Construction of an economic and environmental assessment of the state of regional forestry in the Russian Federation based on the methods of the fuzzy set theory

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Abstract. This paper proposes a methodology for constructing an assessment of the state of forestry for a sufficiently long period from the point of view of economic and environmental activity in the forestry of the region based on the mathematical apparatus of the fuzzy set theory, which is used to the study of the Central, North-West and Ural Federal Regions of Russia as the richest of forest resources. A feature of this technique is the construction of comprehensive assessments of the state of the forestry in the region for each sub-period, for example, with a duration of 5 years, which are obtained by dividing the study period into sub-periods in a sliding way. This makes it possible to identify the priorities of the activities of organizations and enterprises in the direction of improving the state of forestry in the regions. In addition, when constructing complex assessments of regions, the obtained sets of optimal alternatives make it possible to rank the regions under study by the level of the state of production activity in the forestry of the regions, as well as from the point of view of the area of burned forests and number of fires.

1. Introduction
Forestry is not only a type of economic activity associated with the use, protection and reproduction of forests, but also an important tool for nature conservation. Forestry is one of the main branches of not only agriculture, but also the economy as a whole in many countries of the world. Analyzing and evaluating the existing organization and management of forestry is a rather difficult task. General issues of forest management, methods of assessment and characteristics of forest resources, as well as methods of wild nature protection are discussed in detail in [1]. A partial review of mathematical methods and models used to solve applied problems, both related to classical optimization and heuristic ones, is given. In [2], an analysis of land use plans in the United States is conducted which is of great importance for the sustainability of this industry as a whole. An extensive study of the contribution of forest industry enterprises to the economy of 50 US States was conducted in [3]. The impact of foreign direct investment on the productivity of China's forest industry was studied in [4], and a global study of these issues for the period 2005–2017 was conducted in [5]. The role of the state and, in particular, tax policy in wood pricing is discussed in [6].
The economic and environmental functions of forestry are inseparable from each other. Another area that has been actively developing in recent years is the study of ecosystem functions of forest range. One of these models, describing a spatially dynamic approach to optimizing the production of ecosystem services for forestry, is considered in [7]. Economic assessment of forest lands is the basis for optimizing forest management in a region of any country. Similar studies of Czech and Slovak forest ranges were conducted in [8], and a review and comparison of methods of financial and economic analysis of forest enterprises were made in [9]. As an example of forest ranges valuation in Russia, we can cite the method of economic valuation of forests [10], which takes into account only the costs of forest renewal. It should be noted that this methodology practically does not address the issues of accounting for the costs of forest protection.

As can be seen from the above, the state of the forest industry is affected by a variety of heterogeneous economic, political, social, environmental and other factors. The relevant statistics are also often incomplete and distorted, so it is necessary to use mathematical methods that take these features into account to analyze them in this case. The use of fuzzy set theory methods [11] makes it possible to take into account the uncertainty not only in the analyzed data, but also the uncertainty associated with unaccounted factors.

In this paper, to assess the state of forestry in the region, a sample of six indicators characterizing its production, economic and environmental activities is proposed with their further ranking based on the methods of maximin and minimax convolution of the fuzzy set theory.

All of the above proves the relevance and novelty of the research conducted in this paper, as well as the validity of the mathematical methods used.

2. Methodology

We propose a method for constructing a comprehensive assessment of the state of regional forestry using the methods of the fuzzy set theory, which allow one to take into account the state of various sectoral economies, as well as to reveal not only the level of the state of forestry in each studied region, but also to rank these regions by degree state of forestry. This technique is a modification of the methods used to select the mode of transport for regional freight and passenger transportation [12].

Let us describe the stages of constructing a comprehensive assessment of the state of regional forestry.

Stage 1. Formation of a list of key indicators characterizing the production, economic and environmental activities of forestry in the studied regions: $X_1$ – number of enterprises and forestry organizations; $X_2$ – the average annual number of employees of organizations (people); $X_3$ – reforestation (thousand ha); $X_4$ – total standing timber (million m$^3$); $X_5$ – area of burned forests (ha); $X_6$ – number of fires (ha); $GRP_i$ – gross regional product (GRP) (trillion rubles) of the $i$-th region, $i = 1,..,k$; $F_i$ – total area of the forest fund and forests not included in the forest fund (thousand ha), of the $i$-th region, $i = 1,..,k$; $S_i$ – area of the $i$-th region, $i = 1,..,k$.

Data collection on the main indicators characterizing various aspects of the state of forestry in the selected regions for the study period, for example, 2009 - 2017.

Stage 2. The study period is divided into sub-periods of duration, for example, 5 years using the sliding method 2009–2013, 2010–2014, 2011–2015, 2012–2016, 2013–2017.

Stage 3. The selection of criteria for assessing the state of forestry in the regions and their division into two groups: the first group contains those indicators ($X_1$, $X_2$, $X_3$, $X_4$), for which, the greater its value, the better the state of the region’s forestry industry is assessed; the second group is indicators ($X_5$, $X_6$), for which, the lower its value, the better the state of the industry according to this criterion.

Stage 4. For each of the sub-periods indicated in stage 2, for 2013, 2014, 2015, 2016, 2017, we define as the expected or desired estimates of the indicators (see stage 3) $X_{ji}$, $j=1,2,3,4,5,6$, $i=1,..,k$ in relation to the highest values of the corresponding indicators of the region.
Stage 5. To characterize the production results and the level of economic development of the region, the gross regional product (GRP) is used. The criteria for assessing the state of forestry in the region introduced at the third stage are of different importance, and therefore the proposed estimates of indicators for each region obtained at stage 4 are proposed to be considered as fractions of the values of these estimates of indicators in the gross regional product (GRP) of the region:

$$\frac{X_{ji}}{GRP_i}, \quad j=1,2,3,4,5,6, \quad i=1,...,k .$$  \hspace{1cm} (1)

Step 6. For a possible further comparison of the state of forestry in the regions (districts), we determine the ratio of the total area of the forest fund and forests not included in the forest fund of the region to the total area of the corresponding region using the formula:

$$\frac{F_i}{S_i}, \quad i=1,...,k .$$  \hspace{1cm} (2)

Step 7. To determine the fuzzy sets for the first and second groups of indicators, the formula is used:

$$\frac{X_{ji}}{GRP_i} \cdot \frac{F_i}{S_i}$$  \hspace{1cm} (3)

Stage 8. Constructing comprehensive assessments of the state of forestry in the studied regions at the end of each of the considered sub-periods (stage 2), i.e. for 2013, 2014, 2015, 2016, 2017 by methods of maximin and minimax convolution.

Stage 9. The study of the dynamics of the constructed integrated assessments of the state of forestry of the studied regions.

Stage 10. Analysis of the study and development of recommendations (strategies) to improve the state of forestry in the studied regions.

3. Results and discussion

Let us apply the proposed methodology to study the state of forestry in the Central, North-West and Ural Federal Regions of Russia. In the problem under consideration, these regions are alternatives, which in the future we will denote: $a_1$ – Central Federal Region; $a_2$ – North-West Federal Region; $a_3$ – Ural Federal Region. The information base for the study is the annual data on the main indicators characterizing the state of forestry in these regions for 2009–2017 [13]. Let us carry out the indicated stages of the proposed methodology for the first subperiod, using the values of the studied indicators for 2009-2013 (table 1).

Table 1. The values of the studied indicators and their maximum values for the period 2009-2013.

| Research indicators | Values of indicators in 2013 for Federal Regions | The maximum values of indicators in 2009-2013 for Federal Regions |
|---------------------|--------------------------------------------------|---------------------------------------------------------------|
|                     | $a_1$ | $a_2$ | $a_3$ | $a_1$ | $a_2$ | $a_3$ |
| $X_1$               | 1572  | 2816  | 894   | 2001  | 5034  | 1370  |
| $X_2$               | 8247  | 33845 | 7085  | 12552 | 49030 | 8752  |
| $X_3$               | 70.9  | 190.5 | 60.4  | 70.9  | 190.5 | 63.8  |
| $X_4$               | 3938.8| 10394.8| 8106.8| 3989  | 10425.3| 8128.8|
| $X_5$               | 281   | 52367 | 198549| 261643| 132431| 372637|
| $X_6$               | 244   | 1306  | 2718  | 6907  | 2389 | 9836  |

We construct the estimates $X_{ji}$ of the considered indicators as expected or desired in comparison with their maximum values for the period 2009 – 2013 (table 2).
The studied indicators of the state of forestry in the regions have different significance, therefore, according to the proposed methodology (stage 4), the expected indicator estimates for each region will be presented in the future in the form of estimates in relation to one of the basic economic indicators of the region – gross regional product (GRP), determined by (1), and in the future, these estimates will be called the expected estimates of the indicator, taking into account its significance (table 3).

The resulting estimates in table 3 will be used in the future to build comprehensive assessments of the state of forestry in the regions.

For further possible comparison of the state of forestry in the studied regions, we define the ratio of the total area of the forest fund and forests not included in the forest fund of the region to the total area of the corresponding region according to (2) (table 4).

To build fuzzy sets $\mu_{X_1}, \mu_{X_2}, \mu_{X_3}, \mu_{X_4}, \mu_{X_5}, \mu_{X_6}$ of the studied indicators, including three alternatives, we determine the products of the expected estimates of the indicators obtained in table 3 taking into account their significance for the corresponding region from the table 3 by the corresponding coefficients of table 4. This will allow the obtained, thus, the expected estimates of indicators should be used to compare them in different regions:

$$\mu_{X_1} = 0.01552/1572+0.070583/2816+0.054536/894;$$

### Table 2. Estimated values $X_{ji}$ in 2009–2013.

| Research indicators | Values of expected performance estimates for Federal Regions in 2013 |
|---------------------|---------------------------------------------------------------------|
|                     | $a_1$           | $a_2$           | $a_3$           |
| $X_1$               | 0.785607        | 0.559396        | 0.652555        |
| $X_2$               | 0.657027        | 0.690292        | 0.809529        |
| $X_3$               | 1               | 1               | 0.946708        |
| $X_4$               | 0.987415        | 0.997074        | 0.997294        |
| $X_5$               | 0.001074        | 0.395429        | 0.532821        |
| $X_6$               | 0.035326        | 0.546672        | 0.276332        |

### Table 3. Expected estimates $X_{ji}/GRP_i$ of indicators in 2013 taking into account their significance.

| Research indicators | Expected indicator estimates in 2013, taking into account their significance |
|---------------------|-----------------------------------------------------------------------------|
|                     | $a_1$           | $a_2$           | $a_3$           |
| $X_1$               | 0.041001        | 0.100731        | 0.086223        |
| $X_2$               | 0.03429         | 0.124301        | 0.106964        |
| $X_3$               | 0.05219         | 0.18007         | 0.12509         |
| $X_4$               | 0.051533        | 0.179543        | 0.131774        |
| $X_5$               | 5.61·10^{-5}   | 0.071205        | 0.070402        |
| $X_6$               | 0.001844        | 0.098439        | 0.036512        |

### Table 4. Values of coefficients $F_i/S_i$ for the respective Federal Regions in 2013.

| Values of coefficients $F_i/S_i$ |
|---------------------------------|
| $a_1$           | $a_2$           | $a_3$           |
| 0.378542        | 0.700711        | 0.632500        |
\[ \mu_{X_1} = 0.01298/8247+0.087099/33845+0.067655/7085; \]
\[ \mu_{X_2} = 0.019756/70.9+0.126177/190.5+0.079119/60.4; \]
\[ \mu_{X_3} = 0.019507/3938.8+0.125808/10394.8+0.083347/8106.8; \]
\[ \mu_{X_4} = 2.12 \cdot 10^{-5}/281+0.049894/52367+0.044529/198549; \]
\[ \mu_{X_5} = 0.000698/244+0.068978/1306+0.023094/2718. \]

To identify the best region in terms of the state of forestry in 2013, characterized by the indicators of the first group (stage 3) \( X_1, X_2, X_3, X_4 \), we apply the maximum convolution method of the theory of fuzzy sets. The set of optimal alternatives \( B_1 \), taking into account the varying degrees of significance of the indicators, is defined as the intersection of fuzzy sets, which corresponds to the choice of the minimum value for each region

\[ B_1 = \{ \min \{0.01552; 0.01298; 0.019756; 0.019507\}, \min \{0.070583; 0.087099; 0.126177; 0.125808\}, \min \{0.054536; 0.067655; 0.079119; 0.083347\} \} = \{0.01298; 0.070583; 0.054536\}. \]

We finally get

\[ \max \{0.01298; 0.070583; 0.054536\} = 0.070583, \]

which corresponds to a comprehensive assessment of the state of forestry in 2013 of the three studied regions. The whole set of \( B_1 \) allows ranking regions by the level of forestry in 2013, characterized by indicators of the first group: for 2013, this is the number of enterprises and organizations of forestry and the average annual number of employees (stage 3) which are reflecting production activities in forestry. The best condition in the North-West Federal Region, which corresponds to a rating of 0.070583. In second place is the Ural Federal Region with a corresponding rating of 0.054536, in third place is the Central Federal Region with a rating of 0.01298, and the elements of the set \( B_1 \) are complex estimates of these regions in 2013.

To identify the best region in terms of the state of forestry in 2013, characterized by indicators \( X_5 \) and \( X_6 \), of the second group (stage 3), we apply the minimax convolution method of the fuzzy set theory. The set of optimal \( B_2 \) alternatives, taking into account the varying degrees of significance of the indicators, is defined as the intersection of fuzzy sets, which corresponds to the choice of the maximum assessment value for each region:

\[ B_2 = \{ \max \{2.12 \cdot 10^{-5}; 0.000698\}, \max \{0.049894; 0.068978\}, \max \{0.044529; 0.023094\}\}. \]

Then the set \( B_2 \) has the following form:

\[ B_2 = \{0.000698; 0.068978; 0.044529\}. \]

Therefore,

\[ \min \{0.000698; 0.068978; 0.044529\} = 0.000698. \]

This corresponds to a comprehensive assessment of the state of forestry in 2013 of the three studied regions as a whole. Plenty of \( B_2 \) characterizes the state of forestry in the regions in terms of the number of fires and the area of the burned forest: the best condition according to these two criteria is in the Central Federal Region, which corresponds to a rating of 0.000698. In second place is the Urals Federal Region with a rating of 0.044529, in third place is the North-West Federal Region with a rating of 0.068978. It should be noted that the elements of the set \( B_2 \) are complex estimates of these regions in 2013 according to the above indicators of the second group of indicators.

Similar studies were conducted for the sub-periods of 2010 - 2014, 2011 - 2015, 2012 - 2016, 2013 - 2017.

We present the main results of the analysis of indicators for the last sub-period of 2013 - 2017 using the values of the studied indicators for 2013 – 2017 (table 5).
Table 5. The values of the studied indicators and their maximum values in 2013-2017.

| Research indicators | Values in 2017 for regions | The maximum values of indicators in 2013-2017 |
|---------------------|---------------------------|---------------------------------------------|
|                     | $a_1$  | $a_2$  | $a_3$  | $a_1$  | $a_2$  | $a_3$  |
| $X_1$               | 1069   | 2004   | 582    | 1572   | 2816   | 894    |
| $X_2$               | 5457   | 15963  | 3103   | 8247   | 33845  | 7085   |
| $X_3$               | 85.3   | 243.3  | 60.9   | 85.3   | 243.3  | 60.9   |
| $X_4$               | 3976.2 | 10425.1| 8105.5 | 3977   | 10425.1| 8135.6 |
| $X_5$               | 330    | 13247  | 243681 | 2638   | 52367  | 243681 |
| $X_6$               | 108    | 457    | 1948   | 1189   | 1869   | 2718   |

Similarly to the previous case, to construct fuzzy sets of the studied indicators, we define the products of the expected estimates taking into account their significance for the corresponding region by the corresponding coefficients $\frac{F_i}{S_i}$:

\[
\mu_{X_1} = \frac{0.009859}{1069} + \frac{0.009594}{5457} + \frac{0.014498}{85.3} + \frac{0.014496}{3976.2} + \frac{0.001814}{330} + \frac{0.001317}{108};
\]
\[
\mu_{X_2} = \frac{0.009594}{2004} + \frac{0.040366}{15963} + \frac{0.085584}{243.3} + \frac{0.02165}{13247} + \frac{0.020927}{457};
\]
\[
\mu_{X_3} = \frac{0.025993}{3103} + \frac{0.059129}{60.9};
\]
\[
\mu_{X_4} = \frac{0.025993}{8105.5};
\]
\[
\mu_{X_5} = \frac{0.059349}{243681};
\]
\[
\mu_{X_6} = \frac{0.059129}{243681}.
\]

The set of optimal alternatives $B_1$, taking into account the varying degrees of significance of the indicators of the first group $X_1$, $X_2$, $X_3$, $X_4$ has the form:

\[
B_1 = \{\min \{0.009859; 0.009594; 0.014498; 0.014496\}, \min \{0.009859; 0.009594; 0.014498; 0.014496\}, \min \{0.009859; 0.009594; 0.014498; 0.014496\} \}.
\]

Then we get:

\[
\max \{0.009859; 0.009594; 0.014498; 0.014496\} = 0.014498,
\]

which corresponds to a comprehensive assessment of the state of forestry in 2017 of the three studied regions as a whole for the same indicators reflecting production activity in the forestry of the studied regions as in 2009. The best condition for this type of activity in 2017 in the North-Western Federal Region with a rating of 0.014498. In second place is the Urals Federal Region with a corresponding rating of 0.009594; in third place is the Central Federal Region with a score of 0.009859. Note that the elements of the set $B_1$ are complex estimates of these regions in 2017.

The set of optimal alternatives to $B_2$, taking into account the varying degrees of significance of the indicators of the second group $X_5$, $X_6$, we write in the form:

\[
B_2 = \{\max \{0.00181369; 0.00131694\}, \max \{0.02165; 0.020927\}, \max \{0.05934862; 0.04253536\} \}.
\]

Therefore, the set $B_2$ has the following form:

\[
B_2 = \{0.00181369; 0.02165; 0.05934862\}.
\]

Then we get:

\[
\min \{0.00181369; 0.02165; 0.05934862\} = 0.00181369,
\]
which corresponds to a comprehensive assessment of the state forestry of the regions in terms of the area of burned forests in 2017. The best condition by this criterion is in the Central Federal Region, which corresponds to a score of 0.00181369. In second place is the Northwest Federal Region with a score of 0.02165, in third place is the Ural Federal Region with a rating of 0.05934862.

We'll study the dynamics of the comprehensive assessments of the state of forestry in the studied regions for the period 2009 - 2017, as well as the dynamics of indicators that played a large role in the construction of comprehensive assessments of the state of forestry in the Central, North-Western and Ural Federal Regions (tables 6,7). Note that in 2013, a more important role was played by indicators reflecting the production activities of forestry, as well as the number of fires and the area of burned forests, and in 2017, this is the average annual number of employees of the organization and the area of burned forests.

**Table 6.** Comprehensive Federal Regions estimates in 2013.

| Research indicators | Values of regions estimates in 2013 |
|---------------------|-----------------------------------|
|                     | $a_1$    | $a_2$    | $a_3$    |
| $X_1$               | –        | 0.070583 | 0.054536 |
| $X_2$               | 0.01298  | –        | –        |
| Place               | 3        | 1        | 2        |
| $X_5$               | –        | –        | 0.044529 |
| $X_6$               | 0.000698 | 0.068978 | –        |
| Place               | 1        | 3        | 2        |
| Sum of places       | 4        | 4        | 4        |

**Table 7.** Comprehensive Federal Regions estimates in 2017 and the total sum of places in 2013 and 2017.

| Research indicators | Values of regions estimates in 2017 |
|---------------------|-----------------------------------|
|                     | $a_1$    | $a_2$    | $a_3$    |
| $X_2$               | 0.009594 | 0.040366 | 0.025993 |
| Place               | 3        | 1        | 2        |
| $X_5$               | 0.00181369 | 0.02165 | 0.05934862 |
| Place               | 1        | 2        | 3        |
| Sum of places       | 4        | 3        | 5        |
| The total sum of places in 2013 and 2017 | 8        | 7        | 9|

Comparing the total amount of places for the studied regions, we can conclude that the leading place in terms of forestry in the study period is occupied by the North-Western Federal Region, then the Central and Ural Federal Regions, respectively.

The presented methodology makes it possible to analyze the overall state of regional forestry. In contrast to the research results presented in [7-10], the estimates obtained take into account both its economic and environmental indicators, the dynamics of their change, the influence of different time periods, and regional differences. Due to a variety of factors of different nature that affect the values of these indicators, this approach seems to be more complete and modern in combination with the methods of the fuzzy set theory used, which allow taking into account the uncertainty and incompleteness inherent in statistical data. The above is well illustrated by the analysis of the forest industry in the Federal Regions of the Russian Federation. In the presence of significant features in each district, the proposed method made it possible, nevertheless, to obtain, it seems, adequate estimates of their development, which will help to develop measures for the full development of all areas of forestry for a long period of time.
4. Conclusion
The analysis of the main indicators of the state of forestry in the Central, North-Western and Ural Federal Regions using the methods of the theory of fuzzy sets is carried out. Using this approach allows ranking the regions by the level of their forestry, while increasing the validity of the results. It should be noted that in constructing comprehensive assessments of the state of forestry and studying their dynamics, the following indicators played a more important role: the number of enterprises and forestry organizations, the average annual number of employees of organizations, and the area of burned forests. In addition, in 2017, the structure of integrated assessments is changing. This suggests that by 2017 the degree of importance of the indicators forming these estimates has changed, which indicates a change in the priorities of the organizations and enterprises of the studied industry. Based on the study, the following priority areas for the development of forestry in the studied regions can be proposed: to increase the number of enterprises and organizations of forestry, as well as the number of their employees. In the environmental and economic assessment of forests, it is necessary to take into account not only the costs of reforestation, but also the costs of conservation and protection of forests.

The development of analysis methods for various industries using modern mathematical and statistical models is an important step in the analysis of various industries and complex systems, the state of which is simultaneously influenced by economic, social, environmental and other factors.

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