Adaptive forest management in the context of climate change
(on the example of the Republic of Srpska (Bosnia and Herzegovina) and the Central Black Earth Region of Russia)

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Abstract. The article examines the systems of adaptive forest management in the Republika Srpska (Bosnia and Herzegovina) and forest-steppe and steppe regions of the Central Black Earth region of Russia (within the Voronezh region) in the context of climate change, suggests measures for adaptive forest management. The concept of adaptive measures can be useful to rationalize and focus existing views on adaptation and restoration of forests. This area is designed to help reforestation, with particular attention to the ability of ecosystems to self-organize in the future and adapt to changing environmental conditions. Adaptive capacity. It is imperative to consider new or unparalleled ecosystems to ensure the best mix of ecosystem services in the face of future uncertainties. Substantiation of improving models of forestry in the context of climate change and ensuring their practical implementation. Directions for further research in this area should relate to the development of risk-based planning approaches and multi-stakeholder decision-making.

1. Introduction
The final statement of the XII World Forestry Congress provides a policy and institutional framework for governance, including the development and adoption of a legislative framework for sustainable forest management, forest policy development and implementation of programs to reduce deforestation and forest degradation in line with and in synergy with strategies in related sectors [1].

Sustainable management is essentially adaptive management as the environmental, economic and social conditions are constantly changing. Sustainability means a trajectory (movement) that can have a range of acceptable results, as well as a range of strategies to achieve those results. Adaptive forest management is an approach to management when actions are planned and carried out and the results of actions taken are monitored to adjust future plans and strategies, and improve management efficiency.

Adaptive forest management and forest landscape restoration are two major concepts for forest (landscape) adaptation enhancing the functionality of both forests and forest landscapes under multiple
pressures of global change [2-4]. The global change includes the alteration of growing conditions for forests due to climate change impacts, in particular, due to extreme weather events [5, 6] and accompanying pathogen pressures [7, 8]. However, also, the requirements for ecosystem services by an expanding world population and shifting social demands for food, bioenergy, and water supply are rapidly increasing. To meet these geographically variable social requirements in the face of the effects of climate change on local growing conditions is one of the major challenges in the twenty-first century for the management of forests and forest landscapes.

Adaptive forest management is forward-looking and aims to preserve and develop the functionality of specific forests as a prerequisite for fulfilling the future need for forest ecosystem services [9, 10]. This is dedicated to all measures that adapt intact forests to changing growth and management conditions due to environmental setting, but also, e.g., due to diverse economic perspectives.

Adaptive forest management comprises all actions that increase the adaptive capacity of forests and forest landscapes to changing environmental conditions.

The purpose of this study is to consider adaptive forest management in the context of the drying up of oak forests and climate change in the Republic of Srpska (Bosnia and Herzegovina), as well as in the forest-steppe and steppe regions of the Central Black Earth region of Russia (within the Voronezh region). This region is a special landscape zone with transitions from forest to steppe, with a warm and dry temperate continental climate.

The relevance of the study is due to the fact that under the conditions of the transition to market relations, there is no methodology for transferring the forest complex to the principles of adaptive development, and there is no clear system of goals and guidelines determined not only by current but also by future trends. It is necessary to formulate a new approach to a long-term strategy for the development of the forestry complex, the content of which should be to change the forms and methods of management following the ideas of co-evolution, bio-ecos, economic benefits and social justice.

2. Objects
The object of the study was the forest ecosystems of dying rocky oak forests (mountainous regions) of the Republic of Srpska (Bosnia and Herzegovina) and pine forests and oak forests of the Central Chernozem region (within the Voronezh region)– about relatively small scattered forests, a significant part of which is declared a nature reserve (figure 1).

![Figure 1. The natural zoning map of the Central Black Earth Region.](image-url)
In the steppe zone, there are no natural forests, and artificial plantations are represented mainly by forest belts for various purposes.

The analysis and reliability of the conclusions is ensured by the application of such methods of scientific research as systemic and comparative analysis, generalization. The research is based on the monitoring data obtained during the forest inventory for the allotted period of time (10 years).

3. Results and discussion

A necessary condition for ensuring sustainable forest management is the adaptation of the developed national and international criteria to regional and local levels of management. This problem is being addressed in the process of developing national and regional standards for sustainable forest management as the basis for voluntary forest certification. Unfortunately, the system of forest management bodies in Russia does not fully meet the requirements of sustainable forest management. The reason is the constant change in the forest management system, the separation of powers for forest supervision. Adaptive management is aimed at preserving forest ecosystems, it is an interactive process based on monitoring results, making optimal decisions in conditions of uncertainty (risk) to reduce them over time. With the help of this type of management, using the well-known systems for assessing and forecasting carbon stocks in forest ecosystems, it is possible to correct one of the most important functions of a forest - the carbon-sequestration capacity of the stand. Due to the peculiarities of the biological and economic components of forestry production, it is difficult to predict possible uncertainties associated with climate change, natural disasters of various kinds, storm winds, fires, etc.

A simple and inexpensive passive type of adaptive forest management is one that involves predicting the response of natural ecosystems to management activities. The disadvantage is that monitoring and evaluation systems are in place before the start of management, but monitoring indicators do not have enough control, synchronization of database content and copying data from one source to another, as well as a system of random distribution of compared objects (groups). It is used if the forest is of insufficient ecological and economic importance. This type of management does not provide accurate data on the state of change of an object from the environment caused by management activities or any other activity or natural process.

Active adaptive forest management based on an assessment and forecast system can establish causal relationships between management activities and changes in environmental conditions. The disadvantages of this approach are the greater complexity in relation to passive management, as well as higher costs - monitoring studies must be integrated into management activities. This type of management is applicable in case of significant impact on forest functions, adaptation to climatic conditions, if there is a high risk of biological and abiotic impact [11-13].

The effectiveness of assessing adaptive forest management is determined by changes in the structure, species composition of the forest ecosystem, viability, changes in the age structure, quality of stands, and natural regeneration.

To address the issues of forest management planning in the current uncertain situation with global ecological and socio-economic changes in the environment, there is a need for reliable and scientifically based tools. There is a need for new simple and affordable management methods aimed at increasing the adaptive capacity of forest ecosystems, taking into account the dynamics of vegetation, natural disturbances, and targeted management programs.

One of the optimization methods of management to maintain the adaptive capacity of the forest ecosystem and preserve its biodiversity is a functional network approach. The method, proposed and used by a group of Canadian and Spanish scientists, takes into account the peculiarities of the diversity of species and their functional dependence, attachment to the landscape.

The allocation of territories and their inclusion in the structure of the ecological framework is a laborious process, subject to a certain algorithm of sequential actions, with an assessment of the representativeness and biodiversity of large forest areas, proposed as cores of the framework. The proposed frameworks of the territory (green corridors connecting the nodal sections) are a complex structure that is being developed by specialists in various sectors of the economy and ecology. The
ecological framework itself is not a form of nature protection, it is one of the adaptive management tools that help to restore natural forest communities without external intervention in the face of climate change, which ensures the stability of ecosystem services, the long-term existence of humans and the natural resources they use [8, 9].

The main prerequisite for the ability of forests to adapt to climate change is to maintain the structure, vitality and functioning of forest ecosystems, including their harvesting and carbon sequestration.

Scientists of the Republic of Srpska have proposed strategies for adaptive management of forest ecosystems, which will connect scientific knowledge and real conditions for the management of dying oak forests. This strategy, which aims to preserve existing forest structures, can be applied primarily to plantations at the end of the production period, plantations of sustainable tree species, and plantations of high ecological and economic value. Passive adaptation of forest ecosystems recommended for use in plantations with low ecological and economic significance with high costs of active adaptation, and active adaptation, which is used in plantations of species resistant to climatic conditions, with a pronounced purpose and a high risk of exposure to adverse factors biotic and abiotic nature [14, 15].

There are three main factors of climate change that require the adaptation of woody vegetation. This is an increase in temperature, an increase in the concentration of carbon dioxide, an increase in the accumulation of nitrates. In the course of the studies and the presented models of the development of the situation [according to the data of the third national report on climate change in the Republic of Srpska [6], there is a risk of drought. Given the dynamics of climate change, young stands currently formed as a result of afforestation will be subject to serious risks that will accompany them throughout their entire life cycle.

Due to constant serious unpredictable changes in climatic conditions (drought, precipitation, temperature) in different natural zones, the inventory data on the state of the forest differ greatly. In the Republic of Srpska (Bosnia and Herzegovina), research has been carried out on the adaptive management of rocky oak forests in the face of climate change. The main problem is the drying out of oak forests, and the work was aimed at preserving the full set of forest stands, without introducing other species.

The study of the growing conditions of rocky oak forests, analysis of the average annual air temperatures over ten years shows a sharp increase in air temperature. Changes in climatic conditions are the impetus for the emergence and development of pathogenic organisms, defoliator insects, whose activity enhances (influences) the processes of decay of rocky oak forests [8].

Adaptive forest management is developed taking into account the zonal climatic characteristics and growing conditions. As measures recommended in the process of adaptive management in the plantations of the mountainous regions of Ozren, affected by drought, preventive care and protection of plantations, natural and artificial reforestation, reclamation and sanitary felling to eliminate dried degraded trees are proposed. It is assumed that the formation of mixed forests of different ages of rock oak and black pine on dense mountain soils will increase the adaptive capacity of the forest.

The problems of the rocky oak forests on Mount Ozren in the Republic of Srpska (Bosnia and Herzegovina) include wasteful forestry methods, the prevalence of mature stands, slow and relatively low adaptability of forests to new conditions of climate change. The lack of information on the degree of threat and degree of risk for individual forest communities complicates the processes of reforestation. The unequal adaptation of trees to the structure, soil acidity, and availability of nutrients can significantly affect natural regeneration in the event of a drought threat. Plant communities have different sensitivity to changes in the external environment and do not unambiguously respond to acting factors, which complicates the recovery process. Analysis of the data obtained made it possible to determine that the productivity of mature plantations of rocky oak forests, where trees with an age interval of 80 to 120 years prevail, are below optimal. According to our data, when comparing the main structural elements of a dying stone oak stand, a decrease in the proportion of oak stands in relation to the total mass by 20% in relation to the total was found. The method of visual assessment of crowns showed that sanitary felling of trees leads to a decrease in crown volume (about 20%).
consequence of this is a decrease in the ugliness of acorns, which has a negative effect on the natural regeneration of the oak. At the same time, on the territory of the forest-steppe and steppe zones of the Central Chernozem region (in particular, the Voronezh region), a steady increase in air temperature and a changeable level of precipitation leads to dangerous hydrometeorological phenomena. The groundwater level of the region is formed due to atmospheric precipitation, temperature and relative humidity. Data analysis and calculation of the average value of the groundwater level of the first aquifers in the region is presented in the graph (figure 2).

![Figure 2](image_url)

**Figure 2.** The graph of the groundwater level according to the average annual values for 2010-2021.

There are risks of changes in the species composition and level of biodiversity of the main types of forest ecosystems. The identified negative factors that are of paramount importance in predicting the response of managed forests to climate change (forest fires, forest pests and diseases, unfavorable weather conditions) made it possible to establish the adaptive potential of biological systems. Analysis of the data and comparative characteristics of the ability to adapt made it possible to draw a conclusion about the degree of vulnerability of ecosystems in forest-steppe regions. With the development of any scenario for forest ecosystems with high adaptive potential, the adaptive management process should include measures to increase the area covered with forest, reforestation, timely cleaning of windblows and burnt woods, prevention of the appearance of root rot, and control of the species age structure of plantations.

Thus, the analysis of adaptive forest management systems shows that the climate can affect all forest landscapes and biodiversity of both the Republic of Srpska and the Central Black Earth Region of Russia. Projected changes in climate variables will seriously affect the adaptability and conservation capacity of forests and biodiversity.

The exceptional nature of the forestry sector is that it combines both adaptive capabilities and conditions for mitigating the effects of global climate change associated with sequestration of carbon.

The analysis of the data obtained from the conducted studies allowed us to conclude that the result of a change in climatic factors is the transformation of all components of forest ecosystems at the structural and functional levels, both positively and negatively (figure 3).

Given that the goal of adaptation in the forestry sector is to reduce the vulnerability of social and natural systems, this Climate Change Adaptation Program and Action Plan presents some actions and measures that can be divided into two categories: policy options and management options. Table 1 provides an overview of the main potential adaptations in the forestry sector.
Based on these examples, it can be argued that adaptation to climate change should be based on intersectoral policies. National institutions responsible for the forestry sector, forest ecosystems and climate change need to establish mechanisms to enable them to coordinate with other sectors. Coordination of activities would include, inter alia, clarifying and resolving conflicts, exploiting synergies, and sharing knowledge and experience.

An analysis of the work of scientists [9] on adaptation of forestry and conservation of biodiversity in countries with a similar forest management system (Republic of Srpska and Russia) makes it possible to identify the following possible adaptation measures in forestry:

- forecasting changes in the structure of forests and developing recommendations for adapting forestry to changing climatic conditions;
- development and implementation of the “climate forecast” system, which allows forecasting the average monthly air temperature and the amount of precipitation over the entire territory of the country with a 5-year period;
- conducting targeted analysis of likely climate-related changes for local forests;
- analysis of risks and trends associated with predicted climate warming for all major forest formations;
- determination of the species composition of insects that pose the greatest danger to forest plantations at present, and potentially dangerous, which can give outbreaks of reproduction as a result of changes in climatic conditions in the country;
- carrying out reforestation works to absorb greenhouse gases and, accordingly, increase their sinks;
- optimization of the structure and composition of forest areas and their adaptation to climate change;
- prevention and control of forest fires, especially during dry periods.

**Figure 3.** The effects of ecosystem change in the face of climate change.

The intensity of the photosynthesis process, decrease in stomatal conductance increasing the efficiency of water use, the intensity of the growth rate of plants, increased seed yield.

Changes in the process of photosynthesis, transpiration intensity, increase or decrease in primary production, impact on seed yield.

Decreased precipitation contributes to a slower growth rate and an increase in seed waste due to a decrease in precipitation.

Reduced seed loss, growth of the plant rate, change in the growing season, the density of individual populations, increase in biomass, changes in species competition, species composition.

Changes in the rate of regeneration, increased mortality of stand and temperature-dependent species changes in species competition and species composition, increased soil mineralization.

Increased mortality of mature stand changes in species competition and species composition.
Table 1. Adaptive forest management options [10].

| Possible options for adaptive forest management | Results |
|-----------------------------------------------|---------|
| Adaptive forest management options for the provision and delivery of services based on forest ecosystems | Ensuring the extent of forests. |
| Adaptive forest management options for the provision and delivery of livelihood / sourcing services | Facilitating natural adaptation of biological diversity |
| Adaptive forest management options for the provision and delivery of services for regulation | Ensuring the vitality of forests |
| Adaptive forest management options for the provision and delivery of services to meet cultural needs | Providing tangible socio-economic benefits |
| Variants of forest policy | Maintaining soil and water resources |
| | Maintaining and enhancing the contribution of forestry to the global carbon cycles |
| | Managing human disease and reducing the number and magnitude of natural disasters |
| | Maintaining the cultural property and traditional and local knowledge |
| | Providing services to meet aesthetic needs (scenic landscapes) |
| | Providing services to meet spiritual needs |
| | Providing educational services |
| | Provision of recreational services |
| | Forest policy options Integration of adaptation into international forest policy-making and related programs |
| | Integration of forest adaptation into programs/ projects of multilateral environmental funds (e.g. GEF, climate change funds) |
| | Integration of vulnerability and adaptation issues into national forest plans |
| | Integration of vulnerability and adaptation issues into the decentralization of the forestry sector |
| | Facilitating the identification of ownership, use and access rights to forest-based services in relation to vulnerability and adaptation |
| | Facilitating intersectoral dialogue and dialogue among forest stakeholders |

4. Conclusion
Thus, global climate changes are a challenge to forestry, namely, they lead to a decrease in the stability and vitality of forests, and cause an increase in the number of forest fires.

Under these conditions, an objective necessity is a transition from the traditional forest management system to an adaptive model, which should be based on a dynamic management decision-making algorithm aimed at reducing potential losses and increasing the adaptability of socioecosystems. Practical implementation of climate change mitigation tools goes beyond the forestry management system and necessitates creative approaches in long-term planning, the development of new communications and the formation of shared values with stakeholders, the introduction of multilateral decision-making procedures. In this direction, further research should be carried out to ensure the practical implementation of the economic mechanism for mitigating the effects of climate change in forestry and, in particular, its economic instruments.
Currently, forest ecosystems have a fairly high adaptive potential. However, in connection with the appearance of the above mentioned risk factors, it will be necessary to carry out proactive and strategic adaptation measures of various degrees of advance, aimed at reducing the possible negative consequences that can bring the ecosystem out of balance. Using only situational and tactical measures will not help to strengthen the potential of forest ecosystems and will inevitably lead to significant economic losses. The AM concept can be helpful in streamlining and focusing existing concepts on forest adaptation and restoration as well as to help forest restoration to focus more on the ability of ecosystems to self-organize in the future and to adapt to changing environmental conditions instead of attempting to restore to a previous historical state.

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