there was an increase in annual precipitation with an average of 499 millimetres per year (the level reached 502 millimetres for ten years) (RBC-Ufa Study, 2017).

The results of a ten-year study by the Laboratory of Specially Protected Natural Territories and Biological Resources of the Research Institute of Life Safety of the Republic of Bashkortostan indicate dryness of certain forest lands while maintaining a decrease in biomass growth and changes in tree condition.

The annual precipitation in the republic generally increased from 1966 to 1996, but by 2012 it decreased (Volkov *et al.,* 2013). Climate change is evident from higher average annual temperatures, lower precipitation and deteriorating conditions for the development of forest plants, especially in the southern part of the region. Thus, there is a tendency for deforestation in some areas and the shift of the southern border of the forest territory to the north of the republic.

To understand humidification conditions in a particular territory, the hydrothermal (according to G.T. Selianinov) and humidification (according to Ivanov-Vys-

otskii) coefficients were analysed. The finding demonstrates the synchronic distribution of the curves and uniform changes in hydrothermal indicators in different areas and, accordingly, the entire region as a whole (Galimova *et al.,* 2019). There is a tendency to more semi-dry and dry conditions and fewer semi-moist and wet conditions. At the same time, there is a significant decrease in the control level for the southern part of the Southern Urals and the western foothills due to higher temperatures and reduced precipitation in summer. The southern Cis-Urals and Trans-Urals had more precipitation that resulted in a higher control level.

The conducted analysis of the current state of the agro-climatic resources in the RB (Galimova *et al.,* 2019) revealed:

- obvious changes in the agro-climatic conditions for the region as indicated by the total indicators of active and positive atmospheric temperatures and the climatic index of biological efficiency;
- synchronicity and dynamics of the Ivanov-Vysotskii humidification coefficient and the Selianinov's hydrothermal coefficient, although there were no significant changes in hydrothermal indicators;
- transformations in climate dynamics;
- increasing tendency towards arid conditions during the period of positive temperatures observed in the southern parts of the republic.

The long-term study of changes in the forest composition makes it possible to assess the effects of different natural patterns with a pivotal role of climate conditions that develop the phytocenotic structure. Adverse consequences for forestry became evident due to the higher temperature regime and reduced precipitation.

It should be noted that the period from 1989 to 2019 is characterised by an early transition of air temperature from zero degrees Celsius towards an increase and snow-melting for ten days, compared with previous years. A decrease in the snow cover depth by an average of five centimetres results in reduced moisture reserves by almost a quarter of the level of long-term indicators. Frequent thaws cause evaporation of meltwater in winter or its running into water reservoirs, which negatively affects groundwater depth.

The growing season starts earlier, and its period has lengthened by an average of twelve days.

Climate changes have led to the observed dynamics of the forest species composition.

The area of the RB's forest fund totals 5.7 million hectares or 39.9%. The area under forest in the Russian Federation is 46.6%, with 36.5% in the Volga Federal District. The total wood reserves in the republic amount to about 769 million cubic metres. Soft-leaved species predominate on 3559 thousand hectares. Coniferous trees occupy 1145 thousand hectares and hardwoods about 459 thousand hectares.

The ratio by groups and timber resources is as follows:

- coniferous forests occupy 17% of the forest land and make up 24% of the total stock;
- hard-leaved trees take up 7% of the stock;
- soft-leaved trees account for 76% and 69%, respectively (FAO, 2021).

The share of the RB species by distribution and timber resources is given below:

- *Betula* dominates with 20% of the forest area and accounts for 25% of the total stock. The area under birch forests is presented by *Betula pubescens* Ehrh. (25%) that is inferior to *Betula pendula* Roth (which grows on 75% of the area);
- *Tilia* occupies the second position on 17% of the territory and surpasses *Betula* by 27% in terms of stock;
- *Pinus sylvestris* L. amounts to 12% and 18% of the stock;

- *Populus tremula* L. – 11% and 14% of the stock.
- *Quercus* and *Picea*, *Pinus* and *Populus tremula* account for 15% of the main species' share, growing on 5% of the area (Acting Head of the Republic of Bashkortostan, 2018; Ministry of Forestry of the Republic of Bashkortostan, 2019).

Among coniferous trees:

- *Pinus* occupies, respectively, 67% of the area and 77% of the stock,
- *Picea* 23% of the entire territory and 15% of the stock,
- *Larix* covers only 4% of the area.

Quercus robur L. is in the first place among the hard-leaved trees with 56% (high-trunk – 2%, short-trunk – 54%), with 57% of the stock (respectively – 1.09% and 54.8%). *Acer* grows in the area over 33%, with about 35% of the stock. The share of *Ulmus* is insignificant both in the area of 9.7% and in the stock – 8.5% (Acting Head of the Republic of Bashkortostan, 2018; Ministry of Forestry of the Republic of Bashkortostan, 2019).

Analysis of the soft-leaved tree distribution showed the predominance of *Betula pendula* – 39% of the occupied area and 36% of the stock, and *Tilia cordata* Mill. (32%) with the respective share of 39%. 22% of the area is occupied by *Populus tremula* with 20% of the reserve. The insignificant distribution of the remaining species across the territory is characterised by low productivity. It should be noted that there has been relative stability in the statics of the areas of the main forest-developing species for the last twenty years. As a result of reforestation and the transfer of non-closed croplands to lands covered with forest, significant areas of *Pinus* and *Larix* were recorded. The observed decrease in *Picea* and *Abies* was 15%, *Quercus robur* short-trunk by 34%, high-trunk – 6% and *Acer* – 8% of the area.

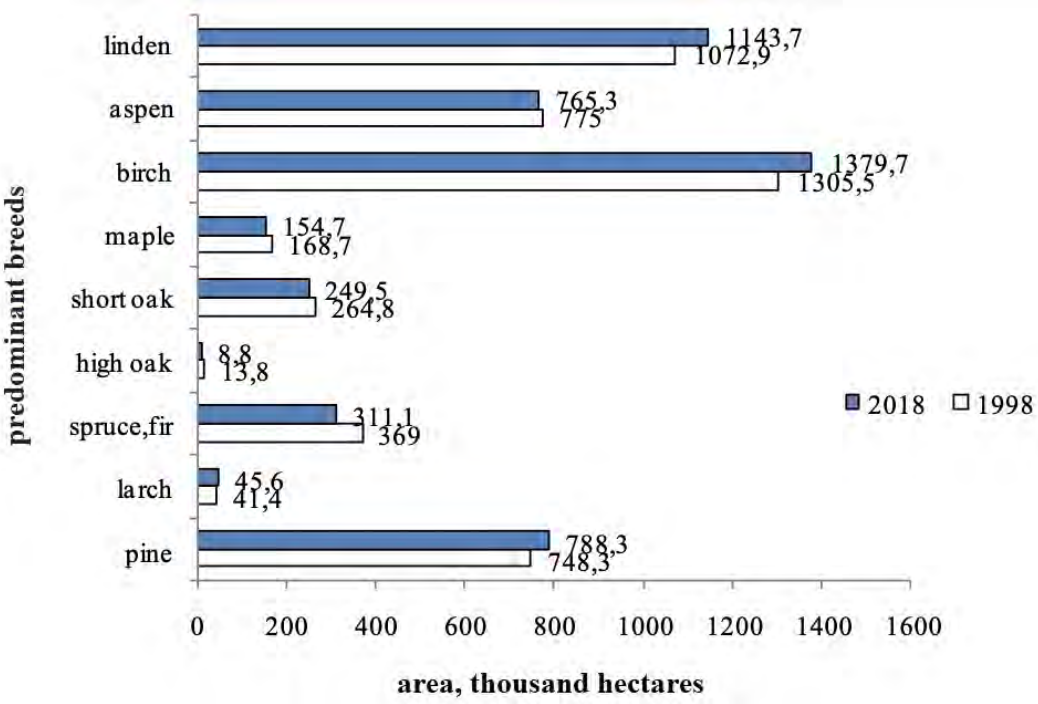

Figure 2. Changes in the areas of the RB's main species for 1998–2018, developed by the authors on the basis of Acting Head of the Republic of Bashkortostan (2018) and the Ministry of Forestry of the Republic of Bashkortostan (2019).

The expected forecast for reduced coniferous areas and increased mixed and broad-leaved forest stands is mainly due to climate transformation (Figure 2).

Based on findings of the World Wide Fund for Nature, the University of Eastern Finland and the Swedish Forest Agency, it is expected that spruce forests will suffer the most significant losses from climate transformation (IPCC, 2001).

It should be noted that the obtained results for the RB coincide with changes in the forest composition of the Scandinavian countries. In some European countries and on the territory of the republic, *Tilia cordata* can be found within the natural range (De Jaegere *et al.*, 2016; Gil & Zajączkowski, 2014). According to scientists, *Tilia* will be able to take a dominant position in adapting forests under the prevailing conditions (Hemery *et al.*, 2010) due to its reproductive ability, overall environmental sustainability, and potential changes in competition between ligneous plants.

Researchers put forward the establishment and preservation of forest territories as one of the options for combating climate transformations. It can be achieved by restoring forests on cut-down areas, growing new ones and protecting them from deforestation.

According to the global forest resources assessment in 2020, 93% – that is, 3.75 billion hectares of the world's forests are naturally renewable, and 7% – 290 million hectares are forest crops. Since 1990, the areas of naturally renewable forests and their reduction rate have slowed down, but at the same time, the area of forest crops has increased by 123 million hectares (Gil & Zajączkowski, 2014; Roshydromet, 2019). However, the growth rate of the territory under forest crops has declined in the last decade.

Forests on the republic's territory are restored by 32 forestry enterprises, the state forest management institution, the Center for the Prevention and Extinguishing of Forest Fires, and forest tenants. The RB's Ministry of Forestry also controls the Ufa Technical School. The annual allowable logging, i.e., the calculated cut, is about nine million cubic metres (including more than one million cubic metres for co-

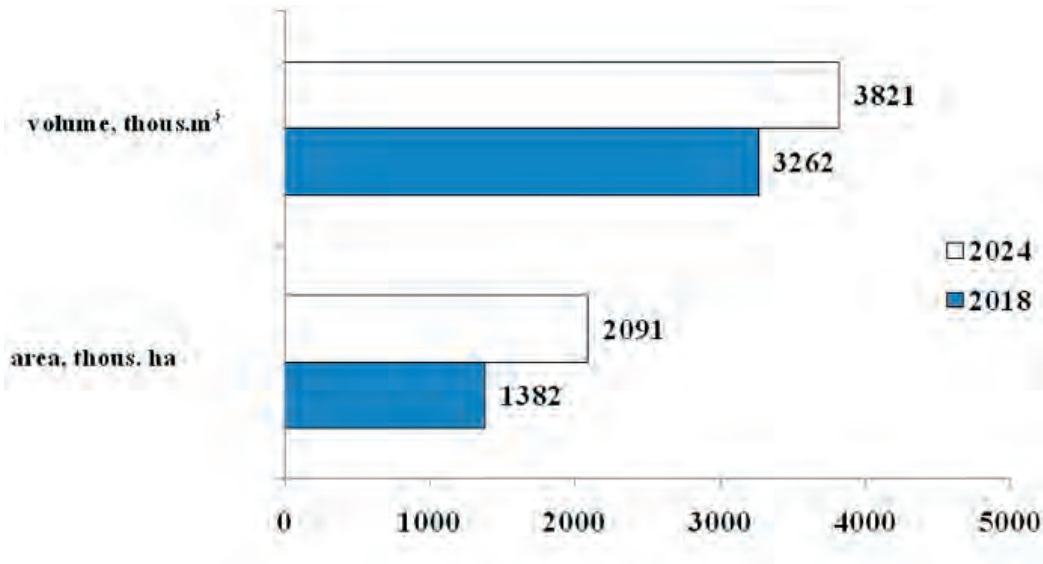

Figure 3. Forest areas allocated for timber harvesting, developed by the authors on the basis of Acting Head of the Republic of Bashkortostan (2018).

niferous forestry systems). According to this indicator, the republic ranks third in the Volga Federal District (VFD) after the Kirov Region and the Perm Territory.

More than one and a half million hectares are leased forest plots of over three million cubic metres. 96% or 1.4 million hectares are accounted for timber harvesting. Forest plots are also allocated for recreational activities (for 662 forest users), agriculture (1222 people), linear objects (514 people), etc. (Acting Head of the Republic of Bashkortostan, 2018) (Figure 3).

On the RB's territory, tenants planned reforestation work on an area of about 6000 hectares or 51% of the total volume for this type of activity. According to the RB's forestry development forecasts, the ratio of logged forest stands should correspond to the area of reforestation in 2019–2024 (Figure 4).

The republic is leading in the Volga Federal District in terms of seed sowing in nurseries. The sowing plan is 120% complete. To increase the reforestation rate, both naturally and artificially, the project "Forest Conservation" was adopted at the federal level to "ensure a balance of forest disposal and reproduction in the ratio of one hundred percent by 2024" (Ministry of Forestry of the Republic of Bashkortostan, 2019).

For comparison, the activities of the Food and Agriculture Organization of the United Nations (FAO) in the field of forestry are aimed at:

- popularisation of the global reforestation movement within the framework of United Nations Decade for Ecosystem Restoration, held under the auspices of FAO;
- expanding the scope of forest and landscape restoration at the basic level within the framework of the Mechanism for the Restoration of Forests and Landscapes, the project "Measures to combat desertification" and restoration initiative financed by the Global Environment Fund;
- participation in one of the recent United Nations initiatives supporting the Great Green Wall campaign (FAO, 2020).

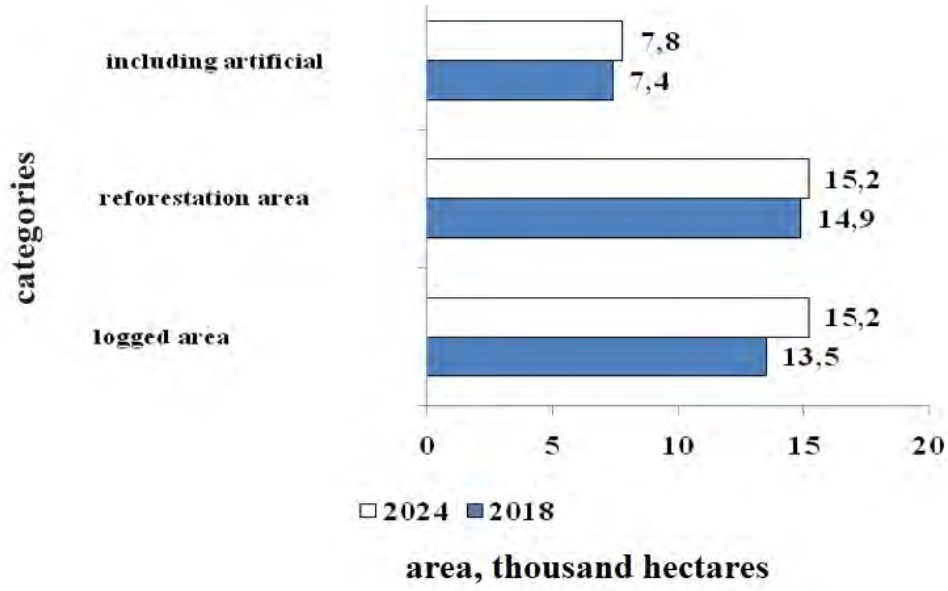

Figure 4. The ratio of the reforestation and continuous logging areas, developed by the authors on the basis of Ministry of Forestry of the Republic of Bashkortostan (2019).

The Ufa city forestry of the Ufa city district has three forest nurseries on a total area of about one hectare. There are also plantations of large-sized seedlings of trees and bushes on an area of 38.4 hectares. Planting material is grown in the volumes of the needs of the Ufa city for landscaping and reforestation on the territory of urban forests. The periods and characteristics of forest use to grow seedlings are applied for a particular territory and recorded in the relevant documents, including forest development projects after the conducted additional surveys.

Combined reforestation is carried out in areas where the natural restoration of valuable tree species forest stands is not provided. Seedlings or undergrowth preserved during logging are planted within a year from the cut forest stands. *Pinus*, *Picea* nurselings or 4–5-year-old *Picea* seedlings are underplanted in areas with no undergrowth on the treated soil, including mineralised strips, furrows, layers, and stumps without tillage. Planting is conducted in spring before the beginning of the growing season and in autumn after the growing season. It can be performed in August after heavy rains. The number of planted nurselings (or seedlings) and the number of sown places should not exceed 50% of the preserved undergrowth (Yanbaev *et al.,* 2020). Schedules of reforestation operations: tillage – July-October; planting – April-May, August-November; agrotechnical care – June-August; forestry care – during the growing season.

Areas with forest crops laid down artificially and in a combined way are considered covered with forest vegetation when characteristics of the main species match the reforestation rules.

Analysis of urban forest crops in Ufa revealed that non-adjusted plants occupy more than 32 hectares, transferred to the land covered with forest vegetation – 5.5 hectares. Age-related forest crops are located on a territory of 2474 hectares. In addition, forest crops under the forest canopy occupy 148 hectares. Old plants in an unsatisfactory state take up 67 hectares, of which *Populus* make up 75%, *Fraxinus* – 6%, *Picea* and *Betula* – 5% each, *Pinus sibirica* Du Tour – 2%, *Pinus* and *Ulmus* – 1.3%, *Larix* and *Acer* – 0.9% (Acting Head of the Republic of Bashkortostan, 2018; City District Council Ufa City of the Republic of Bashkortostan, 2019).

The analysis showed a clear tendency to reduce the share of coniferous species on the republic territory on the example of *Pinus* and *Picea* and an increase in small-leaved species *Tilia* and *Betula*.

Long-term research on changes in the phytocenotic structure of plantings makes it possible to assess the impact of natural factors, including climatic conditions. The consequences of climate transformations have a significant impact on forest resources. In the territory of the republic, large areas suffered from birch disease. Scientists attribute one of the negative causes of bacterial dropsy in *Betula* to climate transformation. This was discussed back in 2013 (Volkov, 2015). A decrease in temperature growth can be a barrier to minimising this process, but it is uncertain.

The sanitary forest inspections detected mechanical damage to the trunk and roots, destructions caused by insects and animals, frost clefts, other diseases on an area of 4431 hectares, including the root sponge on 399 hectares. Significant areas of plants on 10,181 hectares were affected by weather conditions and soil and climatic factors, and 519 hectares were affected by forest fires (Ministry of Forestry of the Republic of Bashkortostan, 2019). Studies of plant diseases and damage revealed "traces" of coniferous, leaf-eating and trunk pests (the affected areas are shown in Figure 5).

The analysis of tree diseases and damage on the republic's territory showed that the most common reason for tree death are insects. In 2012, experts assessed the forest condition in Bashkortostan as satisfactory. The conducted monitoring did not detect any large foci of forest insect pests in

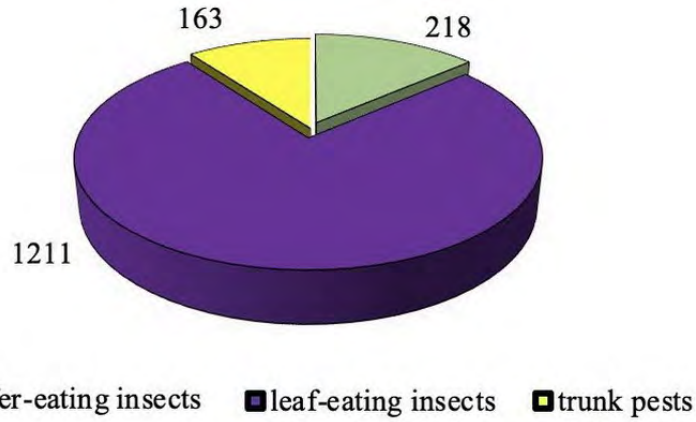

Figure 5. The area of pest foci, in ha, developed by the authors on the basis of the Ministry of Forestry of the Republic of Bashkortostan (2019).

the republic. As reported by the Forestry Ministry's Department of Forest Control and Protection in the RB, the largest forest pest centre of jewel beetles (*Trachys minuta* L.) can be found in the Blagoveshchensk district. It is located on the territory of the Ufimskii forestry covering 1320 ha. In 2014, forest pathology surveys revealed a significant increase in the pest population. The affected forest area reached 3367 ha. In 2019, the most damage was caused by coniferous pests (218 ha), leaf-eating insects (1211 ha) and secondary insects (163 ha). In 2021, forests were treated against the gypsy moth. The pest multiplied in the Orenburg region and then it appeared in the border areas. The total area infested with the gypsy moth reached 476 thousand ha. The most affected area of 241.6 thousand ha was in the Baimakskii, Zilairskii, Zianchurinskii, Kananikolskii, Kugarchinskii, and Khaibullinskii forest districts. A regional emergency was declared. Longhorn beetles of the *Monochamus* genus were found in the Beloretsk forestry, namely the pine sawyer beetle. The insect had not been detected in previous years. Thus, every year there is a dynamic change in the forest areas damaged by pests.

It should be noted that foreign scientists also explore climate change models, predict scenarios and expected consequences (Duveneck & Thompson, 2017). With the development of a warm climate scenario, there are increased outbreaks of destructive insects in Central Europe, North America and China (Duveneck & Thompson, 2017; Huang *et al.,* 2020). The drought contributed to the emergence of bark beetle outbreaks in Central Europe and North America, which led to the death of spruce and pine forests on a regional scale (Huang *et al.,* 2020). Scientists are conducting field studies to establish the causes and correlations between the insect spread and tree species that are subject to their attack singly or over large areas in changing climate conditions. There is clear evidence that in the conditions of global warming, coniferous and deciduous plantations suffer from pests most often and in large areas in Europe, Asia, and America.

The present research found a gradual shift in the main forest species and the *Tilia* and *Betula* expansion on the territory of the Republic of Bashkortostan due to climate change. The same phenomenon is described by scientists of the Republic of Belarus (Bojaxhi & Toromani, 2016) and some European countries (De Jaegere *et al.,* 2016; Gil & Zajączkowski, 2014; Jo *et al.,* 2017). In Turkey, the distribution of valuable coniferous species *Pinus brutia* Ten. also depends on climatic patterns, includ-

ing the average annual precipitation and the average annual temperature (Şentürk *et al.,* 2019). *Larix decidua* Mill. has become promising for Lithuania for its high quality of wood and good adaptiveness to climate changes (Godvod *et al.,* 2018). The Balkan Peninsula plays a key role as a climatic transition zone between the western and eastern Mediterranean and Central Europe (Bojaxhi & Toromani, 2016; Şentürk *et al.,* 2019). Migrations of "local" species are being studied on the American continent and in European countries. In particular, there were studies on the relationship between the growth of *Pinus heldreichii* Christ and the main climatic factors in Bulgaria, Greece, Albania, and Italy (Bojaxhi & Toromani, 2016). Researchers revealed dependence between the growth of *P. heldreichii* and climatic conditions based on different combinations of precipitation and temperature over a certain period. These studies demonstrated the relationship between the development and growth of the local forest on the amount of precipitation and atmospheric temperatures to a greater extent and on the location to a lesser extent.

Thus, planning forestry activities in regions requires measures to use competitive advantages in the conditions of climate transformation based on academic, scientific and technical achievements. At the regional level, it should be noted that the RB's government is interested in effective conservation and protection of forests, their useful properties, resources to achieve a balance of disposal and restoration, increase productivity and quality, growing forest stands resistant to external influences following the legislation at the federal and republican (local) levels through the development of international cooperation and experience exchange.

Conclusions

The conducted comparative analysis of the forest species distribution on the territory of the Bashkortostan Republic in the conditions of climate transformation over the last decades showed the following:

- during the studied period from 1998 to 2018, the share of soft-leaved species by area has significantly increased, primarily *Betula pendula* and *Tilia cordata* respectively, by 70.8 (39%) and 74.2 thousand hectares (32%);
- the areas under coniferous species tend to decline; *Picea* and *Abies* territories decreased by 57.9 thousand hectares or 15%,
- there was a cut in *Quercus robur* short-trunk by 34%, high-trunk – 6% and *Ace*r – 8%.

The expected forecast for reduced coniferous areas and increased mixed and broad-leaved forest stands is mainly due to climate transformation.

The increased sum of active temperatures and vegetation length by an average of twelve days can be considered as positive impacts of climate change. It is beneficial for wood growth. The wood reserves in the RB will increase by more than 10%.

There is a high probability of more negative manifestations in the form of forest diseases and pests, windstorms, fires due to climate transformation, which has already caused a mass disease of birch trees in all the republic's districts in the last years.

The present study found that under warmer climatic conditions, there will be an increase in the number of destructive pests by several times, damaged plants on an area of up to ten thousand hectares and a reduced area of spruce forests by 20% over the last twenty years.

The Russian regulatory framework of forest management was amended by the section on forestry adaptation, including the forest plans of the regions to mitigate climate transformations. However, they provide general provisions and no specific forestry measures. Therefore, the authors of the present study believe that there is a need

for collaborative work between public environmental and scientific organisations and authorities to develop specific measures for adapting forestry to the consequences of climate transformations and introducing them into regional forest management regulations. Currently, to address the issues of minimising forestry losses during sustainable climate changes and getting possible benefits from them, the Russian Government is preparing an Environmental Development Strategy for the period up to 2050, which will help the world community maintain ecological balance.

Further research should be undertaken to continue the analysis, spatial modelling and study of the ecophysiological reactions of species to changes in environmental factors, and their competition that will contribute much to the studies in this field.

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