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The economic consequences of future climate change in the forest sector of Russia

I O Torzhkov¹, E A Kushnir¹, A V Konstantinov^{1,2}, T S Koroleva¹, S V Efimov², I M Shkolnik²

¹Research department, *Saint Petersburg Forestry Research Institute*, 21 Institutsky Prospect, Saint Petersburg 194021, Russian Federation

²Dynamic Meteorology Department, *Voeikov Main Geophysical Observatory*, 7 Karbyshev Street, 194021 Saint Petersburg, Russian Federation

¹E-mail: konstantinov_a82@mail.ru

Abstract. A prediction estimate of the economic consequences of climate change for forestry in the subjects of the Russian Federation at the end of the 21st century was made. The estimate is based on mass ensemble calculations of climate changes with high spatial resolution. Due to the expected growth in productivity, stock of coniferous and hardwood timber will increase, which may lead to an increase in the economic evaluation of forests. As a result of climate-related fire risk changes in the subjects of Russia, an increase in the total amount of forest fires extinguishing costs by the end of the century is expected. An economic evaluation of possible damage shows that, on average in Russia, the amount of forest fires extinguishing costs can increase with the realization of radiation exposure scenarios RCP 4.5 and RCP 8.5, respectively, with an accumulated amount of 211.114 thousand rubles and 248.956 thousand rubles.

1. Introduction

The contribution of Russia's forestry complex to the country's gross domestic product is about 1%. Experts agree that there is potential for growth in the profitability of the forest sector due to the development of production on deep processing of timber and sale of timber products with high added value in the world market. To develop a balanced long-term strategy in the forest sector, a forecast is needed for the development of forestry in Russia, taking into account key factors of influence. One of the most important factors is the climatic one, which can lead to a significant change not only in the species diversity of stands but also in the complete mode of life of the whole biotope, which will undoubtedly affect the human economic activities.

Expected climate changes can disrupt the existing course of relationships between tree species at the stage of natural regeneration of forests, and also increase the potential hazard of fires [1-3]. An increase in the surface air temperature and the associated decrease in the moisture content in the soil can lead to the gradual disappearance of boreal forests, the replacement of the vegetation of semi-arid zones with vegetation of the arid zone. For hardwood, climate change will be less significant than for coniferous species. The death of coniferous species, stimulated by outbreaks of mass reproduction of pests and diseases, winds and fires, will free up space for the development of aspen, birch, alder, willow [4-11].

In order to minimize the impact of natural climate fluctuations on the assessment of climatic trends, it is advisable to use averaging of the prediction estimates for a large ensemble of calculations.



In the study, there are ensemble calculations with a modern high-resolution regional climate model, which builds assessments of changes in the regional climate and their impacts on forestry. The regional model allows to detail the effect of global warming both for individual forest ecosystems in the context of the subjects of the Russian Federation and for the forest sector of the Russian economy as a whole. Previously, such applied research in relation to Russian forest territories was not carried out.

2. Methods and Materials

The regional climate model (RCM) used in the ensemble calculations of future climate changes has a resolution of 25 km and covers the entire territory of north-eastern Eurasia [12]. The input information to the RCM is the calculation of future climate changes by the global model [13] of a lower resolution (~ 200 km). In the process of calculations, the RCM uses data on the air temperature, wind, atmospheric moisture and pressure on the underlying surface, obtained from calculations with the global model for each six-hour interval, on the lateral boundaries of the model area. The experimental setup is similar [12]. As the boundary conditions on the ocean surface, models use data on two variations in the evolution of ocean surface temperature and sea-ice concentrations obtained in the global CMIP5 models [14] ACCESS1-0 (Australia) and CESM1-CAM5 (USA).

A total of 20 experiments were conducted (10 for each of the 2 variants of the boundary conditions on the ocean surface) for scenarios RCP 8.5 and RCP 4.5 of the IPCC [15] – from different initial conditions in the atmosphere and on the underlying land surface for different decades, two periods of which are used in this study – these are the periods of 1990-1999 (basic) and 2090-2099 (prognostic).

The study uses the ensemble average climate changes for both radiation exposure scenarios. The degree of uncertainty of the resulting impact assessments in this study is not evaluated, but it should be noted that the underlying changes in climate characteristics usually show a high degree of robustness in a relatively near future.

Three key abiotic factors affecting the development of the biome are considered: temperature, solar radiation and humidification, of which the first two are the most important. The degree of influence of these abiotic factors on woody vegetation is determined, including changes in the productivity of plantations, species composition and fire threat to stands as a key natural and climatic factor of vulnerability in forestry.

Calculation of economic consequences from possible changes in the tree species composition and productivity of tree stands at the end of the 21st century is based on possible changes in the duration of the growing season and the sum of active temperatures (above 10 °C). These characteristics demonstrate significant spatiotemporal variability in the territory of Russia due to the wide variety of natural zones. For the convenience of data collection and analysis, the principle of zonal-provincial division of A.S. Isayeva is applied [16].

To calculate the economic estimate of the cost of forest planting, the state statistics for the federal districts are used for the average market price per cubic meter of logs (as of March 2017). Economic evaluation of the value of forest planting is carried out by groups of coniferous and deciduous species.

Forecast data on the change of fire danger in the subjects of Russia are calculated on the basis of a complex indicator of fire danger of V. G. Nesterov. Actual data on the state of burning in the regions are collected from the forest plans of the subjects of the Russian Federation and summary plans for extinguishing forest fires.

Calculation of costs for extinguishing forest fires is made in prices of 2016 in proportion to the increase or decrease in the number of fire danger days using data on current costs on the basis of the Single Interdepartmental Information and Statistical System (SIISS) for the period 2008-2012 by average value with indexation for the period up to 2017.

3. Results and Discussion

Weather conditions to a large extent determine the timing of the onset of certain phenological events in the life cycle of woody plants. With climate change, there may be changes in the timing of phenological events (shift towards earlier or later dates).

Calculation of the valuation of forest planting expected in the end of the 21st century in the subjects of the Russian Federation is made on the basis of the supposed changes in the tree species composition and on the basis of possible changes in the growth of tree planting, which in turn are based on a change in such interrelated indicators as the sum of active temperatures and the duration of the vegetation period.

On the basis of ensemble calculations, estimates of changes in the sum of the active temperatures (SAT) of air for each subject of the Russian Federation for the period 2090-2099 were obtained. An analysis of the estimates shows that in all the subjects, in two scenarios, this indicator is projected to increase, this change will be of a heterogeneous nature.

The smallest change in the SAT index for both scenarios is predicted in the areas of the northern taiga of Western and Eastern Siberia. The maximum increase in the SAT indicator is predicted in the areas of the southern taiga of the European-Ural part of Russia. Under the IPCC RCP 4.5 scenario, the maximum increase in SAT is predicted in the Astrakhan Region (884 °C), the minimum increase in SAT is predicted in the Krasnoyarsk Territory (182 °C). According to the more “aggressive” scenario of the IPCC RCP 8.5, the maximum increase in SAT is predicted in the Krasnodar Territory (1535 °C), the minimum increase in SAT is also predicted in the Krasnoyarsk Territory (456 °C). On average in Russia, the sum of the active temperatures increases according to the RCP 4.5 scenario at 638 °C, and according to the RCP 8.5 scenario – by 1043 °C.

An important factor on which the productivity of tree planting depends is the vegetation period, the duration of which here is determined by the time between the transition dates of the mean daily temperature in spring and autumn through +10 °C. Thus, at an average daily temperature in the range of 10-12 °C, most buds of the spruce are buds, while in Scots pine these processes occur at temperatures 8-14 °C.

As the analysis shows, an increase in the duration of the growing season in all zones is expected. However, in the case of the implementation of the scenario RCP4.5, an insignificant change in the described indicator is expected in the northern taiga of Eastern Siberia. The greatest increase (20%) of the vegetation period is predicted in the zone of the southern taiga of the European Ural part. When the RCP 4.5 scenario is implemented, on average for all Russian subjects the vegetation period will last for 25 days longer (169 days) compared to the base period, and under the RCP 8.5 scenario, the vegetation period may increase by 41 days, reaching 185 days. In both scenarios, the smallest increase in the vegetation period is predicted in the Republic of Sakha (9 days (RCP 4.5) and 20 days (RCP 8.5)), and the largest in the territory of the Kabardino-Balkaria Republic (37 and 60 days respectively).

The specific type of stands in specific climatic conditions corresponds to the duration of the vegetation period. Thus, for the active life of coniferous trees, the characteristic duration of the growing season is shorter than for hardwoods. A comparative analysis of the position of the boundaries of the natural and climatic zones at the current time and the end of the 21st century gives reason to believe that there is a possibility of a gradual shift of boundaries from south to north (figure 1). This prediction for the displacement of natural zones agrees with the results of previous studies [5, 8, 11, 15, 17]. The displacement of the boundaries of the latitudinal-zonal bands will inevitably entail a change in the species composition of the forest area in these territories. It is expected that the part of coniferous species will decrease to 35.2% on average by region from the total forest area.

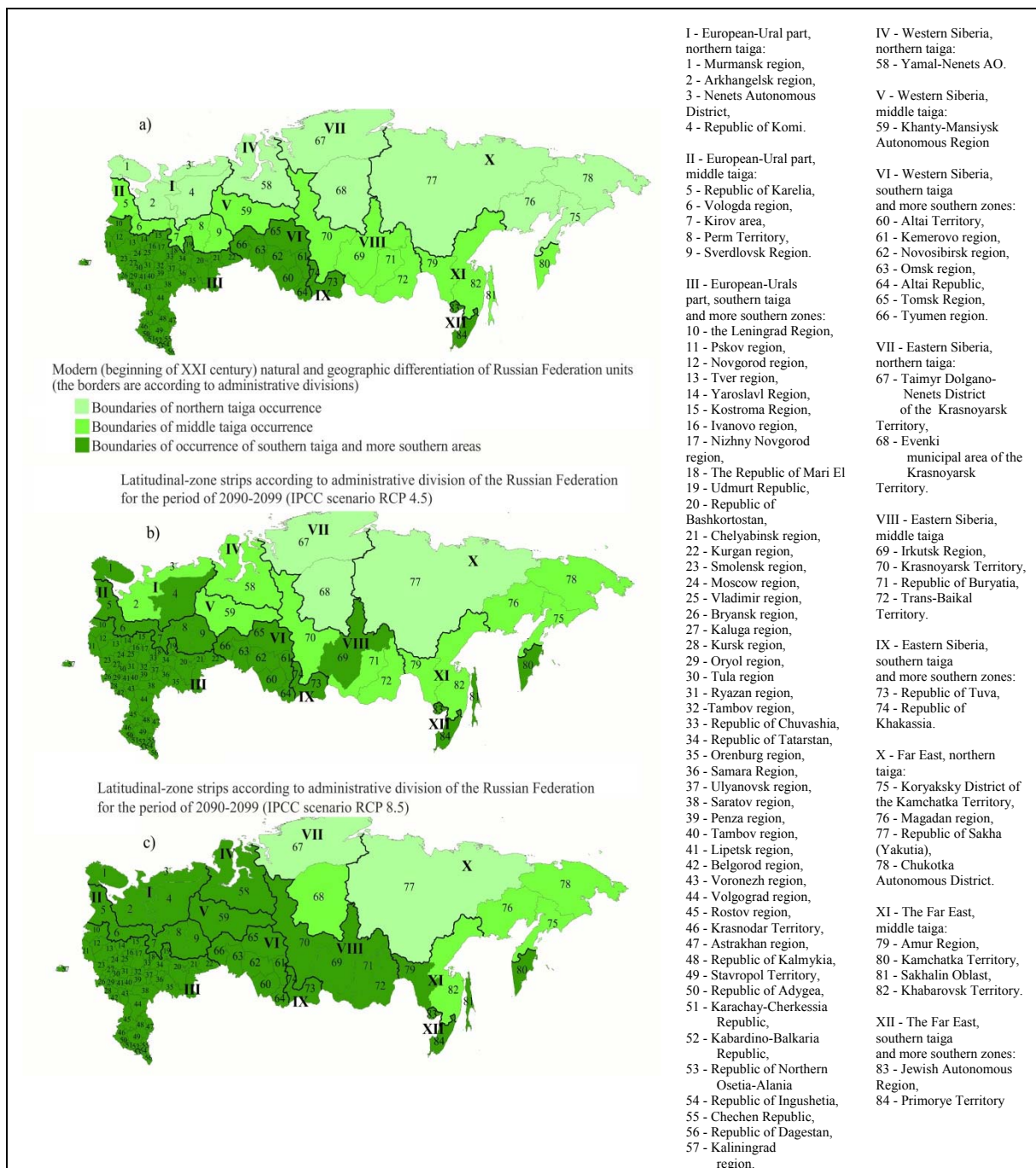


Figure 1. Prediction of distribution of borders of northern, middle and southern taiga for the period 2090-2099 under the IPCC scenario RCP4.5 (b) and RCP8.5 (c) in relation to the current natural and geographical differentiation of the subjects of the Russian Federation (a). Scenario calculations performed on the ensemble of the RCM Voeikov Main Geophysical Observatory.

The economic consequences of the above changes in climatic impacts on the forest sector can be related both to the change in the species composition of forests and to the change in the average annual increase in timber due to an increase in the growing season. Within the framework of this study, it is supposed that the growth of productivity of stands (carbon stocks) is directly proportional to the change in the duration of the growing season [18-20]. In addition, in determining the economic assessment of

the planting, factors that influence the reduction of forest plant stocks are not taken into account: logging, fires, extreme weather events, changes in the age composition, forest diseases and the spread of insect pests.

According to the data of 2014, the cost estimate of coniferous planting exceeded the cost estimate of hardwoods and accounted for about 70% of the total value of forests in Russia.

By the end of the century, it is expected that the cost of hardwood will be 60% of the total economic valuation of timber; the change in the cost structure of planting is associated with the replacement of coniferous species with deciduous trees and the growth of the stock of deciduous planting. In this case, the value of both coniferous and deciduous stands will increase in comparison with 2014 due to an increase in the productivity of plantings. There are differences in the valuation of the stand, depending on which of the scenarios under consideration will further warm the global climate.

By the end of the century, the valuation of forests is expected to increase in both scenarios by increasing the productivity of forests. At the same time, despite the significant differences between the radiation impacts for the RCP 4.5 and RCP 8.5 scenarios, the differences between the changes in valuation estimates for the end of the century are comparatively small. This is due to the fact that the implementation of the scenario RCP 4.5 and the scenario RCP 8.5 can lead to the replacement of coniferous by deciduous trees in the same latitudinal-zonal boundaries: the zone of the middle taiga is shifted to the zone of the northern taiga, and the zone of the southern taiga is in the zone of the middle taiga. However, the large indicators of the expected average annual increment of the stand under the RCP 8.5 scenario (an increase in the annual growth by 23% under the RCP 8.5 scenario and by 13% in the implementation of the RCP 4.5 scenario) allow us to make a forecast for a higher valuation of the stands in this scenario.

A significant impact on forest productivity is due to the increase in the number of forest fires and extreme weather events occurring on the background of global warming, the growth of insect pests and forest diseases, the spread of invasive species. An analysis of the association of these phenomena with negative consequences for biocoenoses has been performed in a number of studies [21, 22]. The increase in the number and intensity of extreme events can lead to a decrease in the valuation of the stand due to continuous decay, loss of quality of stands, replacement by unwanted invasive species with low economic value.

To calculate the possible costs of extinguishing forest fires in both scenarios, a change is calculated by the end of the century to the number of days with classes of fire hazard II-V in the subjects of the Russian Federation (figure 2).

In some regions, both scenarios are predicted to reduce the day with the II-V class of fire hazard. The most noticeable decrease in this indicator, according to the scenario RCP 4.5 and RCP 8.5, is predicted in the Republic of Adygea (decrease, respectively, for 5 and 9 days). A significant increase in the number of days with fire hazard of II-V class under the RCP 4.5 scenario is expected in the Republic of Mari El and Kurgan region (respectively, for 28 and 26 days), and under the scenario RCP 8.5 – in the Chelyabinsk region and the Kurgan region (on days 24 and 31).

The obtained data show a possible increase in the number of days with the II-V class of fire danger in all federal districts, with the exception of the North Caucasus and Southern Federal Districts, on average 9 days by the end of the century. Such assessments are consistent with the conclusions on the contribution of global warming to the change in fire hazard statistics obtained in other studies [21, 22].

To determine the possible increase in the costs of extinguishing forest fires, a cost is calculated for each of the scenarios under consideration. At the same time, it is assumed that the change in the costs of extinguishing forest fires is directly proportional to the change in the number of days with burning according to the complex fire danger indicator Nesterov.

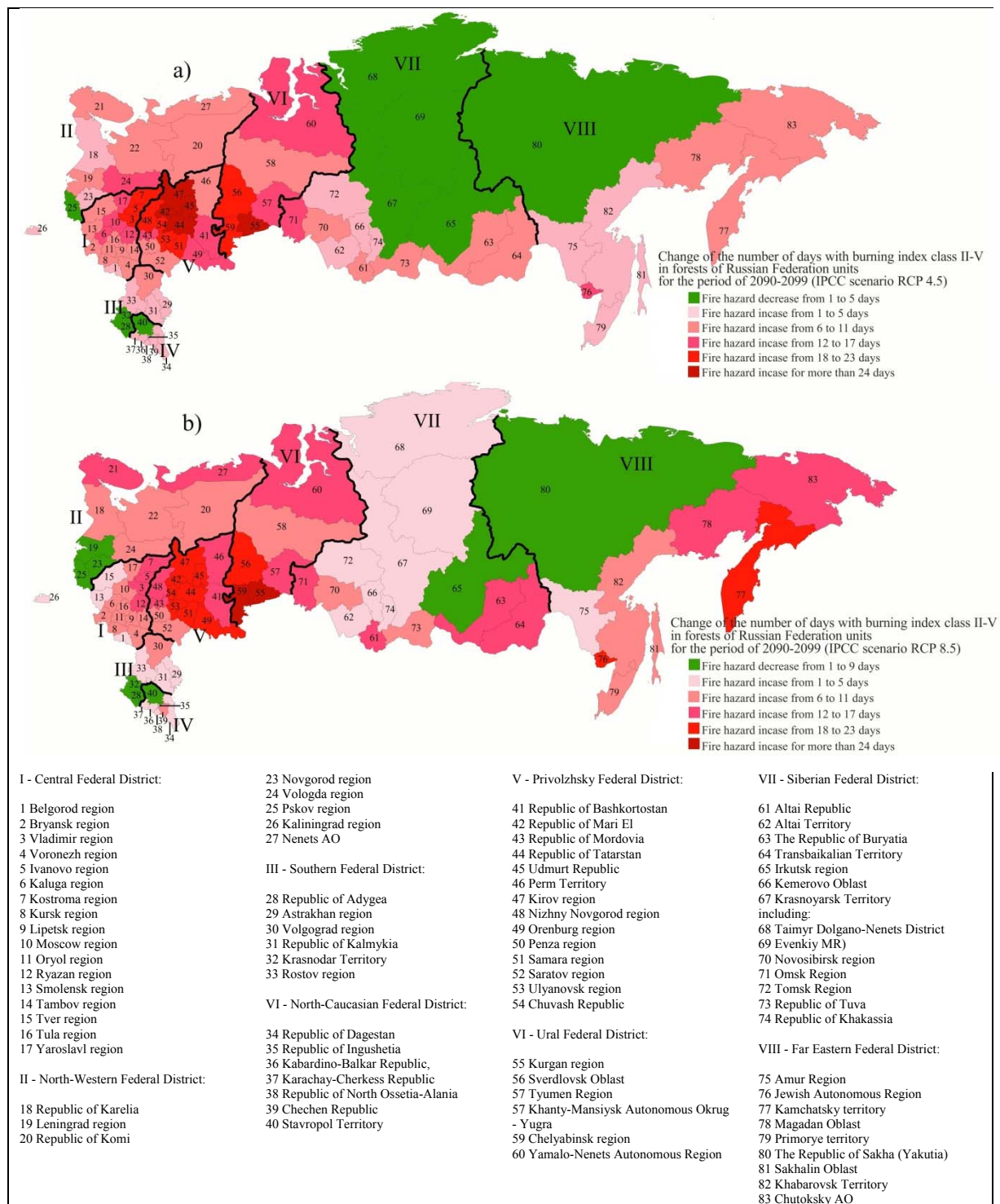


Figure 2. Change in the number of days with a class of fire hazard II-V in the subjects of the Russian Federation for the period 2090-2099, under the IPCC-RCP scenario 4.5 (a) and (b) RCP 8.5

By the end of the century, it is expected to increase the costs of extinguishing forest fires. When the RCP 8.5 scenario is implemented, the increase in costs is expected to be at the level of 249 million rubles per year, the RCP 4.5 scenario is 211 million rubles per year. The leading regions in terms of cost growth for both scenarios are the Tyumen Region. (from 3361 to 3841 million rubles), the Khanty-Mansiysk

Autonomous Region – Yugra (up to 1663 million rubles), the Sverdlovsk region (up to 1392 million rubles), the Republic of Buryatia (from 683 to 1093 million rubles.), the Trans-Baikal Territory (from 599 to 1078 million rubles.), Arkhangelsk region (from 831 to 935 million rubles). In a number of regions, it is possible to reduce costs by the end of the 21st century due to a decrease in the number of days of fire on the complex fire risk indicator of Nesterov: according to the RCP 4.5 scenario, the Krasnoyarsk Territory (decrease by 304.7 million rubles, the Republic of Sakha (Yakutia) (decrease by 226.3 million rubles), under the scenario RCP 4.5, costs in the Irkutsk region are expected to decrease (110.5 million rubles). The decrease in the number of days with a high risk of fires in such regions is due to the possible increase in the frequency of intensive precipitation in the future, leading to a decrease in the climate-conditioned pyrogenicity in forests.

4. Conclusion

The climatic changes predicted in the territory of the regions of the Russian Federation will have different economic consequences. Due to the increase in average annual temperatures, an increase in the vegetation period is expected, which may lead to a shift of the polygons of the southern taiga and more southern regions to the territory of the middle taiga, and the shifting of the current boundaries of the middle taiga to the territory of the northern taiga. The consequence of such changes will be the replacement of coniferous species with deciduous stands and an increase in the average annual tree stands growth by 13% in the case of the RCP 4.5 scenario and 23% in the implementation of the RCP 8.5 scenario, which will significantly increase the economic valuation of the forest fund – from 193 trillion rubles up to, respectively, 426 trillion rubles and 453 trillion rubles respectively; thus there will be a redistribution of the commodity structure of stands in such a way that deciduous species will possess a large stock of wood, their part in the total stock will increase from 30% to 51%. It is expected that the overall economic assessment of boreal forests in the Russian Federation as a result of climate change will increase substantially. At the same time, it is expected that the number of days with high fire-retardancy will be increased by an average of 9 days per year, which may lead to an increase in the cost of forest fire extinguishing from RR1.521/year (RCP 4.5) to 249 million rubles/year (RCP 8.5).

When both scenarios are implemented, both positive and negative consequences for the forestry sector are predicted. The increase in the duration of the growing season can favorably affect the productivity of tree stands, which in turn can lead to benefits. On the other hand, the shift of the natural areas to the north can have negative consequences for the forest complex due to the replacement of coniferous species with deciduous.

In the future, it is advisable to expand the study on the assessment of future changes in the forest sector of the Russian economy based on the use of super-ensembles of different high-resolution climate models that will serve as a starting point for a comprehensive assessment of the uncertainties accompanying quantitative assessments of future changes in impacts on forest ecosystems. The use of spatially detailed information on the future climate will lead to a comprehensive assessment of the expected changes in forest biological productivity and clarification of existing forestry strategies in the context of climate nonstationarity, will open the way for optimizing the management of the Russian agro sector in general and for developing adaptation measures at the national level in the forestry complex to changes in the regional climate.

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