Evaluation of ecological restoration effect of rare plant
Rhododendron chrysanthum population in Changbai Mountain Area

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Abstract. In order to study the population viability and restoration effect of Rhododendron chrysanthum population after restoration, an ecological evaluation method based on analytic hierarchy process and fuzzy comprehensive evaluation was proposed. The ecological evaluation index system was established with the help of analytic hierarchy process (AHP) and the index weight was determined. The fuzzy comprehensive evaluation method was used to evaluate the restoration effect of Rhododendron chrysanthum population from three aspects: target layer, criterion layer and index layer. The results showed that this method could effectively evaluate the ecological effect of Rhododendron chrysanthum population after restoration, in which 33% of the restoration effect of Rhododendron chrysanthum population might be “very good” and 67% might be “good”. According to the principle of maximum membership degree, the comprehensive evaluation of the restoration effect of Rhododendron chrysanthum population in the experimental area was excellent.

1. Introduction
Changbai Rare and endangered plants are the strong evidence of plant origin, floristic evolution and paleogeological change due to their special habitat and rare quantity. The research on the protection of rare and endangered plants plays a key role in the protection of plant diversity, which is of irreplaceable scientific significance [1]. The study of vegetation restoration after human disturbance is a hot spot in community and ecosystem dynamics studies, and many scholars have made in-depth studies on the definition, development process and research status of ecological restoration [2-6]. However, there are few reports on the ecological evaluation of rare plant populations after restoration.

Rhododendron chrysanthum, a small perennial evergreen shrub of Ericaceae, is a national protected plant. The natural distribution of Rhododendron chrysanthum is narrow and patchy, which is mainly distributed in Changbai Mountain of northeast China. Because of its special growing environment, the wild resources are extremely limited, coupled with certain man-made destruction factors, resulting in lack of resources. With the decline of Rhododendron chrysanthum population, a lot of exposed ground, coupled with strong winds, many parts of alpine tundra are seriously eroded, which destroys the integrity of alpine tundra landscape and exacerbates the deterioration of ecological environment. Rhododendron chrysanthum population was restored by layering propagation in the field.
In this study, a comprehensive evaluation system was established based on the evaluation of the population viability, community structure, ecological function and soil microenvironment of the restored *Rhododendron chrysanthum* population. On this basis, a qualitative and quantitative analysis method was used to make ecological evaluation of the restored *Rhododendron chrysanthum* population, so as to guide the research on ecological restoration of rare and endangered plants. According to this, the restoration of ecological function of the restored area as a whole ecosystem is evaluated.

2. Materials and methods

2.1. Experimental location

Experimental location, located at the altitude of 1992m, 42°03′N, 128°03′E, the upper limit of *Betula ermanii* forest, abundant light in the forest, sparse *Betula ermanii* and short *Rhododendron chrysanthum*.

2.2. Layering time

The layering time is in July, 2013.

2.3. Survey items and time

Ecological dominance index, tree species richness and population coverage are selected as the research object of community characteristic index.

Plant growth in the current year, plant height and base diameter are selected as the research object of growth condition index.

Soil total N, soil total K and soil total P are selected as the research object of soil microenvironment index.

The survey time is Layering time is July, 2018.

2.4. AHP-Fuzzy comprehensive evaluation method

2.4.1 Using AHP to determine the weight

Weight is a measure of the relative importance of an indicator. The weight of evaluation factors directly affects the rationality of the whole evaluation system, which has a great influence on the evaluation result. There are 5 steps in determining the weight of all indicators by AHP method [7].

2.4.2 Evaluation procedure of Fuzzy comprehensive evaluation method

The fuzzy comprehensive evaluation method can avoid the subjectivity in the evaluation process and make the evaluation result more scientific and objective [8].

3. Example analysis

3.1. Specific ecological index data of Rhododendron chrysanthum population restoration area

(1) Community characteristic index

Ecological dominance index is 1.412; Tree species richness is 28 species; *Rhododendron chrysanthum* population coverage is 65%.

(2) Growth condition index

Plant growth is 3.76 cm in the current year; Plant height is 26 cm; Base diameter is 0.447 cm.

(3) Soil microenvironment index

Soil total N is 0.52%; Soil total K is 1870.1 mg·kg⁻¹; Soil total P is 366.76 mg·kg⁻¹.
3.2. Determination of weight

(1) A hierarchical model structure was established according to the characteristics of community ecology. In this paper, the ecological evaluation index system of the *Rhododendron chrysanthum* population restoration area was divided into three layers.

Target layer A is restoration effect of *Rhododendron chrysanthum* population.

Criterion layer B contains Community characteristic index (B1), Growth condition index (B2), Soil index (B3).

Index layer C contains nine indexes, namely Ecological dominance index (C1), Tree species richness (C2), The population coverage (C3), Plant growth in the current year (C4), Plant height (C5), Base diameter (C6), Soil total N (C7), Soil total K (C8), Soil total P (C9).

(2) The calculation of ecological index weight in *Rhododendron chrysanthum* population restoration area. The results are given in Table 1.

| B     | WBi  | C     | WCij | Wij |
|-------|------|-------|------|-----|
| B1    | 0.6483| C1    | 0.6834| 0.443 |
|       |      | C2    | 0.1168| 0.0758 |
|       |      | C3    | 0.1998| 0.1295 |
|       |      | C4    | 0.6267| 0.1439 |
| B2    | 0.2297| C5    | 0.2797| 0.0642 |
|       |      | C6    | 0.0936| 0.0215 |
|       |      | C7    | 0.6250| 0.0763 |
| B3    | 0.122 | C8    | 0.2385| 0.0291 |
|       |      | C9    | 0.1365| 0.0167 |

The consistency test results of the total hierarchical ordering show that the consistency ratio is 0.0036 < 0.10. It shows that the result of the hierarchy total ordering has satisfactory consistency.

3.3. Fuzzy comprehensive evaluation

(1) The determination of index membership degree

The determination of index membership degree of tree species richness index (C1) was taken as an example to explain the calculation process of membership degree of positive index. The specific data of ecological indicators are shown in Table 2 below.

| Tree species richness index | Very good | Good | Commonly poor | Poor | Very bad | Example |
|-----------------------------|-----------|------|---------------|-----|----------|---------|
| V_<sub>1</sub> = 31, V_2 = 27, V_3 = 20, V_4 = 14, V_5 = 10, |
| V_2 < U_i < V_1, so according to the above formula, the calculation process is as follows: |
| R_1 = \frac{U_i - V_2}{V_1 - V_2} = \frac{28 - 27}{31 - 27} = 0.25, V_2 < U_i < V_1; |
| R_2 = \frac{V_1 - U_i}{V_1 - V_2} = \frac{31 - 28}{31 - 27} = 0.75, V_2 < U_i < V_1; R_3 = 0, U_i > V_3; R_4 = 0, U_i > V_4 |
| R_5 = 0, U_i > V_5 |

Table 1. Response Total hierarchical arrangement weight value

Table 2. C1 Evaluation criteria
Therefore, the relative membership degree of “tree species richness index” is (0.25, 0.75, 0, 0, 0), indicating the “tree richness index” of the community has a 25% chance of being very good and a 70% chance of being good.

According to the steps above, the membership degree of the current index corresponding to the five grades of the comment set can be calculated, and the membership can be summed up to get the fuzzy comprehensive evaluation matrix, as shown in Table 3:

Table 3. C1 Evaluation criteria

| B Criterion layer B | C Index layer C                             | Fuzzy comprehensive evaluation matrix |
|---------------------|---------------------------------------------|--------------------------------------|
|                     |                                             | Very good | Good | Commonly poor | poor | very bad |
| B1 Community        | Ecological dominance index                  | 0.25      | 0.75 | 0             | 0    | 0        |
| characteristic index| Tree species richness                       | 0.33      | 0.67 | 0             | 0    | 0        |
|                     | The population coverage                     | 0.41      | 0.59 | 0             | 0    | 0        |
|                     | Plant growth in the current year            | 0.02      | 0.98 | 0             | 0    | 0        |
| B2 Growth condition index | Plant height                  | 0.5       | 0.5  | 0             | 0    | 0        |
|                     | Base diameter                               | 0.28      | 0.72 | 0             | 0    | 0        |
| B3 Soil microenvironment index | Soil total N                   | 0.5       | 0.5  | 0             | 0    | 0        |
|                     | Soil total K                               | 0.96      | 0.4  | 0             | 0    | 0        |
|                     | Soil total P                               | 0.34      | 0.66 | 0             | 0    | 0        |

(2) The first-level evaluation
The “community characteristic index” in criterion B layer is taken as an example to describe the calculation process of first-level fuzzy comprehensive evaluation in detail. It can be seen from Table 52 that the weight of each index under B1 relative to this layer is $W_1 = [0.3366, 0.6634, 0, 0, 0]$.

It can be seen from Table 4 that the fuzzy comprehensive evaluation matrix $R_1$ is composed of the evaluation sets of indicators C1, C2, C3:

$$B_1 = W_1 \times R_1 = [0.3366, 0.6634, 0, 0, 0]$$

Table 4 The fuzzy comprehensive evaluation results of each index in criterion layer B

| B Criterion layer | Wi                 | Ri          | Bi                      |
|-------------------|--------------------|-------------|-------------------------|
| B1 Community       | [0.6834, 0.1168, 0.1998] | [0.33 0.67 0 0 0] | [0.3366, 0.6634, 0, 0, 0] |
| characteristic     |                    |             |                         |
| index              |                    | 0.25 0.75 0 0 0 |                         |
|                    |                    | 0.41 0.59 0 0 0 |                         |
| B2 Growth          | [0.6267, 0.2797, 0.0936] | [0.02 0.98 0 0 0] | [0.1786, 0.8214, 0, 0, 0] |
| condition index    |                    | 0.5 0.5 0 0 0 |                         |
|                    |                    | 0.28 0.72 0 0 0 |                         |
| B3 Soil            | [0.6250, 0.2385, 0.1365] | [0.5 0.5 0 0 0] | [0.5879, 0.4121, 0, 0, 0] |
| microenvironment   |                    | 0.96 0.04 0 0 0 |                         |
| index              |                    | 0.34 0.66 0 0 0 |                         |
The fuzzy calculation results of the above indexes were generated into first-level evaluation results, as shown in Table 5.

Table 5. Fuzzy comprehensive evaluation result of evaluation index

| B layer factor set | Evaluation results |
|-------------------|--------------------|
|                   | Very good | Good | Commonly poor | very bad |
| B1                | 0.3366    | 0.6634 | 0  | 0 | 0 |
| B2                | 0.1786    | 0.8214 | 0  | 0 | 0 |
| B3                | 0.5879    | 0.4121 | 0  | 0 | 0 |

(3) The second-level comprehensive evaluation
Regarding the above calculated fuzzy calculation results of each index in criteria B layer as the single factor judgment of target layer A is equivalent to the fuzzy evaluation matrix R. For each element Ui, weight assignment Wi was given in U, where: 
\[ W = (W_1, W_2, \ldots, W_p), \sum_{i=1}^{p} W_i = 1, \quad Wi \geq 0, \]
the fuzzy comprehensive evaluation result of target layer A is as follows: 
\[ B = W \times R \]
\[ W = [0.6483, 0.2297, 0.122] \quad B = W \times R = [0.3309, 0.6691, 0, 0, 0] \]

It can be seen that 33% of the restoration effect of *Rhododendron chrysanthum* population in the experimental area might be “very good” and 67% might be “good”. According to the principle of maximum membership degree, the effect of population restoration is good in this experimental area.

4. Conclusion and discussion
In this paper, the vegetation growth condition, community ecological index and soil microenvironment index of the restoration area of *Rhododendron chrysanthum* population were comprehensively evaluated and analyzed, and the following conclusions could be drawn: when the rare plant *Rhododendron chrysanthum* population was restored by layering propagation in the field, the plant growth condition was the most intuitive and influential index to verify the population restoration effect. The final evaluation results showed that the restoration effect of *Rhododendron chrysanthum* population in the restoration area was “good”. Thus, the use of AHP method to give weight coefficient to the indicators, the combination of qualitative description and quantitative calculation, rigorous judgment and scientific calculation can greatly enhance the scientificity and effectiveness of evaluation. Then, the fuzzy comprehensive evaluation method is used to conduct multi-level fuzzy comprehensive operation and obtain the required evaluation results. The method of AHP-fuzzy comprehensive evaluation combines the experience which is difficult to quantify with the complex and varied evaluation indexes. The combination of qualitative and quantitative, experience and science effectively solves the problems of the ambiguity and subjectivity in the evaluation process, and the accuracy, validity and practicability of the evaluation are improved.

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