Economic model of forestry adaptive capacity in the context of climate change

Tatiana Bezrukova[1*], *Aydarbek* Gyiazov[2], and *Irina* Kuksova[1]

[1] Voronezh State University of Forestry and Technologies named after G. F. Morozov, 394087 Voronezh, Russia
[2] Economics and Right of the Batken State University, 720300 Kyzyl-Kiya, Kyrgyz Republic

Abstract. The article presents the theoretical foundations for the application of the economic model and the adaptive potential of forestry in the context of climate change, since the conservation and rational management of all types of forests is recognized as a critical factor in economic and social development and environmental protection. It is assumed that the model will be constructed as a weighted directed graph, which describes various methods for calculating the weight coefficients of the model based on statistical assessment and expert assessment, and also provides recommendations for their application to assess relationships of various natures. The developed economic model of the adaptive potential of forestry in the context of climate change will optimize the structure of forests taking into account probable climate changes, preserving their forestry and biological values, and increasing resistance to insect pests and forest diseases. Secondary resources will be preserved, and ecosystem services will be increased, fire hazard and losses from the impact of negative climatic phenomena will be reduced. A distinctive feature of which is the low level of resource provision and management potential, the need to consolidate as the main direction of development the adaptive potential for substantiating technologically simplified stages, with the development of standard organizational tools for applied use.

1 Introduction

The importance of the forestry complex in the Russian economy is determined by the wide territorial distribution of forest resources and huge timber reserves. At the same time, forests play a key role in combating climate change as a reservoir of carbon dioxide. Forest ecosystems are renewable and one of the largest reservoirs of biomass and soil carbon on land. They play an important role in the global cycle as carbon accumulators and sources of its emission. Carbon reserves in forests are concentrated in above-ground biomass, dead and decaying organic remains and soil humus [1].

Forest vegetation is an important reservoir of carbon. Therefore, recently, with the expected global warming, great importance has been attached to the role of forests in carbon

* Corresponding author: bezrukova_t_l@mail.ru

deposition, since forest ecosystems convert atmospheric carbon into an inactive state for a long time and remove it from the cycle [2].

The success of the forest sector of the economy largely depends on climatic components. At the same time, one of the key positions of sustainable development of the forest sector is the preservation of the productivity of forest systems, their ecological potential while reducing the total damage from weather anomalies. The solution to this issue is impossible without taking into account changes in natural and climatic factors, as well as expected weather conditions for the coming years. The processes of global warming occurring in the climate system at the earth's surface, sharp changes in the values of climatic characteristics have a significant impact on forestry and other sectors of the economy, as well as areas of social life [3,4].

Forestry is the most sensitive to anthropogenic and climatic changes in the economy. The adequacy of actions in the field of building a system of measures to mitigate the consequences of these impacts and the development of adaptive forest management programs are determined by the correctness of the vulnerability assessments of the economic system.

Climate change leads to changes in the frequency, intensity, spatial scale, duration and timing of extreme meteorological and climatic events. Changes in extreme events can be associated with changes in the mean, dispersion or form of probability distributions, as well as a complex of all these indicators [5].

Changing climatic conditions are the basis for the discrepancy between interspecies interactions in ecosystems, changes in the boundaries of forest vegetation zones, shifts in the timing of phenological events in plants and animals [6]. The nature and severity of the consequences of climate events depend not only on the events themselves, but also on the susceptibility and vulnerability of socio-economic systems. In turn, high susceptibility and vulnerability are usually the result of imbalances in the development process associated with environmental degradation, the inability to manage the natural resource block. Climate change can have a more serious impact on economic sectors that have close ties to climate. The most climate-dependent economic sectors are agriculture, forestry, and the use of water resources.

The task of bringing anthropogenic forests closer to natural forests in terms of sustainability in order to reduce the share of care (care, protection and conservation) was set for foresters by G.F. Morozov, who bequeathed to conduct business in such a way that the constancy of use was evident, but so that the forest did not suffer noticeable damage in its biological sustainability, was, if possible, independent in terms of renewal, and differed from the spontaneous in its greater productivity [7, 8].

Followers of the concept of organic growth (M. Mesarovich, E. Pestel) call for a deep restructuring of the modern economy and the widespread introduction of new resource- and nature-saving technologies, while, in their opinion, further economic growth and some moderate growth in gross consumption are possible [9].

For this study, it is important to talk about the balanced development of the forest sector as an economic system. It should be noted that the activities of the forestry sector are based on the use of a renewable natural resource - forests, which have a major environmental component, are subject to the influence of external and internal, controlled and uncontrolled factors, which allows us to consider the forestry sector as an open ecological and economic system.

Speaking of economic systems in the context of the forestry sector, we note that in 1987, the International Commission on the Environment adopted a definition according to which sustainable development (balanced) is development in which the needs of the current generation are met without jeopardizing the ability to meet the needs of future generations [10].

Academician N.N. Moiseyev, in an attempt to understand the meaning of sustainable development, calls for giving it content, freeing it from political layers, which corresponds to scientific ideas about the relationship between nature and society at the present stage of development [11].

2 Methodology

The concept of sustainable forest management has been developing for the last two decades, but has not yet acquired a concrete form. The Basic Principles on Forests developed for UNCED state: "Forest resources and areas should be managed sustainably and meet the social, economic, environmental, cultural and spiritual needs of present and future generations." Despite the fact that the forest sector is objectively a strategic competitive advantage of the regions of Russia, unfortunately, this natural advantage still remains only potential, due to multiple factors limiting its development [12].

The multifactorial impact of climate change and the diversity of its consequences for forest ecosystems in Russia predetermine the need to develop an economic model of the adaptive potential of forestry in the context of climate change.

The essence and nature of adaptive potential, according to V.S. Shmakov, is that its possession is a direct prerequisite for adaptation. Accordingly, the holders of potential should simultaneously be subjects of adaptation. The possible lack of connection between these variables leads to the emergence of adaptive barriers that create a system of factors that counteract the adaptive process, slowing down and complicating its implementation [13].

The need to study the adaptive potential of forestry in the context of climate change is due to the fact that it is necessary to describe the relationships between various factors and determine the nature of their changes under the influence of external conditions. In the process of systemic modernization, it is important to pay special attention to the mechanism for the formation of adaptive potential as a condition for increasing the level of efficiency of forestry modernization processes in the context of climate change.

Therefore, it is proposed to conduct systematic observations to assess changes in the growth (decrease) rates of indicators in the aggregated index of adaptive potential and organize ongoing monitoring of the impact of management decisions on ensuring ecosystem sustainability [14].

The essence of the proposed model of the adaptive potential of forestry in the context of climate change is that it is necessary to take into account the system of basic socio-economic indicators of forestry, which are interconnected with the level of development of the economy and adaptive climate changes. This will contribute to the growth of forestry efficiency in the conditions of a changing climate in the design and implementation of events and forest management, reduction of losses from adverse weather conditions, growth of forest productivity of the future and improvement of environmental conditions for the conservation of biological diversity of flora and fauna [15]. The results of the study clearly show the statics and dynamics of data developed according to the methods of official statistics. At the same time, an important role in mitigating climate change is given to sustainable forest management and rational use of forest resources, including the preservation of native forests and their productivity, the fight against deforestation, the prevention of fires and outbreaks of mass reproduction of insects, regulation of timber harvesting with subsequent reforestation.

It should be noted that at present, the methodological apparatus for studying and assessing climate change on the main climate-dependent sectors of the economy, including forest management, has not been fully formed. Therefore, the purpose of activities to assess the adaptive potential based on the fuzzy reasoning model in the forest sector is to identify ecological systems that are most vulnerable to the effects of climate change and the risks of negative impacts. The first step in any such assessment is to determine the possible consequences for both ecosystems and human well-being. After the probable consequences have been identified, they begin to analyze the vulnerability of forests and forest-dependent forms of economy to them [16].

Assessments of the adaptive potential based on the fuzzy reasoning model include an analysis of the potential of ecosystems and communities to adapt to changing climatic conditions, as well as:

- analysis of current and expected loads on forest areas;
- analysis of current climatic conditions, and how they affect forest areas;
- forecast of changes in climatic conditions, and their potential impact on forests. Vulnerability and risk assessment can be qualitative (e.g. high, medium or low) or quantitative, depending on the information and resources.

Climate change will undoubtedly have economic consequences for the forest sector and, consequently, for all participants in forest relations. These effects can be both positive and negative.

Classification of the set of adaptation measures can be carried out depending on the time, duration, scale, responsibility and specific goal of each measure and adaptation strategy. In terms of the time (terms) of implementation, adaptation measures can be:

- proactive, if they are aimed at preventing the impact and are carried out before the adverse impact occurs. This type of measures is preventive in nature. Proactive measures are based on an assessment of the likely consequences and potential vulnerability of the system [17];
- situational, if these measures are implemented at the same time as the adverse impact;
- reactive, if these measures are implemented after the adverse impact has occurred or has begun to occur. These measures are intended to compensate for or compensate for the losses caused by the adverse impact. Because reactive measures are implemented after an adverse impact has occurred, their planning relies less on modelling potential impacts.

In terms of the duration of implementation, adaptation measures can be:

- tactical, when the period of their implementation and achievement of the result are observed for 5 years;
- strategic - if these measures are intended for implementation in the medium and long term, they are usually part of long-term programs.

In accordance with the spatial scale, adaptation measures can be:

- localized, if these measures are implemented in a specific economic sector or geographic region. In relation to forests and forestry, adaptation measures can be localized in a specific forest area or can be applied to the industry as a whole;
- dispersed, if the scale of their implementation is continuous in geographical and sectoral terms. As a rule, they are aimed at solving several common problems. Dispersed measures are of a general nature, they can include activities in the field of education, planning and capacity building. The analysis of the main classification features characterizing adaptation measures for the purposes of applying them to the object of study, as well as the degree of their priority are presented in the table, which describes the parameters of forest resistance to various scenarios of climate dynamics due to changes in the species composition and structure of forest stands. The classification of priority is applied to the set of adaptation measures: high, medium and low priority.

The coefficients of these features can be determined by sample points and do not require additional information, although their complexity is constantly increasing. At the same time, the number of determined coefficients significantly exceeds the number of sequence points.

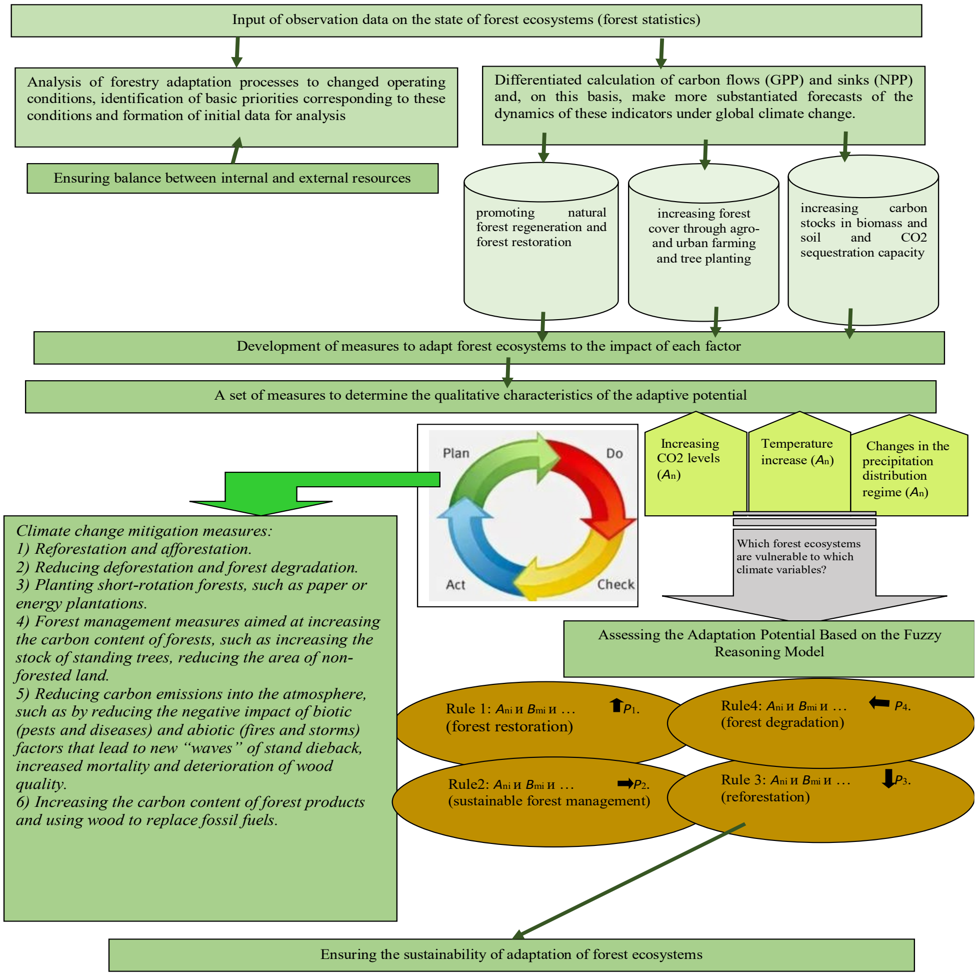

Fig. 1. Economic model of forestry adaptive capacity in the context of climate change.

3 Results

The problem of determining the coefficients of this dependence is a problem of fuzzy regression analysis. Fuzzy numbers in the sample are specified by parametric membership functions of the same type. Let us assume that the dependence of the parameters of the membership function of a fuzzy number on the influencing factors is described by linear models [18]:

$$v_0(x_i, x_j) = a_{00} + a_{01}x_i + a_{02}x_j$$

$$v_1(x_i, x_j) = a_{10} + a_{11}x_i + a_{12}x_j \qquad (1)$$

$$\dots$$

$$v_{10}(x_i, x_j) = a_{10,0} + a_{10,1}x_i + a_{10,2}x_j$$

The coefficients of these models are found using the least squares method.

As external criteria, we will use the minimum bias criterion, which is calculated using the formula

$$K_{cm}^2 = \frac{\sum_{i=1}^{n}\sum_{j=0}^{10}(\mu_A(0.1\cdot j)-\mu_B(0.1\cdot j))_i^2}{\sum_{i=1}^{n}\sum_{j=0}^{10}\mu_E(0.1\cdot j)^2} \quad (2)$$

where μ_A - is the output membership function of the model, the estimates of the coefficients of which are obtained for the subsample;

μ_B - is the output membership function of the model, the estimates of the coefficients of which are obtained for the subsample;

μ_E - are the actual membership functions of the sample.

The criterion for stopping the generation process is the proximity of the average criterion of the series models on two adjacent series of the method, that is:

$$-\varepsilon < K_{\text{см}\,p+1}^2 - K_{\text{см}\,p}^2 < \varepsilon \quad (3)$$

The described method for determining the dependence of the adaptive potential on the influencing climatic conditions was tested on the following initial statistical data. The following functional dependence was obtained

$$P = \sum_i \widetilde{a}_i w_i \quad (4)$$

where $\widetilde{a}_i$ - are fuzzy coefficients;

w_i - are generalized variables given in the table

Table 1. Dynamics of development of adaptive potential based on the fuzzy reasoning model.

Measures to mitigate climate change w_i	**Measures to mitigate climate change**	**Priority of appropriate measures in relation to the forest sector**	**The value of the membership function of the fuzzy coefficient Pn**				
reforestation and afforestation	Proactive/ strategic/ localized	high	0.043	0.156	0.2788	0.015	0.01
reducing deforestation and forest degradation	Reactive/ tactical/ dispersed	average	0.0137	0.081	0.065	+0.045	0.023
planting forests with short rotation periods, such as plantations for paper or energy production	Situational/ tactical/ localized	average	0.0231	0.003	0.092	0.0412	0.0321
forestry measures aimed at increasing the	Proactive/ strategic/ localized	high	0.064	0.049	0.038	0.026	0.023

carbon content of forests, such as increasing the growing stock, reducing the area of non-forested land							
reducing carbon emissions into the atmosphere, for example by reducing the impact of disturbances	Situational/ tactical/ localized	low level	0.0047	-0.003	0.0063	0.0052	0.0046
increasing the carbon pool in forest products and using wood to replace fossil fuels	Situational/ tactical/ localized	low level	-0.032	0.006	0.0041	0.0031	0.0021

As follows from the presented analysis, the highest priority in the formation of the adaptive potential of forestry is given to preventive, strategic and localized measures implemented by the public sector. This is explained, first of all, by the peculiarities of the production and consumption structure in this sector of the economy, as well as the long period of response of forest ecosystems to adverse climatic impacts. The adoption of predominantly situational and tactical measures significantly reduces the economic efficiency of the implementation of the adaptation strategy as a whole, and does not contribute to strengthening the potential in this area.

4 Conclusion

Climate change may require adjustments to logging schedules, modernization of logging infrastructure, and changes in forest management practices. Such changes may increase the costs of management and, in some cases, may require significant additional investment in infrastructure, equipment, and training. In addition, loggers should use economic models to estimate the costs of implementing adaptation measures, as well as the costs when such measures are not used.

The ecological potential of Russian forests is due to their role in stabilizing the composition of atmospheric air and the Earth's climate as a whole, mitigating the effects of global warming. In the near future, ecosystem services may become even more important than the resource potential of forests, aimed at meeting the needs for wood raw materials and non-wood products. Currently, scientific research and practical steps are being stimulated to combine accounting methods and systems for assessing carbon stocks and flows, adaptation measures and forest management methods are being developed aimed at counteracting global warming. Based on the analysis and classification, it was concluded that there are various adaptation measures applicable to forestry. The best results in forestry can be achieved through proactive, strategic and localized measures implemented by government agencies due to the specific structure of production and consumption in this economic sector, as well as the long response time of forest ecosystems to adverse climatic impacts.

The adoption of predominantly situational and tactical measures significantly reduces the economic efficiency of implementing the adaptation strategy as a whole, and does not contribute to strengthening the potential in this area. Based on the study, it can be concluded that in relation to forestry, the system of adaptation measures is aimed at maintaining, improving and/or restoring the ecosystem functions of forests, which forms the basis for sustainable management of this economic sector. As we can see, the proposed scientific and methodological apparatus for assessing the adaptive potential can be used in the context of unstable economic relations when determining anti-crisis measures. The advantage is that the adaptability indicator is considered, reflecting the scheme of forestry adaptation processes to climate change. This makes it possible to quantitatively take into account the degree of adaptability in order to formulate adaptive measures.

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