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Investigation of the Success of Natural Regeneration Fields by Multi-Criteria Decision Making Technique

Erol İMREN[1*], Halil Barış ÖZEL[2]

[1]Department of Forest Industrial Engineering, Faculty of Forestry, Bartin University, Bartın, Turkey
[2]Department of Forest Engineering, Faculty of Forestry, Bartin University, Bartın, Turkey

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Abstract − Natural regeneration management is one of the most important steps of silvicultural practices, and it is important for the short-term regeneration of forests that have completed their natural cycles. Sustainability of forests is possible with the correct determination of the problems and the implementation of the correct plans. In this study, the most successfully assessed area has proven to be accurately determinable with the PROMETHEE method, which is an effective ranking method that works by taking numerical data from the determined trial areas in the natural Scotch pine (*Pinus sylvestris L.*) regeneration area of a forest management directorate. Among the criteria used in the numerical method, we can find the average height, average root neck diameter, and an average number of natural youths. For these criteria, weighting was done with the help of the entropy method. Within the scope of these findings, it has been seen that the success in natural Scotch pine regeneration areas to be realized in other regions is tangibly seen in the numerical data. In addition, this numerical method is important in terms of time efficiency, labor, and economic outputs allocated to these studies.

Keywords − *Success of natural regeneration, PROMETHEE method, Scotch pine (Pinus sylvestris L.)*

Çok Kriterli Karar Verme Tekniğiyle Doğal Gençleştirme Alanlarının Başarısının İncelenmesi

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Araştırma Makalesi

Öz − Doğal gençleştirme yönetiminin silvikültürel uygulamaların en önemli adımlarından birisi olup, doğal süreçlerini tamamlamış ormanların kısa vadede tekrar dönüşümü için önem arz etmektedir. Ormanların sürdürülebilirliği problemlerin doğru tespiti ve doğru planların yapılarak uygulama konması ile mümkün olabilmektedir. Bu çalışmada bir orman işletme müdürlüğünün doğal sarıçam (*Pinus sylvestris L.*) gençleştirme sahasındaki belirlenmiş deneme alanlarından sayısal veriler alınarak, etkin bir sıralama yöntemi olan PROMETHEE yöntemi yardımıyla en başarılı alan tespiti yapılmaya çalışılmıştır. Sayısal yöntemde kullanılan kriterlerde alanlardan elde edilen verilerin ortalama boy, ortalama kök boğaz çapı ve ortalama doğal gençlik sayısı dikkate alınmıştır. Bu kriterler için entropi yöntemi yardımıyla ağırlıklandırma yapılmıştır. Elde edilen bu bulgular kapsamında başka bölgelerde gerçekleştirilecek doğal sarıçam gençleştirme alanlarında başarıyı sayısal veriler karşılaştırmada kullanılabilirliği görülmüştür. Ayrıca bu sayısal yöntem ile bu çalışmalara ayrılan zaman, emek ve ekonomik çıktıların heba olmaması adına önem taşımaktadır.

Anahtar Kelimeler − *Doğal gençleştirme başarısı, PROMETHEE metot, Sarıçam (Pinus sylvestris L.)*

[1] eimren@bartin.edu.tr
[2] halilbarisozel@gmail.com
*Corresponding Author

1. Introduction

The excessive and unplanned consumption of natural resources, which meet the shelter nutritional needs of human beings, jeopardizes the future of life. Deteriorated natural living conditions due to rapidly increasing population and global warming threats in recent years have damaged all ecosystems and significantly damaged the ecological cycle. Within the framework of the research and the models created, it is reported that fossil-based energy resources will decrease significantly as of 2050 and will reach the endpoint in 2080 (Akyol, 2010). In the face of this situation, the demand for clean energy sources has increased rapidly. The protection and evaluation of forests and forest ecosystems in every sense come to the forefront as a subject that draws attention in all international meetings, especially due to their superior characteristics in carbon storage (Akyol and Tolunay, 2014).

In order to ensure the continuity of forest resources, first of all, it is necessary to manage these resources correctly and to ensure the renewal and sustainable management of forest areas whose natural life processes are filled with successful silvicultural practices. The most important method used in this regard is natural regeneration practices (Genç, 2004). Re-establishment of forests with natural regeneration practices is accepted by world silviculturists as the most permanent and most valuable forest-building activity, as it is based on making maximum use of natural ecological conditions and silviculture suitable for nature (Ata, 1995). For this reason, there is a need for natural regeneration studies to be carried out primarily by making use of seeds obtained naturally from healthy seed trees in order to ensure the continuity of valuable pure and mixed stands that are shaped under different ecological conditions in our country. Scotch pine is the most important tree species at the beginning of these important forest tree species due to its wide geographical distribution and high zones.

“Scotch pine (*Pinus sylvestris L.*)” is an important primary forest-tree species that can grow rapidly in areas where it is provided with optimum growing conditions since its youth. For this reason, it can proclaim its dominance in the soil of its environment by growing very quickly even in front of forest types, especially when it has sufficient upper light. For this reason, the first years of the species, which has a pile root system, consist of keeping the natural youth in the field by making use of the moisture and organic matter conditions in the upper soil layer. Therefore, the ecological conditions in the first 5-10 years must show suitable conditions for the species to stick in the field (Atay, 1988; Boyer, 1999).

Important research was carried out by Alemdağ (1967) on forest organizations, which are very important in terms of silvicultural decision-making in Scotch pine forests in Turkey.

A study was conducted by Akgül and Aksoy (1984) on the general soil characteristics of Scotch pine ratios in Bolu-Şerif Yüksel Research Forest and the differences were revealed by these emerging characteristics in all pure and mixed forest establishments in the research forest.

Important research has been carried out on the differences between neighborhood relations and solidarity on youth development and growth in stand microecology in Scotch pine forests in Lithuania (Brumelis et al., 2005).

In a comprehensive study in European Scotch pine forests, vital information was obtained about natural regeneration processes and pre-forest types in Scotch pine natural forests, which will contribute to practitioners (Boratynskı, 1991).

Actual and important results were given by Boydak (1977), in which very detailed information was obtained on the seed productivity of Scotch pine forests in the Eskişehir-Çatacık region, and especially on the period range of abundant seed years, which is very important for natural regeneration applications.

In the results of the research on the development of Scotch pine natural youth cores and the possibilities of benefiting from these samples in the main stand establishment, it was emphasized that the cluster establishments can be utilized in this regard (Lhotka, 2006).

A study on the applicable principles of natural regeneration studies in Scotch pine forests of the Large Area Trench Management revealed the importance of side and diffuse light in growth, especially in the first years (Loftis, 1990).

Within the scope of this research, the youth dynamics and the factors affecting the success of natural regeneration in natural regeneration practices carried out in pure Scotch pine forests within the borders of the Kastamonu-Daday region were examined and it was tried to produce data that would provide an important contribution to the practitioners in this regard. The study aims to determine the entropy-weighted PROMETHEE method, which is one of the most efficient and multi-criteria decision-making techniques, confirmed by the data obtained from 20 natural regeneration application areas.

2. Materials and Methods

2.1. Materials

When the meteorological data in the study area (Kastamonu-Daday) is examined, the annual average temperature results 8.4 °C, the hottest month is July (24.5 °C), and the coldest month is January (-1.4 °C). According to these data, the vegetation period is 6 (May-October) months. The average annual precipitation is 578.6 mm. The soil generally has a sandy-clay mud texture, and the structure has a clastic texture.

Measurements and observations were carried out in 20 different test areas of 25x40m, taken from the natural regeneration areas carried out in the research area in 2019. In this context, height and root neck measurements were made in natural Scotch pine youths, and information on some variables about ecological conditions and conditions related to standing establishments were collected. The obtained information was digitized and converted into objective formats to be used in statistical analysis.

2.2. Methods

The concept of Entropy, which has been adapted to the information theory by Shannon (1948), is now widely used in physics, mathematics, and engineering sciences (Wu et al. 2011; Ömürbek et al. 2017; Imren et al. 2021). The concept, formulated by probability theory, has been proposed as a measure to examine inequalities between information sets. The entropy weight method is an objective weight method. In particular, it is very suitable for measuring the relative intensities of different criteria in terms of representing the average inside information conveyed in decision making (Shannon, 2001; Zeleny, 2012; Huang et al. 2021). The method generally consists of the following stages (Wang 2009; Özdağoğlu et al. 2017; Gumus et al. 2020; Zhao et al. 2020; Ayçin and Güçlü 2020; Imren et al. 2021; Kurt et al. 2021, Kelleci et al. 2022).

Step I: Normalization of the decision matrix; The values of the criteria with different units in the decision problems should be standardized to take values in the range of [0,1] with the normalization process. The normalization process is performed using Equation (2.1).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad i = 1,2, \dots . m \text{ and } j = 1,2, \dots . n \qquad (2.1)$$

Here i; alternative, j; criterion, m; the number of alternatives in the decision matrix, n; the number of criteria in the decision matrix, x_{ij}; $i.j$ of the alternative. its value in the criterion, r_{ij}; shows the normalized values in the decision matrix.

Step II: Finding the entropy values of the criteria; The entropy values (e_j) of each evaluation criterion are calculated as shown in Equation (2.2). Here, the k value, $k = \frac{1}{lnm}$, is a constant coefficient and takes a value between $0 \leq e_j \leq 1$.

$$e_j = -k \sum_{i=1}^{m} r_{ij} ln r_{ij} \tag{2.2}$$

Step III: Calculation of weight values; Finally, the weights (W_j) of the criteria are calculated with the help of the degrees of differentiation ($D_j = 1 - e_j$) of each criterion (Equation 2.3). The sum of all weights must be 1.

$$W_j = \frac{1 - e_j}{\sum_{i=1}^{n}(1 - e_i)} \tag{2.3}$$

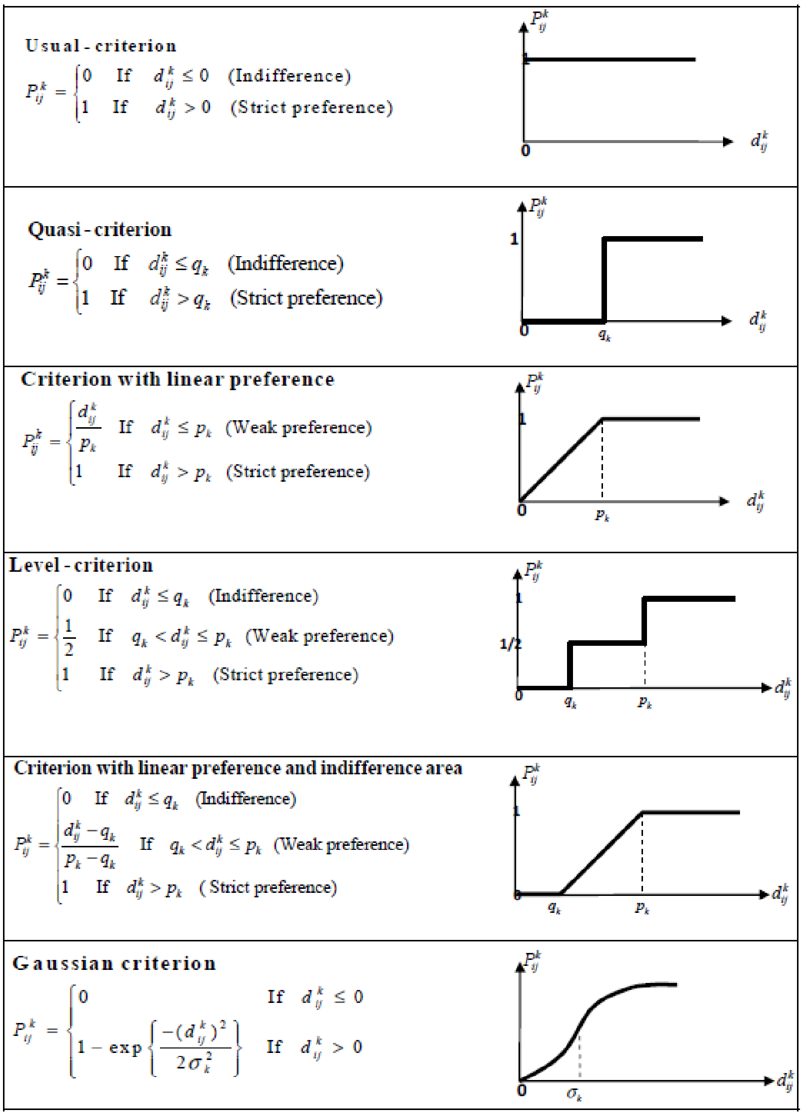

Figure 1. Preference functions according to generalized criteria types (Frikha et al, 2017)

The PROMETHEE method for complete sequencing was developed by J. P. Brans in 1982. Since its development, it has been widely used to solve multi-criteria problems in various fields. Various versions of the PROMETHEE method have also been added to the literature to help complex decision-making situations over time (Brans and Mareschal, 2005).

PROMETHEE was developed to provide a complete ranking on a limited set of viable alternatives. The basic principle of this method is based on a pairwise comparison of alternatives along with each specified criterion. For each criterion, the preference function translates the difference between the evaluations obtained by the two alternatives into a degree of preference ranging from zero to one (Ignatius et al., 2012). Vincke and Brans (1985) proposed six basic types (Fig.1) (Albadvi et al., 2007) to facilitate the selection of the preference function by customizing it.

For each criterion in preference functions, the value q of an insignificance threshold, the value of the absolute preference threshold p, or the value of s, an intermediate value between p and q, is fixed. The step-by-step procedure for the implementation of PROMETHEE is as follows (Behzadian et al., 2010):

Step I: the breadth of deviations between the measurements of the alternatives on each criterion, a and b being the two alternatives;

$$\mathrm{d_j}(a,b) = g_j(a) - g_j(b) \qquad j = 1, \dots, k \tag{2.4}$$

is calculated as. That is, deviations are determined based on pairwise comparisons with $d_j(a,b)$. When these deviations are insignificant, the dominance relationship becomes stronger.

Step II: The preference function is determined using Equation (2.5).

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \qquad j = 1, \dots, k \tag{2.5}$$

By inverting the preference function $(-d_j(a,b))$ the equality criteria can be minimized. Here, $P_j(a,b)$ is the probability obtained from the comparison of two alternatives a and b in terms of a criterion, and F is j. indicates the preference of alternative "a" over alternative "b" in each criterion, as a function of $d_j(a,b)$ used for the criterion. So it turns into $0 \leq P_j(a,b) \leq 1$.

Step III: A global preference index is calculated.

$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \qquad \forall a,b \in A \tag{2.6}$$

Here, $\pi(a,b)$ denotes the degree to which a is preferred over b overall criteria, that is, its weight (w_j). A set is a finite set of possible alternatives.

Step IV: The positive and negative superiority values of the alternatives are calculated.

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \tag{2.7a}$$

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \tag{2.7b}$$

Here $\phi^{+}(a)$ denotes how one alternative a outperforms the others. $\phi^{-}(a)$, on the other hand, expresses how one alternative a is left behind by the others.

Step V: Ranking by calculating the full superiority value.

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{2.8}$$

Basic statistics (mean, standard deviation, minimum and maximum values, change intervals), rankings (ϕ, ϕ^{+}, ϕ^{-}), and the Visual PROMETHEE package program was used for the solution of the application.

3. Findings

The e_j, d_j and entropy weights (W) for the criteria were calculated using equations (2.1-2.3). These weights were obtained from the values of height growth, root neck diameter development, and natural youth number measured in the application areas, and were used to determine the performance ranking to be made with the PROMETHEE method.

Table 1
Entropy weights of the criteria

	average height (cm)	**average root neck diameter (mm)**	**the average number of youth /m²**
e_j	0,997175	0,991763	0,989812
d_j	0,002825	0,008237	0,010188
W	0,13293	0,387624	0,479446

After assigning weight to each criterion with the entropy method, the criteria and preference function parameters of all data obtained from the study were summarized (Table 1). Accordingly, the average number of youth criteria was determined as 48%, average root neck diameter of 39%, and average height criteria as 13%. In the study, the type V linear (linear) function was used as the preference function type, which provides a precise measure of the differences between the conditional distribution of the insignificance threshold (q) and the absolute preference threshold (p), and the results are presented.

Table 2
Preference parameters and statistics of criteria

	Parameters			
Criteria	q	p	Mean	Standard deviation
Height	2,57	4,18	3,5	0,45
Root neck diameter	1,27	2,71	1,9	0,47
The number of youth /m²	4,56	11,48	8,05	1,96

When Table 2 and Table 3 are examined, they are seen that the most successful one according to the valid criteria for each trial area is the action9 area ($\Phi = 0{,}4222$). The most unsuccessful trial area was action12 ($\Phi = -03555$). When the negative and positive superiority is examined in Figure 2, action9 comes first in terms of positive superiority. In terms of negative superiority, action17 and action9 take the first place. The trial fields, whose net advantage is in the green zone, came out in the first place.

Table 3
Positive priorities and negative priorities according to PROMETHEE

Rank	**action**	**Phi**	**Phi+**	**Phi-**
1	action9	0,4222	0,4222	0
2	action17	0,3849	0,3849	0
3	action7	0,3034	0,3244	0,021
4	action6	0,2855	0,2921	0,0066
5	action8	0,211	0,2569	0,0459
6	action16	0,1971	0,2296	0,0325
7	action5	0,1333	0,1944	0,0611
8	action20	0,1125	0,1887	0,0762
9	action18	0,0982	0,1764	0,0782
10	action4	0,0878	0,1734	0,0855
11	action11	0,0533	0,1605	0,1072
12	action3	-0,0121	0,1314	0,1435
13	action10	-0,0668	0,1063	0,1731
14	action13	-0,1831	0,0639	0,247
15	action14	-0,2369	0,0429	0,2798
16	action15	-0,3023	0,0119	0,3142
17	action19	-0,3255	0,0081	0,3336
18	action12	-0,3555	0	0,3555
19	action1	-0,3726	0	0,3726
20	action2	-0,4344	0	0,4344

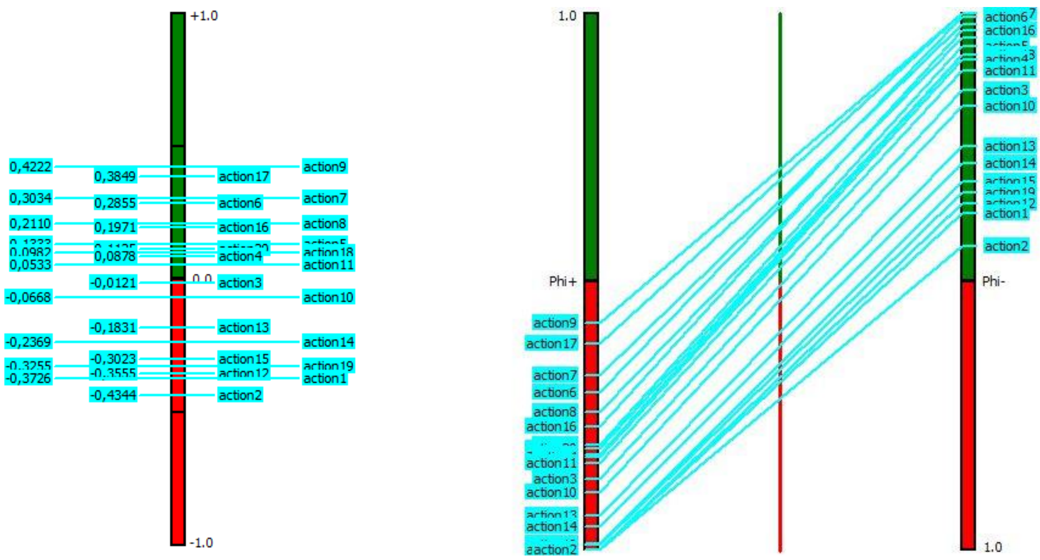

Figure 2. Clear advantages of trial sites

According to the direction of the decision bar on the GAIA plane, the trial areas that should be preferred most appropriate for the criteria determined are shown. The accuracy of the calculated values with a value of 99.7% is shown (Figure 3).

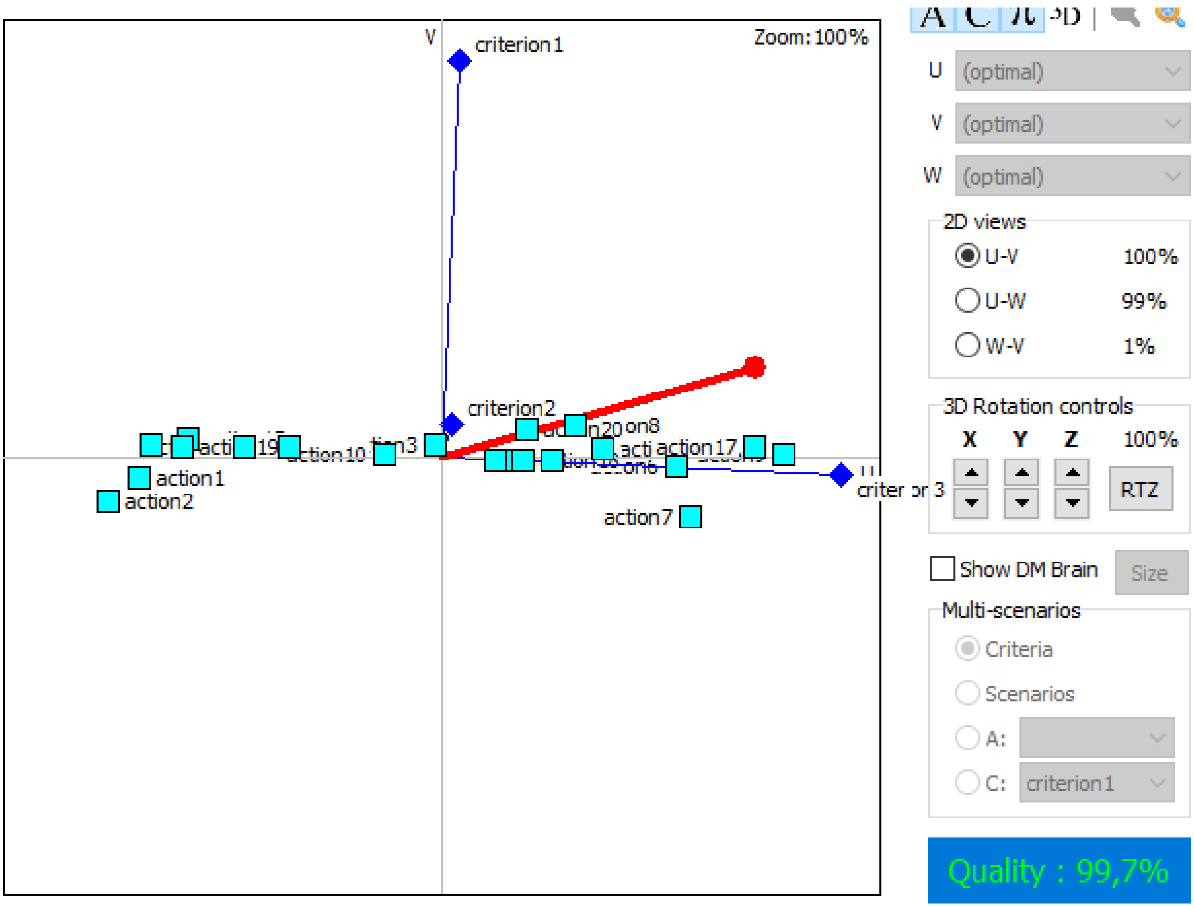

Figure 3. GAIA plane

4. Conclusions

Rapid developments in technology and information flow have enabled the analysis of data and the rapid conclusion of decision-making processes. In this context, it is important to determine the successful areas of studies in natural regeneration areas. In this research, which was carried out in the natural regeneration areas of Scotch pine in the Kastamonu-Daday region, the growth dynamics of natural Scotch pine youth and the effects of the factors affecting the success of natural regeneration were examined through numerical data and an application was made for the success of natural regeneration areas. PROMETHEE, one of the sorting methods, was used in the application. In the evaluation process with PROMETHEE, each the criterion is in addition to the ranking. The ability to use a different preference function; The second is to obtain partial and complete rankings of alternatives. Thanks to these advantages, the accuracy has been increased in the detecting successful areas of natural regeneration.

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Author Contributions

Erol İMREN : Conceived and performed the analysis.

Halil Barış ÖZEL : Collected data for the analysis.

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