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The effect of the forest road network on grassland ecosystems with the contribution of the SWOT-AHP method

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Abstract. Forest road edges are habitats for many grassland species because these species grow in open environments with sufficient light. The study area was the Regional Unit of Kavala (Eastern Macedonia and Thrace, Greece). The Strengths, Weaknesses, Opportunities, and Threats (SWOT) were recorded according to the literature review and the criteria were also ranked using the AHP (Analytic Hierarchy Process) method. According to the comparison of the SWOT criteria, Strengths occupy a percentage of 43.6%, followed by Weaknesses and Threats with a percentage of 24.5% and 17.3% respectively. Opportunities have the smallest percentage (14.6%). Regarding the sub-criteria of Strengths, the sub-criteria "The edges of forest roads protect high plant diversity, and a significant degree of endemism" ranks first with a percentage of 32.4%. From the comparison of the sub-criteria of Weaknesses, the sub-criteria "Forest roads create gaps by removing vegetation and divide the ecosystem" occupies the first place with a percentage of 37.9%. After comparing the sub-criteria of Opportunities, the sub-criterion "Through the forest road network there is access to new areas (grassland ecosystems)" receives the largest percentage (46.6%). The biggest Threat is the sub-criterion "The road network probably contributes to global macroclimate change" with a percentage of 52.4%.

1 Introduction

Road edges are habitats for many grassland species [1] because these species are well adapted to open grazed grasslands [2-3] and silvopastoral systems [4] and grow in open environments with sufficient light [5]. In addition to grassland plants and invasive species largely colonize the edges of forest roads [6]. This fact may be due to the microclimatic changes produced at the edges of the roads, which favour the spread of these species [7]. Further, the forest road edges protect high plant diversity and a significant degree of endemism, especially in native and light-demanding species [8]. This occurred because some species benefit from increased light intensities, and some species benefit from reduced interspecific competition in compacted roadside soils [9]. The length of the road contributes to the transport of seeds over long distances, due to the maintenance of the road network, and the passage of vehicles, people, and animals [10].

On the other hand, the road network creates problems in the conservation of ecosystems [11]. This has occurred due to wildlife mortality caused by vehicle collisions and due to habitat loss and degradation [12] created by the natural encroachment of roads and traffic noise [13]. Forest roads create linear gaps by removing vegetation and dividing the ecosystem, thus creating a new ecosystem that has different and contrasting properties compared to the forest interior [11]. Also, the microclimate changes at road edges alter floristic composition [11] because abiotic factors (e.g., soil depth, temperature, and moisture) change [14]. Additionally at the edge of the road, the availability of light and nutrients increases, creating soil disturbance [15] because roads create gaps and, in this way, soil and vegetation are removed [14].

Road edges can help confront forest fires through biomass harvesting [16]. Also, through the forest road network animals have access to new areas [17] due to the presence of predators such as the wolf which chooses to move through the forest roads, for easier movement and food search [18]. At the edges of the road, the growth of fast-growing species can be favoured, due to the increased consumption of light and soil nutrients [19]. In addition, in snowy areas herbivores to avoid deep snow may use the road network for easy transport as an alternative solution [17]. The road network enhances species of vegetation that prefer a higher pH since limestone gravel is usually used in the forest road network which, together with dust and runoff, contributes to the increase of soil pH [14].

Forest roads disturb to a significant extent the ecosystem [20]. The construction of a forest road network can bring about adverse effects, such as can favour the introduction of pests [21] which can damage native vegetation and cause soil erosion [22]. Roads create micro- and meso-climatic changes and possibly contribute to global macro-climate change by altering

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the solar radiation, wind, humidity, and temperature they receive [23]. Road edge microclimate effects can extend to surrounding habitats [24] and have been recorded from a few meters to hundreds of meters from the natural forest edge [25]. In this way, smaller forest patches are affected to a greater extent than larger forest patches [24]. Furthermore, roads can affect animal movement [26]. Animals avoid using areas with high human development for their movement [27] because of noise and accidents caused by cars [28].

The purpose of this work was, through the SWOT-AHP method, to highlight the effect of the forest road network on grassland ecosystems. Also, it informs planners aware if these forest road networks create problems that occur in the natural environment and if possible, to cross the grasslands.

2 Study area

The study area was the forest road network in the Regional Unit of Kavala. It is part of East Macedonia and Thrace (Greece) (Figure 1), with a total area of 2,111 km^2. The length of the forest road network of the area is 3971.77 km. According to the deliverables of the CORINE program of the European Union (Copernicus Europe's eyes on Earth) (https://land.copernicus.eu) the grassland areas (Figure 1) were 18,020.005 ha. The length of the forest road network which crosses grasslands in the Regional Unit of Kavala is 835.15 km. The particularity of the area is the high-length forest road network that crosses the grassland ecosystems.

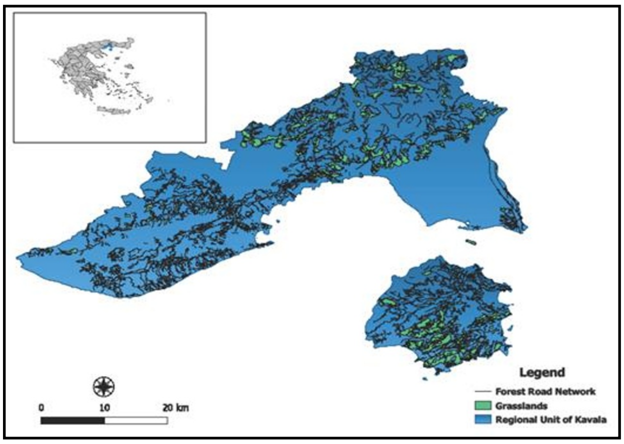

Fig. 1. Study area, Regional Unit of Kavala (Eastern Macedonia and Thrace, Greece).

3 Methodology

In this study, the SWOT - AHP method was applied to evaluate the criteria regarding the utilization of forest road network on grasslands and their influence on flora and fauna. SWOT analysis is a method for formulating strategies [29]. It is a decision-making tool for analyzing the internal and external environment of an organization [30]. The SWOT method records the criteria but cannot prioritize the importance of each criterion [31]. When the SWOT method integrates the AHP method in decision making then the SWOT method turns into a hierarchical structure [32]. The hybrid SWOT – AHP method interprets the SWOT criteria (Figure 3) with quantitative values and makes them comparable [33]. For collecting data, a structured questionnaire was constructed, and 100 closed-ended questionnaires were distributed to foresters for the comparison of the SWOT criteria (Strengths, Weaknesses, Opportunities and Threats).

AHP Analysis

Pairwise comparison was performed and presented in a weight table. Where aij is the relative weight and 1/aji is the inverse preference ratio and is placed on the opposite side of the main diagonal.

$$A = (a_{ij}) = \begin{bmatrix} W_1/W_1 & W_1/W_2 & \dots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \dots & W_2/W_n \\ \vdots & \vdots & & \vdots \\ W_n/W_1 & W_n/W_2 & \dots & W_n/W_n \end{bmatrix} \quad (1)$$

The Consistency Index (CI) calculation was followed and then the Consistency Ratio (CR) was calculated.

$$CI = \frac{(\lambda \max - n)}{(n-1)} \quad (2)$$

The CI consistency index is determined by normalizing the difference below. The consistency index RI is the random index generated for a random matrix of order n and CR is the consistency ratio [34]. The general rule is that CR should be CR≤0.1 for the table to be consistent.

$$CR = \frac{CI}{RI} \quad (3)$$

4 Results

In the present study, the SWOT-AHP hybrid method was used (Figure 2). This hybrid method has a wide range of applications and has been used in many studies.

Fig. 2. SWOT (Strengths, Weaknesses, Opportunities, Threats).

Four criteria (Strengths, Weaknesses, Opportunities and Threats) and their sub-criteria were rated by

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foresters using a questionnaire. The degree of importance after the pairwise comparison of (Strengths, Weaknesses, Opportunities, and Threats) is depicted in Figure 3. Strengths occupy the largest percentage (43.6%), immediately after Weaknesses occupy 24.5%, followed by Threats with 17.3% and Opportunities have the smallest percentage (14.6%).

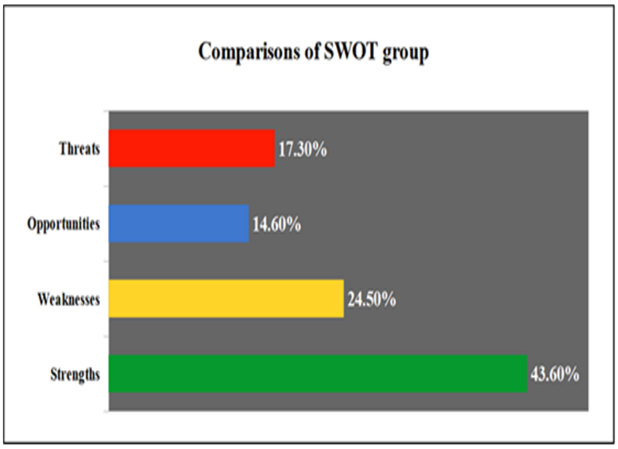

Fig. 3. Comparisons of SWOT group.

The comparisons of the Strengths group (Figure 4) show that the sub-criteria «Forest road edges protect high plant diversity and a significant degree of endemism» occupy the largest percentage (32.4%), the sub-criteria «Road edges are habitats for many grassland species» follows by a small difference 30.0%, followed by the sub-criteria «The length of road contributes to the transport of seeds over long distances» with 20.8% and the sub-criteria «Invasive species colonize at the edges of forest roads» have the smallest percentage (16.7%).

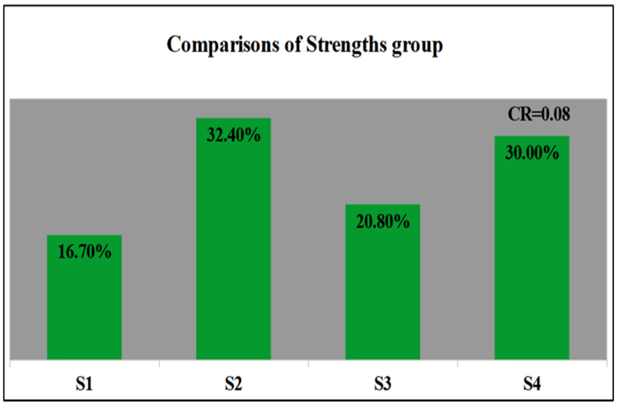

Fig. 4. Comparisons of Strengths group.

The comparisons of the Weaknesses group (Figure 5) show that the sub-criteria «Forest roads create linear gaps by removing vegetation and dividing the ecosystem» occupy the largest percentage (37.9%), immediately after the sub-criteria «At the edge of the road, availability of light and nutrients increases, creating soil disturbance» occupy 25.4%, followed by the sub-criteria «The road network creates problems in the conservation of ecosystems» with 23.7% and the sub-criteria «Microclimate changes at road edges alter floristic composition» have the smallest percentage (13.0%).

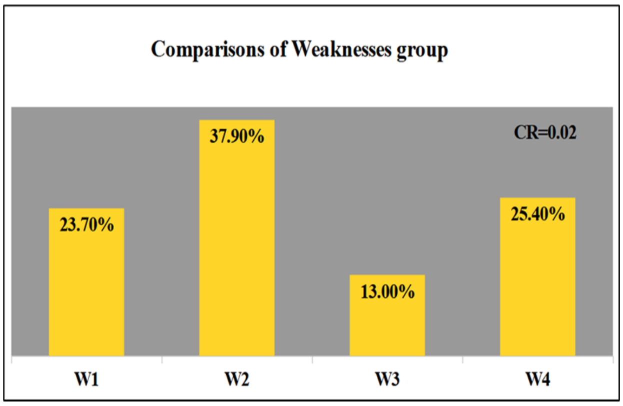

Fig. 5. Comparisons of Weaknesses group.

The comparisons of the Opportunities group (Figure 6) show that the sub-criteria «Through the forest road network animals have access to new areas» take the first position with a percentage (46.6%), the sub-criteria «Herbivores may use the road network for easy transport» follows with 24.9%, followed by the sub-criteria «At the edges of road, the growth of fast-growing species can be favored» with 15.4% and the sub-criteria «The road network enhances species of vegetation that prefer a higher pH» take the last position with the smallest percentage (13.2%).

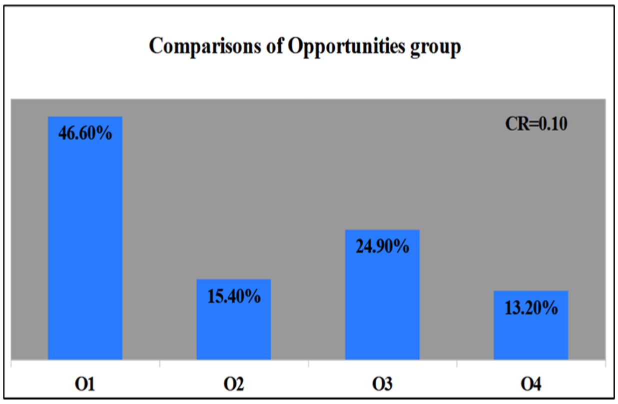

Fig. 6. Comparisons of Opportunities group.

The comparisons of the Threats group (Figure 7) show that the sub-criteria «Roads possibly contribute to global macro-climate change» occupy the largest percentage (52.4%), the sub-criteria «Roads can affect animal movement» follows by a big difference with 25.8%, followed by the sub-criteria «Forest road construction can favor the introduction of pests» with 14.2% and the sub-criteria «Road edges microclimate effects can extend to surrounding habitats» have the smallest percentage (7.6%).

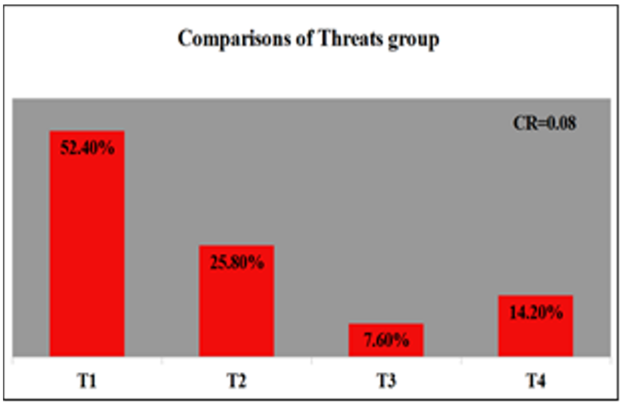

Fig. 7. Comparisons of Threats group.

Figure 8 summarizes the results of the SWOT criteria (Strengths, Weaknesses, Opportunities and Threats) as well as the percentages held by each sub-criteria analyzed above.

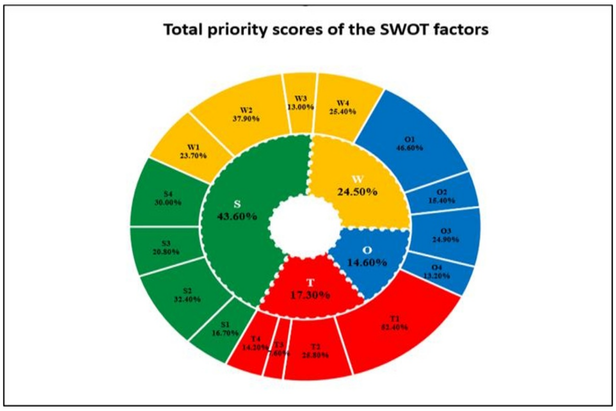

Fig. 8. Total priority scores of the SWOT factors.

4 Conclusions

According to the comparison of the SWOT criteria, Strengths occupy a percentage of 43.6%, followed by Weaknesses and Threats with a percentage of 24.5% and 17.3% respectively. Opportunities have the smallest percentage (14.6%). Regarding the sub-criteria of Strengths, the sub-criteria "The edges of forest roads protect high plant diversity, and a significant degree of endemism" ranks first with a percentage of 32.4%. From the comparison of the sub-criteria of Weaknesses, the sub-criteria "Forest roads create gaps by removing vegetation and divide the ecosystem" occupies the first place with a percentage of 37.9%. After comparing the sub-criteria of Opportunities, the sub-criterion "Through the forest road network there is access to new areas (grassland ecosystems)" receives the largest percentage (46.6%). The biggest Threat is the sub-criterion "The road network probably contributes to global macroclimate change" with a percentage of 52.4%. The AHP method contributes to prioritizing criteria and serves managers and policymakers to formulate strategies.

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