Methods of assessing the effectiveness of reforestation based on the theory of fuzzy sets

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Abstract. Purpose of the study: development of a new universal fuzzy-multiple methodology that allows assessing the effectiveness of reforestation based on a variable set of indicators, the significance of which is taken into account on the basis of expert assessments, in contrast to existing assessment methods. The systems of fuzzy-logical conclusions, the so-called standard multilevel [0,1] classifiers, were used as a mathematical tool for constructing the assessment methodology. As a result of the implementation of the methodology, an assessment of reforestation in the Rostov region was carried out on the basis of a set of 23 indicators characterizing the dynamics of reforestation, thinning activities, and patrolling of the forest fund in the region. In comparison with the already existing estimation methods, the proposed estimation method has a number of such advantages, such as: simple calculation scheme; when constructing estimates, taking into account a large number of heterogeneous significant indicators that can vary depending on the available statistical material and the characteristics of the specific practical problem being solved; the possibility of varying the weight of the contribution of the studied indicators to the corresponding comprehensive assessment; the possibility of analyzing on its basis the situation in the region under consideration.

1. Introduction

Currently, active work is underway to create methods for assessing the effectiveness of reforestation. So, in articles [1-2] a method for evaluating the mechanism of the integrated use of forest resources in the region. The methodology consists of six stages: characteristics of the region's forest resources; assessing the current level of the mechanism for the integrated use of forest resources in the region; formation of criteria and a system of indicators for assessing the mechanism of the integrated use of forest resources in the region; quantitative assessment of the effectiveness of the mechanism for the integrated use of forest resources in the region; a qualitative assessment of the effectiveness of the mechanism for the integrated use of forest resources in the region; analysis of factors affecting the increase in the efficiency of the mechanism for the integrated use of forest resources in the region.

Integral assessment of the relative sustainability of forest management includes the ranks of environmental, social and economic indicators (1),

\[ W_{ow} = (n \cdot A_l \cdot B_l \cdot C \cdot D)^{1/2} \] (1)
where \( n \) – number of indicators under the root; \( A_i \) – the sum of the squares of the relative performance of system stability; \( B_i \) – sum of the relative performance in terms of (reserves); \( C \) – employment in the forestry sector in the region to the total number of able-bodied population; \( D \) – the share of the forest sector in the region's gross domestic product of the region.

The relative indicators of stability in formula (1) are: the ratio of the forested area of the forest fund to the total area of the forest fund as one of the indicators of forest cover; the ratio of the area of mature and over mature forests to the area covered by forest of the forest fund as an indicator of the usability of forests; the ratio of the area of economically demanded species to the area covered by forest as an indicator of the market potential of the forest fund; the ratio of the area of the first group of forests (green zones) to the area covered by forest of the forest fund as an indicator of the performance of the protective functions of forests; the ratio of the area occupied by soft-leaved species to the area occupied by conifers as an indicator of the biological diversity of forests; the ratio of the area of the damaged forest (diseases, pests, windblows, fires, etc.) to the area of the forest fund covered with forest as an indicator of the phytosanitary state of forests; the ratio of the area of reforestation to the area of felling as a criterion for reforestation of forests; the ratio of the area of felling areas recovered with valuable coniferous species to the area of felling as an indicator of the economic value of forests; the ratio of the total volume of harvesting to the annual growth of forests in terms of stock as an indicator of the continuity of forest use; the ratio of the volume of actually felled forest to the volume of the allowable cut as a criterion for the correct exploitation of forest resources; the ratio of the stock of forests available for exploitation to the total stock of the forest fund shows the possible potential for the timber industry complex.

The article [3] assesses the impact of fires, insects and windfall on the quality of stem wood using the example of the forests of the Krasnoyarsk Territory, as well as the development of correction factors when calculating the payment for harvesting commercial wood in plantations damaged by fires, insects and windblows.

The paper [4] examines the system of coefficients that allow assessing the efficiency of reforestation by years. It has been established that for forest cultures at the age of 1-3 years, the criteria for assessing the effectiveness of reforestation are: 1) compliance of the actually performed work with the projected technology of creating forest cultures; 2) safety of forest crops by area; 3) survival rate of forest cultures. For forest crops at the age of 5 years, the indicator ‘Entering young growth into forest-covered lands of the forest fund’ is introduced. For plants over five years old, a system of indicators is introduced: 1) the share of forest crops in the composition of forest lands covered with forest vegetation; 2) the dynamics of forest lands not covered with forest vegetation that need reforestation; 3) the coefficient of forest restoration; 4) coefficient of efficiency of reforestation; 5) the coefficient of the introduction of young stands into the category of economically valuable plantations; 6) the dynamics of the species composition of plantations (the coefficient of breed change). An integral indicator for assessing reforestation in this work, as well as in the previous one, is absent. Articles [5-6]. With the help of the given costs, compare and evaluate various technological processes of logging and reforestation work performed in the process of developing forest areas. The article [7] compares the biometric parameters of Scots pine forest cultures of different ages, created by rows and biogroups, and constructs approximate mathematical models of their development using the method of reforestation by clumps (biogroups); including the polynomial approximation.

The paper [8] reveals the patterns of natural reforestation in various forest conditions for coniferous-deciduous forests of the Middle Volga region. The authors have developed a methodology for scoring the quantitative and qualitative characteristics of the undergrowth for the objective purpose of reforestation methods in the taxation allotment. Using the module ‘Classification and Regression Trees’ in the STATISTICA environment, the authors carried out a cluster analysis of the main silvicultural factors influencing the presence and density of undergrowth. They developed interpolated ten-point scales of taxation indicators to assess the prospects of reforestation methods. Each scale is corrected by the correction factor of the influence of this factor on the appearance of undergrowth. For the analyzed taxation allotment, a point assessment of silvicultural factors is accumulated. Based on
the sum of points, reduced to a 10-point scale, all taxation units of the forest area are assessed according to the prospects of artificial or natural reforestation.

The paper [9] searches for the most acceptable approaches to assessing the success of reforestation. The authors proposed a system of six indicators and equations for their calculation; the final score is calculated on the basis of the generalized integral indicator.

The article [10] provides a comprehensive analysis of the dynamics of reforestation in the Russian Federation. When conducting the study, the authors used methods of analysis and synthesis, statistical methods for calculating absolute, relative, average values, methods for constructing and studying series of dynamics, tabular, graphical, monographic, method of statistical groupings.

Thus, the analysis of literature shows that for evaluating the effectiveness reforestation currently widely used statistical whose coefficient, point patterns, and construction of standard integrated indicators. As the experience of the application of these methods and models, they have a rather low flexibility, do not allow a significant variation of the complex of the studied parameters do not take into account expert assessments.

In this paper we propose a new method, based on the method of fuzzy sets theory [11-13], to evaluate the effectiveness of reforestation in three groups: the dynamics of indicators of the reforestation, the dynamics of the implementation of measures for thinning and information about patrolling the territory of the forest fund.

The novelty of the proposed method consists in the possibility of aggregation of arbitrarily large number of diverse parameters for formation evaluation, without significantly complicating the model may account expert estimations, as well as varying the weighting coefficients different groups.

2. Experimental part

Estimation of the dynamics of reforestation performed based on a set of 15 indicators taking into account the positive and negative of the dynamics of their changes (data are taken from the annual publication ‘Ecological Bulletin Don’ [14] (table 1). Data are presented for 10 years, from 2009 to 2018.

| Table 1. Dynamics of reforestation, Rostov region. |
|--------------------------------------------------|
| Indicators                                       | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| Reforestation fund (thous ha)                    | 29   | 29   | 32   | 33   | 33   | 32   | 31   | 30   | 29   | 29   |
| Reforestation, all (ha)                         | 1,500| 1,500| 2,121| 1,517| 1,500| 1,513| 888  | 1,145| 1,200| 1,200|
| including burns                                 | 411  | 348  | 713  | 128  | 120  | 136  | 26   | 27   | 21   | 0    |
| Survival annual coniferous, %                   | 46   | 51   | 53   | 50   | 59   | 60   | 42   | 56   | 64   | 47   |
| Survival annual deciduous, %                    | 68   | 60   | 63   | 56   | 66   | 59   | 55   | 52   | 64   | 62   |
| Cultural care of forest plantations, ha         | 15,22| 9,694| 10,2 | 12,81| 12,19| 17,11| 13,30| 13,32| 14,57| 13,92|
| Soil cultivation under forest crops, ha         | 2,000| 2,000| 1,872| 1,524| 1,510| 1,516| 1,496| 1,329| 1,100| 1,210|
| Cultivation of standard planting material, thou. Pcs. Procurement and purchase of seeds, kg | 5,542| 6,082| 6,836| 3,422| 2,852| 3,473| 3,870| 6,218| 5,556| 5,651|
|                                             | 3,489| 4,096| 3,746| 2,026| 771  | 2,706| 3,433| 1,693| 551  | 1,449|
Putting young trees in category of plants: 1,007, 1,154, 1,314, 530, 396, 398, 579, 659, 615, 435
Write-offs of forest crops, only, ha: 835, 1,948, 969, 1,057, 825, 581, 547, 204, 150, 310
Including decommissioned forest crops the first year of creation, ha: 543, 1,088, 863, 739, 342, 350, 364, 74, 12, 214
Incorporated valuable forest crops:
- Pine: 972, 999, 1,583, 798, 740, 726, 282, 588, 610, 602
- Locust acacia: 517, 451, 408, 695, 745, 781, 597, 545, 590, 598
- Oak: 0, 0, 0, 0, 15, 3, 9, 4, 0, 0

Assessment of the dynamics of the implementation of measures for thinning carried out based on a set of five indicators in the 10 years from 2009 to 2018 (table 2).

| Year   | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|--------|------|------|------|------|------|------|------|------|------|------|
| Activity                                                                 |
| Clarifying and cleaning (ha)                                             | 900  | 637  | 664  | 493  | 535  | 572  | 220  | 427  | 536  | 535  |
| Thinning (ha)                                                            | 416  | 273  | 262  | 208  | 121  | 138  | 172  | 156  | 182  | 329  |
| Accretion cuttings (ha)                                                  | 293  | 201  | 273  | 204  | 132  | 196  | 123  | 161  | 256  | 267  |
| Sanitary clear felling (ha)                                              | 409  | 534  | 458  | 338  | 202  | 93   | 160  | 267  | 229  | 316  |
| Selective sanitary felling (ha)                                          | 502  | 491  | 566  | 511  | 458  | 355  | 431  | 380  | 510  | 418  |

Evaluation patrol forest areas carried out based on a set of three indicators for 10 years, from 2009 to 2018 (table 3).

| Indicator                                                                 |
|--------------------------------------------------------------------------|
| Number of patrol routes (pc)                                             | 366  | 359  | 311  | 300  | 292  | 292  |
| The total length of patrols (km)                                         | 37,788 | 36,112 | 35,786 | 33,958 | 33,319 | 29,822 |
| The number of raids carried out on the territory of the forest fund of the Rostov region (units). | 4,919 | 5,094 | 5,300 | 4,730 | 4,027 | 3,870 |

Thus, the effectiveness of reforestation in the Rostov region needs to be assessed by 23 indicators based on available statistical data for 10 years.
3. Methods and materials

3.1. Fuzzy logic as a universal tool for assessing the state of complex systems based on sets of indicators

Currently, fuzzy logic tools are widely used in economic research. The mathematical theory of fuzzy sets, proposed in 1965 by Lotfi A Zadeh, a professor of technical sciences at the University of California at Berkeley, allows one to describe fuzzy concepts and knowledge, operate on this knowledge and draw fuzzy conclusions [11-13]. More recently, the application of the methods of fuzzy logic in solving economic problems was considered by economists as a kind of newfangled excess. But today we can talk about a turning point in the assessment of this scientific situation [15].

The following ideas of fuzzy logic are most in demand.

**Idea 1.** Fuzzy classification. All levels of economic parameters can be measured not only quantitatively, but also qualitatively. To do this, it is necessary to define the linguistic variable ‘Parameter X Level’, the carrier of which is the domain of X parameter definition, and the term-set of values are fuzzy subsets of ‘Very Low Level, Low Level, Average Level, High Level, Very High Level’ of Parameter X. For pentascals, it is necessary to construct a system of membership functions of the carrier X to the corresponding fuzzy subsets. The simplest way to specify is a system of trapezoidal fuzzy numbers [15]. This idea corresponds to the use of a system of fuzzy-logical conclusions - standard fuzzy multi-level [0,1] – classifiers.

The pentascal is optimal in most cases, but in some cases it is advisable to use the simplest case of a binary scale such as High, Low or Bad, Good. Depending on the problem statement, the number of terms can vary: for example, in accordance with the established classification of assessing the state of systems, three, four or even ten terms can be used.

**Idea 2.** Qualimetry based on aggregation of factor hierarchies

Let some property of an economic, social or any other system be represented as a tree-like hierarchy of factors, moreover:

- within the framework of the hierarchy, systems are defined for the relationship of preference of one sub-property to another for one level of the hierarchy;
- the sub-properties that make up the lower levels of the hierarchy can be measured both quantitatively and qualitatively (including verbally).

In this case, it is possible to carry out a comprehensive assessment of the properties of the system if: 1) to make all measurements on a qualitative basis, making a fuzzy classification of quantitative factors according to the scheme described above; 2) to simulate Fishburn weight systems for modeling preference systems; 3) to aggregate normalized values of indicators in the framework of two-dimensional convolution, where one of the systems of weights is the weight of the factors, and the other with the system of weights is the nodal points of the standard fuzzy multi-level [0,1] - classifiers (figure 1). When a numerical value of a comprehensive assessment of a system property is obtained, linguistic recognition of the qualitative level of a given complex property can be made based on the corresponding fuzzy classifier.

The universality of these two ideas of fuzzy logic is proved by their wide application in solving such problems as strategic planning, a comprehensive analysis of the state of the corporation, analysis of the creditworthiness of a bank borrower, risk assessment of an investment project, optimizing a stock portfolio, assessing the investment attractiveness of securities, forecasting stock indices, choosing a manager companies, real estate appraisal, transport logistics, selection of a corporate information system, analysis of the news background, construction and analysis of sociograms, analysis of collective behavior of people [16, 17].
Figure 1. General scheme for calculating a complex numerical estimate.

We have developed a methodology for assessing the effectiveness of agricultural production based on the use of standard five-level fuzzy \([0,1]\) – classifiers [16]. The algorithm for implementing the system of fuzzy-logical conclusions is given in detail in [16, 17]. This algorithm, due to its high universality, as well as the software developed on its basis, turned out to be possible to use also for assessing the effectiveness of reforestation.

3.2. Algorithm for assessing the state of systems based on standard five-level fuzzy \([0,1]\) -classifiers

For a better understanding of the work, we provide a brief description of the algorithm.

Stage 1. Formation of a list of significant indicators, on the basis of which the effectiveness of reforestation is assessed: 1) group of dynamics of reforestation; 2) a group of dynamics of the implementation of measures for thinning; 3) a group patrolling the territory of the forest fund.

Stage 2. The ranking of the studied indicators according to their importance for assessing the effectiveness of reforestation, the calculation of their weight coefficients based on expert estimates.

Stage 3. Calculation of normalized (that is, belonging to the interval \([0,1]\)) numerical values of the studied indicators for the considered period \(n\) years on the basis of formulas determined by the meaning of the problem.

Stage 4. Setting linguistic variables. To the indicators selected in Stage 3, we compared linguistic variables with term sets of five terms: ‘very low level of the indicator’; ‘Low rate’; ‘Average level indicator’; ‘High level indicator’; ‘A very high level indicator’. The membership functions of linguistic variables are determined using standard trapezoidal functions [16].

We introduce the linguistic variables: \(\gamma = \) ‘a comprehensive assessment of the effectiveness of reforestation’; \(\gamma_1 = \) ‘assessment of the dynamics of reforestation’; \(\gamma_2 = \) ‘evaluation of dynamics of
implementation of measures to thinning’; \( \gamma_3 = \text{‘rating patrolling forest areas’} \). Universal set for each linguistic variable is numeric interval \([0,1]\), and the set values of the four variables \( \gamma, \gamma_1, \gamma_2, \gamma_3 \) – term set \( G = \{G_1, G_2, G_3, G_4, G_5\} \), where \( G_1 = \text{‘steady trend towards reduction in growth’} \); \( G_2 = \text{‘tendency to decrease growth’} \); \( G_3 = \text{‘tendency to stagnation’} \); \( G_4 = \text{‘upward trend’} \); \( G_5 = \text{‘steady upward trend’} \). The accessory functions also have a standard trapezoidal shape.

Stage 5. The transition from the numerical values of indicators to the numerical values of estimates based on the general algorithm of the standard five-level fuzzy \([0,1]\) - classifiers shown in figure 1.

Stage 6. Linguistic recognition of the obtained numerical estimates in accordance with the definition of the term set \( G = \{G_1, G_2, G_3, G_4, G_5\} \); analysis of the assessments of the effectiveness of reforestation, recommendations for the correction of the current situation.

The contribution of each of the indicators to the final assessment is not equivalent. The indicators have a different scale and dimension. In addition, currently there are no generally accepted standards for the indicators under consideration. ‘Positive’ is the trend of continuous positive growth indicators; ‘Negative’ - zero or negative growth for each of the indicators.

The calculation of the aggregated values \( x_i (i = 1,2, ..., m) \) of the studied indicators of the efficiency of reforestation for the considered period of \( N \) years was carried out on the basis of the scheme given earlier in [18]. The scheme allows you to aggregate time series of data for each of the indicators and takes into account the significance of different time periods due to weight coefficients \( k_i \), determined on the basis of the Fishburn rule (2):

\[
x_i = \sum_{i=1}^{N-1} k_i I_i, \quad k_i = \frac{2(N-i)}{(N-1)N}.
\]

The time periods are numbered in the reverse order (i.e., in the example under consideration, the first period is 2018, and the last, 10th, 2009). \( I_i \)- normalized, that is, divided by the highest value, indicator values by years.

The growth of most of the indicators in tables 1-3 corresponds to an increase of efficiency of regeneration. At the same time, growth indicators 11 and 12 of table 1 corresponds to a decrease of efficiency of regeneration, so the aggregated values are calculated as one minus the value calculated by formula (2).

4. Results and discussion

The calculation of estimates

\( \gamma_1 = \text{‘assessment of the dynamics of reforestation’} \);
\( \gamma_2 = \text{‘evaluation of dynamics of implementation of measures to thinning’} \);
\( \gamma_3 = \text{‘rating patrolling forest areas’} \) and
\( \gamma = \text{‘a comprehensive assessment of the effectiveness of reforestation’} \);

in accordance with the above algorithm can be seen in tables 4-7.

The highest aggregated value of the indicator corresponds to the best situation, and the smallest to the worst. As follows from table 4, the highest values in time dynamics correspond to such indicators as the reforestation fund (thousand ha), the survival rate of coniferous and deciduous annuals. The worst situation is with indicators such as reforestation in burned areas (ha), the laying of valuable forest crops - oak and pine. Thus, the proposed technique allows for the quantitative comparison and ranking of the dynamics of heterogeneous indicators, incomparable on the basis of conventional models.

The obtained aggregate assessment shows that the assessment of the dynamics of reforestation indicators in the Rostov Region corresponds, rather, to the term ‘good’ than ‘satisfactory’.
Table 4. Calculation of the assessment of the dynamics of reforestation, Rostov Region.

| The aggregated value of the index | weight indicator | 1 | 2 | 3 | 4 | 5 |
|----------------------------------|------------------|---|---|---|---|---|
| Reforestation fund (thous ha)    | 0                | 0 | 0 | 0 | 0 | 1 |
| Reforestation, all (ha)          | 0.615            | 1/15 | 0 | 0 | 0.3 | 0.7 | 0 |
| including burns                  | 0.158            | 1/15 | 0.9 | 0.1 | 0 | 0 | 0 |
| Survival annual coniferous, %    | 0.843            | 1/15 | 0 | 0 | 0 | 0.1 | 0.9 |
| Survival annual deciduous%       | 0.874            | 1/15 | 0 | 0 | 0 | 0 | 1 |
| Cultural care of forest plantations, ha | 0.797 | 1/15 | 0 | 0 | 0 | 0.5 | 0.5 |
| Soil cultivation under forest crops, ha | 0.701 | 1/15 | 0 | 0 | 0 | 1 | 0 |
| Cultivation of standard planting material, thous. Pcs. | 0.719 | 1/15 | 0 | 0 | 0 | 1 | 0 |
| Procurement and purchase of seeds, kg | 0.480 | 1/15 | 0 | 0 | 1 | 0 | 0 |
| Putting young trees in category of plants | 0.456 | 1/15 | 0 | 0 | 1 | 0 | 0 |
| Write-offs of forest crops, only, ha | 0.726 | 1/15 | 0 | 0 | 0 | 1 | 0 |
| Including decommissioned forest crops the first year of creation, ha | 0.709 | 1/15 | 0 | 0 | 0 | 1 | 0 |
| - Pine                           | 0.427            | 1/15 | 0 | 0.2 | 0.8 | 0 | 0 |
| - locust acacia                  | 0.792            | 1/15 | 0 | 0 | 0 | 0.6 | 0.4 |
| - oak                            | 0.228            | 1/15 | 0.2 | 0.8 | 0 | 0 | 0 |
| weight terms                     | 11/150           | 11/150 | 31/150 | 59/150 | 38/150 |

$\gamma_1 = \frac{11}{150} \cdot 0.125 + \frac{11}{150} \cdot 0.3 + \frac{31}{150} \cdot 0.5 + \frac{59}{150} \cdot 0.7 + \frac{38}{150} \cdot 0.885 = 0.634$

(‘More good than satisfactory’)

As follows from table 5, indicators for assessing the dynamics of the implementation of measures for thinning can be ranked, in order of dynamics deterioration, as follows: selective sanitary cutting, through cutting, clarification and cleaning, thinning, clear sanitary cutting. The resulting aggregate
assessment shows that the assessment of the dynamics of the implementation of measures on thinning in the Rostov Region corresponds, rather, to the term ‘good’ than ‘satisfactory’.

Table 5. Lead flows calculation measures the thinning.

| Activity                              | The aggregated value of the index | weight indicator | 1 | 2 | 3 | 4 | 5 |
|---------------------------------------|-----------------------------------|------------------|---|---|---|---|---|
| Clarifying and cleaning               | 0                                 |                  | 0 | 0 | 1 | 0 | 0 |
| Thinning (ha)                         | 0.498                             | 1/5              | 0 | 0 | 1 | 0 | 0 |
| accretion cuttings (ha)               | 0.700                             | 1/5              | 0 | 0 | 0 | 1 | 0 |
| Sanitary clear felling (ha)           | 0.485                             | 1/5              | 0 | 0 | 1 | 0 | 0.9 |
| Selective sanitary felling(ha)        | 0.786                             | 1/5              | 0 | 0 | 0 | 0.6 | 0.4 |
| weight terms                          |                                   |                  | 0 | 0 | 0.6 | 0.32 | 0.08 |

\[ \gamma_2 = 0 \cdot 0.125 + 0 \cdot 0.3 + 0.6 \cdot 0.5 + 0.32 \cdot 0.7 + 0.08 \cdot 0.885 = 0.59 \]  
(‘More satisfactory than good’)

Finally, as follows from table 6, the indicators for assessing the patrol of the forest fund territory can be ranked in the following order: the total length of the patrol routes; the number of raids conducted on the territory of the forest fund; number of patrol routes. The obtained aggregate assessment shows that the assessment of patrolling the territory of the forest fund of the Rostov region corresponds to the term ‘excellent’.

Table 6. Calculation of evaluation patrolling forest Rostov region.

| Indicator                                    | The aggregated value of the index | weight indicator | 1 | 2 | 3 | 4 | 5 |
|----------------------------------------------|-----------------------------------|------------------|---|---|---|---|---|
| Number of patrol routes (pc)                 | 0.837                             | 1/3              | 0 | 0 | 0 | 0.1 | 0.9 |
| The total length of patrols (km)             | 0.881                             | 1/3              | 0 | 0 | 0 | 0 | 0 | 1 |
| The number of raids carried out on the territory of the forest fund of the Rostov region (units). | 0.838 | 1/3 | 0 | 0 | 0 | 1.1 | 0.9 |
| weight terms                                 |                                   |                  | 0 | 0 | 0 | 1/15 | 14/15 |

\[ \gamma_3 = 0 \cdot 0.125 + 0 \cdot 0.3 + 0 \cdot 0.5 + 1/15 \cdot 0.7 + 14/15 \cdot 0.885 = 0.87 \]  
‘excellent’

Table 7 aggregated the three assessments considered into the final assessment of the effectiveness of reforestation in the Rostov Region. At the same time, based on Table 7, it is possible to analyze the effectiveness of reforestation by groups. As the values of the estimates indicate, the best situation is in the area of patrolling the territory of the forest fund (‘excellent’). Rather, ‘good’ than ‘satisfactory’ can be assessed the dynamics of indicators for reforestation. Finally, the dynamics of the implementation of thinning operations can be assessed as ‘satisfactory’ rather than ‘good’.

The final assessment of the effectiveness of reforestation in the Rostov region is ‘good’.
Table 7. Calculation of final assessment the effectiveness of regeneration in Rostov region.

| Evaluation                                                                 | Numerical evaluation value | Weight indicator | 1  | 2  | 3  | 4  | 5  |
|---------------------------------------------------------------------------|----------------------------|------------------|----|----|----|----|----|
| Evaluation of the dynamics of reforestation, G1                           | 0.63                       | 0.5              | 0  | 0  | 0.2| 0.8| 0  |
| Assessment of the dynamics of the implementation of measures for thinning, G2 | 0.59                       | 0.3              | 0  | 0  | 0.6| 0.4| 0  |
| Evaluation patrolling forest, G3                                          | 0.87                       | 0.2              | 0  | 0  | 0  | 0  | 1  |

\[ \gamma = 0 \cdot 0.125 + 0 \cdot 0.3 + 0.28 \cdot 0.5 + 0.52 \cdot 0.7 + 0.2 \cdot 0.885 = 0.87 \text{ (‘good’)} \]

Thus, the analysis shows that in order to improve the situation with reforestation in the Rostov Region, it is necessary to pay attention to the implementation of measures for logging, primarily thinning and clear cutting. In the field of general indicators of reforestation, attention should be paid to reforestation in burned areas (ha), as well as the laying of valuable forest crops - oak and pine.

5. Conclusion
A technique is proposed for a comprehensive assessment of the effectiveness of reforestation in the region based on standard five-level fuzzy [0,1]-classifiers, which is a modification of the methodology for assessing the effectiveness of agricultural production proposed in [16]. The practical significance of the method lies in the fact that it allows you to create a comprehensive assessment of the effectiveness of reforestation by the time series of three groups: the dynamics of indicators for reforestation, the dynamics of measures for thinning and information about patrolling the territory of the forest fund. In this case, the contribution of each of the considered indicators is estimated using a weight coefficient reflecting its significance.

Compared to existing assessment methods, the proposed assessment methodology has a number of advantages such as: 1) a simple and universal calculation scheme; 2) taking into account when calculating estimates of a large number of heterogeneous significant indicators that allow variation depending on the available statistical material and the features of the specific practical problem being solved; 3) the possibility of varying the weight of the contribution of the studied indicators to the corresponding integrated assessment; 4) the possibility of applying it for ranking regions according to the effectiveness of reforestation; 5) the possibility of analyzing on its basis the situation in the region under consideration and the formation of practical recommendations based on calculated integrated indicator estimates.

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