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MULTICRITERIA EVALUATION BY GIS TO DETERMINE TRAIL HIKING SUITABILITY IN A NATURAL PARK

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ABSTRACT

This paper presents a method for assessing the suitability of a paths network in a protected natural park for hiking, using a geographic information system. The evaluation is based on multi-criteria methods including the weighted linear sum and the distance to the ideal point. The results show that hiking activities can be developed in other sectors of the study area, which are as suitable as those currently established. This would decongest saturated areas and add value to other sectors of the natural park. Thus, development associated with this form of tourism can be extended to all the population centres in the area of influence of the natural area.

Key words: Suitability of the trail network, GIS, multi-criteria evaluation, protected area.

RESUMEN

En este trabajo se muestra un método de evaluación de la aptitud de viario para desarrollar una actividad turístico/deportiva como es el senderismo en un espacio natural protegido, mediante un sistema de información geográfica. La evaluación está basada en métodos multicriterios como son la sumatoria lineal ponderada y la distancia al punto ideal. Los resultados muestran que la actividad senderista puede ser desarrollada en otros sectores de la zona de estudio, con la misma aptitud que los actuales, de forma que se puede descongestionar las zonas más saturadas y poner en valor otros sectores del Parque Natural, de manera que el

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desarrollo ligado a esta actividad turística pueda ser ampliada a todas entidades de población influenciadas por la presencia del espacio natural.

Palabras clave: Aptitud de la red viaria, SIG, evaluación multicriterio, Espacio Natural Protegido.

I. INTRODUCTION

Hiking is a sports/recreational activity that is increasingly popular among tourists of all kinds, but especially in the field of rural tourism. This leisure activity has both positive and negative impacts on the environment (Wenjun *et al*., 2005, Törn *et al.*, 2009). Among other advantages of developing such initiatives in rural areas, it has evolved and expanded greatly in recent decades because of the low cost involved. Nevertheless, the strong growth of hiking activities in certain areas has generated negative impacts that can outweigh the benefits derived from this activity. As well as taking note of the positive effects reported from the implementation of hiking trails, measures should be applied to reduce the impact on the environment and on the population affected.

In the studies of hiking are useful the Geographical Information System (GIS) to analyze the features of the trails (in example Rand, 2004 and Cakir, 2005), but mostly it optimal tool for network analysis and suitability of trails.

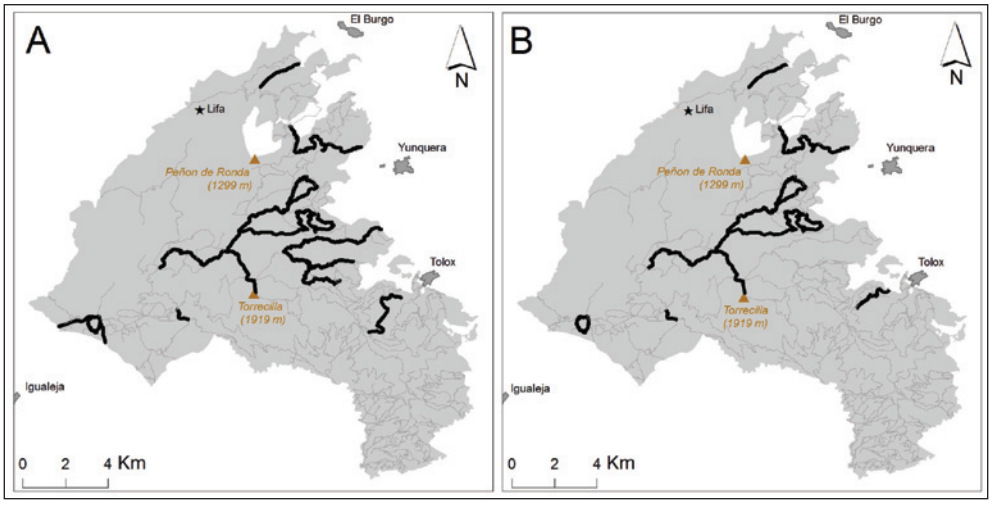
The assessing of the trails infraestructure suitability for hiking is a technique that can be used to analyse the accuracy of the model proposed for the development of this activity in the natural environment. Little has been published by way of methodological background in this respect, although Ocaña and Galacho (2002), Luque (2003 and 2004) and Ocaña *et al*. (2008) can be cited as generic studies on the capacity of the land regarding the development of this recreational activity and, more specifically, the studies by Xiang (1996), Leung and Marion (1999), Bridgland, *et al.* (2001), Mende and Newsome (2006) and Galacho, *et al.* (2011), who proposed a method for assessing the suitability of paths and tracks for hiking.

The present study describes a new methodology to analyze the suitability of the paths and tracks and then offer the best trails to the managers of the protected areas and to the hikers. The method is based in databases publics and in the suitability analysis of the paths and tracks sections of the network. This unit of analysis was applied to every section of the paths and tracks network. These segments physically exist (they are visible) and are functional (they connect possible routes). These characteristics of the trail section will allow creating trails by network analysis on next stage of the project.

The study area is Sierra de las Nieves, a natural park within the network of protected areas in Andalusia (southern Spain). This particular study area was chosen for several reasons: first, it forms part of an R&D project being carried out by the University of Málaga (*Methodological development to assess the capacity of protected areas for recreational uses,* funded by the Ministry of Science and Innovation, project SEJ2007-67690, and by the Regional Ministry of Innovation, Science and Enterprise, project P07HUM-03049) in collaboration with various agencies, including the Department of the Environment of the Andalusian Government and the Governing Board of the Sierra de las Nieves Natural Park,

as a result of which various synergies have been identified during the research phase. Second, it contains two important natural/tourist features; on the one hand, Torrecilla peak, which at an altitude of over 1918 m is the highest point in the provinces of Sevilla and Málaga; and on the other, a large population of Spanish firs (*Abies Pinsapo*), which in 2010 was included in the IUCN Red List of threatened species. These two features attract a multitude of hikers to the surroundings. Third, it is just two hours from the cities of Malaga and Seville, which have a combined population of 1.5 million people, many of whom are potential hikers, with over 5,000 registered members of hiking clubs in 2012, according to the Andalusian Mountaineering Federation. Finally, there exists a Public Use Plan in which hiking-related interventions are still evolving and pending completion (Fig. 1).

Figure 1
TRAILS SHOWN IN THE PUBLIC USE PLAN FOR SIERRA DE LAS NIEVES NATURAL PARK (HIGHLIGHTED IN BOLD). IMAGE A SHOWS THE TRAILS INCLUDED UP TO 2009, AND IMAGE B, THOSE FROM 2009 TO THE PRESENT.



Source: Prepared by the authors.

II. METHODOLOGY

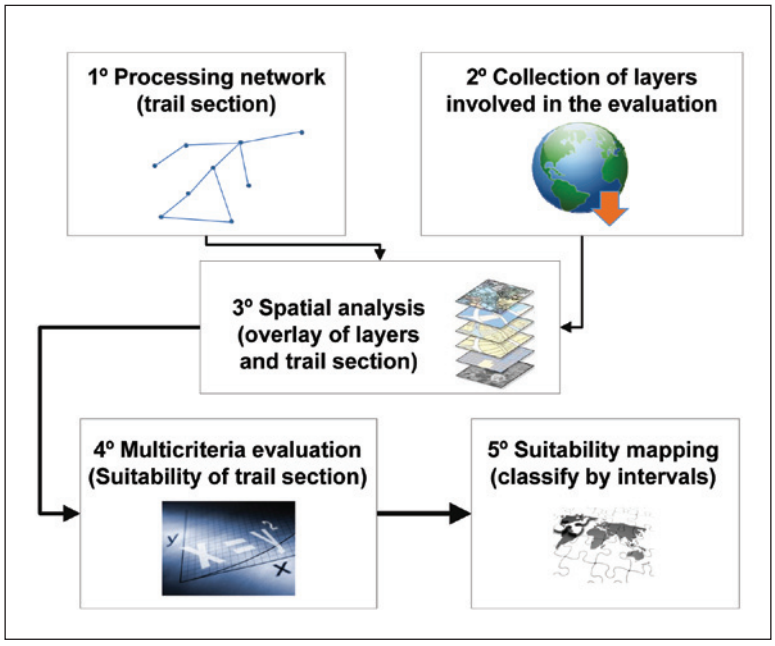
The hiking suitability of paths was determined through a multi-criteria evaluation of the suitability of each of the sections making up the network in the study area, the Sierra de las Nieves Natural Park. In this analysis, the weighted linear sum and the distance to the ideal point are used as multi-criteria methods; these approaches have been thoroughly presented by Gómez and Barredo (2006) and Malczewski (1999), who provided extensive documentation on models and concepts related to this question.

The trail section suitability is conditional by its use: sports, recreative, scientific, etc. The use of the trails depends of the land managers (political), but the characteristics of the trails for every use can be analyzed for the researchers. Therefore, the suitability analysis has been separated in two parts. On the one hand, the calculation of the criteria using weighted linear

sum, which allows knowing the intrinsic characteristics of every trail section according to the factors related with that criterion, independently of the final use of the trail. On the other hand, the suitability of the trail section by ideal point analysis of every criterion. The weight of every criterion depends of the final use of the trails. In this work, the trails have been analyzed for any use and user, and there are not weights for the criteria.

The methodology developed can be summarized in some steps (Fig. 2). Firstly, the network has to be defined and the layers have been collected. Then, the layers and network have been overlayed to calculate the factors. Using the multicriteria evaluation, the factors were transformed into criteria and these into suitability. Finally, the classification of the suitability scores allowed makes the map.

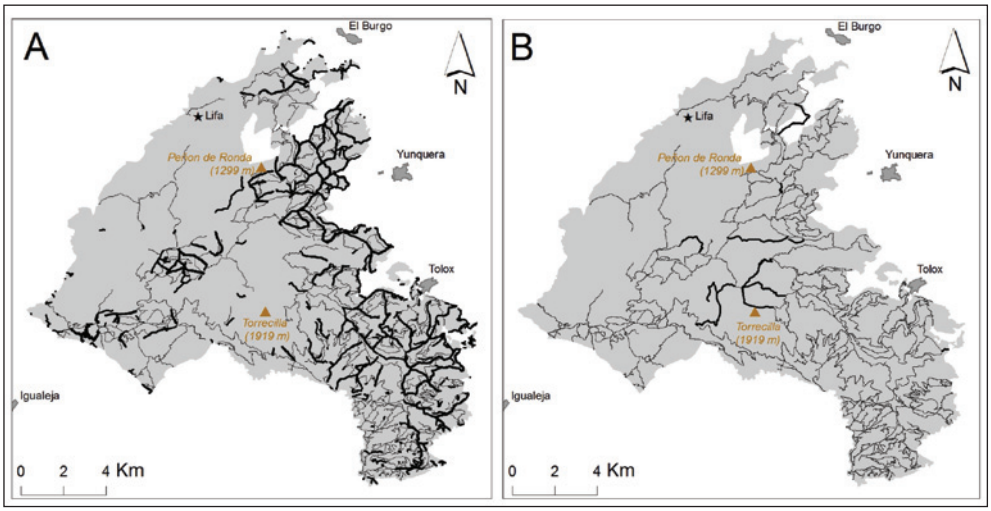
Figure 2
METHODOLOGICAL FRAMEWORK FOR ASSESSING THE SUITABILITY OF THE ROAD IN SIERRA DE LAS NIEVES



Source: Prepared by the aythors.

The sections of the trail network examined in this study are essentially those paths and tracks established by the Andalusian Regional Government. The sections analysed are those shown at a scale of 1/10000 in vector format on the Topographic Map of Andalusia ((*Mapa Topográfico Andalucía*: MTA10). Some short, isolated sections and most fire breaks were excluded from the analysis of this trail network. In addition to the trails shown on the MTA10, certain sections in the study area known to be used by hikers were considered. This knowledge was obtained from interviews with users of the study area and from references published in www.wikiloc.com, accessible from Google Earth 6.2.2 (Fig. 3).

Figure 3
TRAILS NETWORK IN THE STUDY AREA. IMAGE A SHOWS THE TRAILS INCLUDED IN THE MTA10; THE SECTIONS NOT ANALYSED ARE HIGHLIGHTED IN BOLD. IMAGE B SHOWS THE TRAILS ANALYSED, WITH SECTIONS ADDED FROM OTHER CARTOGRAPHIC SOURCES HIGHLIGHTED IN BOLD



Source: Prepared by the authors.

The sections making up the trail network of the study area were assessed for hiking suitability according to three criteria:

1. 'Hikability' or practicality (C_1)
2. Natural interest (C_2)
3. Land management (C_3)

Each of these criteria reflect issues related to the purpose of this study, i.e. to determine the natural suitability of the trails for hiking (criterion 1), their interest or attraction as a means of exploring the territory (criterion 2) and their correlation with the planning of public spaces (criterion 3), with special reference to protected natural areas.

Each of the criteria is expressed in the mapping of the sections, using various factors, which in turn are the combination of different variables.

Since the variables used are qualitative and quantitative, the first step was to standardise the values by which the variables were measured. In every case, the variables were scored between 0 and 1, to unify criteria and to maintain the importance of each one. Values close to 1 indicate high suitability for hiking, while values close to 0 imply very low suitability.

The qualitative variables were analysed from the percentage results of the survey carried out as part of project P07HUM-03049; these values are readily convertible to scores between 0 and 1. When these data were not available, panels of experts were consulted. The survey was conducted at the starting points of different hiking trails in the study area; thus it was

possible to evaluate the suitability of the trail sections taking into account the opinions of all types of persons making use of these trails, and not relying solely on 'expert' assessments.

The quantitative variables were normalized by dividing by the maximum (Voogd, 1983). The maximum is the largest theoretical value the variable can achieve, regardless of the maximum values of the study area. If the variable does not have a maximum length, for example in the case of the length of a trail section, class intervals were used.

For cases in which the value of the variable is not homogeneous throughout the length of the trail section, the value assigned is the average value, weighted by length, of the weights of the homogeneous segments making up the variable (Equation 1):

$$\sum_{1}^{n} svs \times \%$$

Equation 1: *svs* = the suitability value of the variable n for each section; % = percentage of the total length of the section, with a given *svs,* in the section. Thus, the final value of section suitability ranges from 0 to 1, with 0 being the lowest suitability value and 1 the highest.

Once the variables had been scored for each section, each criterion was assessed, by decision rules (Gómez and Barredo, 1996) based on the weighted linear sum and the distance to the ideal point.

The dataset for each variable associated with each trail section analysed were entered into a Geographic Information System (GIS) created specifically for this project. The GIS was generated using ESRI technology applied by the ArcGIS 9.3.1 program. With this software, a vector dataset (polyline) was created, representing each of the trail sections. In this way, a single layer of geographic information was created, storing all the data necessary to carry out the multi-criteria assessment.

1. Criterion 1 (C_1): "Hikability" or Practicability

The suitability value for C_1 is calculated from the weighted linear sum of the scores obtained by the following four factors: surface, trail type, average slope and slope obstacles, the respective scores of which, in turn, were obtained as explained below. The weighted sum of the factors is normalized between 0 and 1 (the theoretical values of criterion 1) by dividing by 6 in order to compare the results of each criterion in the final suitability assessment (Equation 2).

$$C_1 = \frac{(F_{11} \times 1) + (F_{12} \times 2) + (F_{13} \times 2) + (F_{14} \times 1)}{6}$$

Equation 2: C_1 = hikability criterion; F_{1i} = factor i (i = 1 to 4) of Criterion 1

1. Factor F_{11}: Surface

This factor corresponds to the type of material of which the trail is constituted, i.e., the type of soil and vegetation cover trodden by hikers. Surface types were identified in accordance with hikers' opinions, obtained from a survey of users of public facili-

ties in the study area. Four types of surface were classified, ordered from high to low valuations: soil, rock, rock with grass and grass with soil. These categories were scored and classified according to the persons who selected them, among all those who did not select the option "no preference" to the survey question regarding the type of trail surface preferred for hiking.

Using the above categories, matching elements in the information layers described in the GIS were then selected. The following information layers were used to obtain the categories listed in the survey:

- Soil types, 1:100000 scale, obtained as part of the project Stop Desertification in the Mediterranean ("*Lucha contra la desertificación en el Mediterráneo*": LUCDEME).
- Vegetative cover, 1/10000 scale, published by the Regional Ministry of the Environment (Junta de Andalucía).

After defining all the categories considered in the survey (Table 1) for each homogeneous section of trail in the natural park, the percentage of the length of each trail section with a different suitability value, by surface type , was evaluated. This yielded an average suitability value for the entire section as a weighted sum of the values of each homogeneous segment.

2. Factor F_{12}: Type of trail

The second factor concerns the width and the type of trail preferred by hikers. By comparing the preferences expressed against the elements included in the vector data of the Topographic Map of Andalusia (MTA10), two trail categories were identified: paths and tracks.

From these categories derived from the MTA10 dataset, the suitability of the sections was estimated according to the survey results on hikers' trail-type preferences. Paths, preferred by 78% of respondents, were assigned a suitability value of 0.78, and tracks were assigned a value of 0.02 (Table 1).

3. Factor F_{13}: Slope

The average slopes of the trail sections were obtained from a digital elevation model (DEM) with a spatial resolution of 10x10 m, taken from the "Digital Terrain Model of Andalusia. Relief and topography" published by *Junta de Andalucía*. From this DEM, and using the ArcGIS slope function (Burrough and McDonnell, 1998) the slope of each pixel of the trail was calculated; thus, the calculation was performed only for the trail pixels shown. The average slope for each section of trail was then calculated and ordered into five classes (from flat to steep), with the trail suitability decreasing as the average slope increased (Table 1).

4. Factor F_{14}: Slope obstacle

This factor was included to compensate for the limitations of the previous one. Thus, factor 4 refers to the amount of trail distance with a continuous steep slope that a hiker must cover in a given section. It was determined using the same digital model as for the

previous slope factor, from which sections of the trail with a slope greater than 30% were selected. This threshold was taken because such a slope requires considerable effort to climb, and if it persists for a considerable proportion of the section, will pose an obstacle to the hiker's progress. Having selected the homogeneous sections that met the above condition, their percentage of the total section length was calculated, and the suitability value weighted by this percentage.

Thus, any section in which 100% of its length contained a slope exceeding 30% was assigned a suitability value of 0, and any section in which 0% of its length contained a slope exceeding 30% was assigned a value of 1 (Table 1).

2. Criterion 2 (C_2): Natural interest

The suitability value of criterion 2 was calculated from the weighted linear sum of the scores obtained by the vegetative environment factors and landmarks of interest. The sum of the factors was divided by 5 to normalize between 0 and 1 the theoretical minimum and maximum values of criterion 2 and thus to make them comparable with the other suitability criteria (Equation 3).

$$C_2 = \frac{(F_{21} \times 3) + (F_{22} \times 2)}{5}$$

Equation 3: C_2 = natural interest criterion; F_{2i} = factor i (i = 1 to 4) of criterion 2

1. Factor F_{21}: Natural vegetation

This factor takes into account hikers' preferences with respect to their trail surroundings. According to the survey results, the most important aspect is the vegetation in the trail area. Preferences are unequivocally in favour of woodlands, compared to any other type. 46% of respondents favour woods, and this figure rises to almost 90% when broken woodland is included. As regards the type of wooded land, the majority of hikers preferred the area's most emblematic element, the *Abies pinsapo* forest. Taking into account these preferences, three categories were selected to evaluate the natural vegetation factor: areas with forest of *Abies pinsapo*, other types of woodland and other types of vegetation (Table 1).

These categories were identified from the natural vegetation units shown in a vector dataset model, 1/10,000 scale, published by the Andalusian Regional Ministry of the Environment.

The final assessment of the suitability of each section, for this factor, is again the average of the values corresponding to the homogeneous segments of each section, weighted by their respective lengths.

2. Factor F_{22}: Features of interest

This factor reflects the presence of points of interest, man-made or natural, in the vicinity of the trail, which represent an attraction for hikers and for tourism in general. The various features identified in the GIS were located through fieldwork and by consulting the National Topographic Map, 1:25000 scale, and the websites www.conocestusfuentes.com and www.

espeleomalaga.com, as described by Cañero (2011). This is the only information that was not derived directly from a published map source.

The features identified are listed in Table 1. Each one was scored according to its category, by a panel of experts. With respect to visibility, to be eligible for consideration, every such features had to be within a certain maximum distance from the trail; thus, the resource in question truly represents one associated with the trail, rather than with any other activity.

Accordingly, depending on the dimensions and significance of each feature, areas of influence were established, and two types of feature differentiated: those which are easily visible from the trail and those which are not. To do so, two distances were determined for the catchment area. Those which are easily identifiable were assigned a catchment radius of 100 m, while the rest were assigned a distance of 50 m (Table 1). The percentage of the length of the section in which a scenic feature is located was then calculated and the formula shown in equation 1.

The unit of study was the length of the section associated with a given scenic feature, and not the number of features, because the maximum trail length in which features may be seen (100% of the section) is known, the factor can be normalized between 0 and 1 of that maximum. In contrast, if the number of points along the trail section were used, there would be no maximum value for the number of features to be found and therefore it would not be possible to normalize the values. Furthermore, the selection of intervals with a given number of feature points, indicating a high or low number of points of tourist interest, could suffer from an absence of objectivity.

Table 1
SCORING FOR THE FACTORS INCLUDED IN EACH COMPONENT OF THE MULTI-CRITERIA ASSESSMENT

Factor F_{11}		
Type of surface	Preferred by	Score assigned
Soil	28%	0.58
Grass over soil	1.7%	0.04
Rock	2.9%	0.12
Grass and-rock	0.29%	0.01

Factor F_{12}		
Mapping class	Preferred by	Score assigned
Paths	78.3%	0.78
Tracks	2.3%	0.02

Factor F_{13}		
Class of slope	Slope interval (%)	Score assigned
1	0 – 5	1
2	5 – 15	0.75
3	15 – 30	0.5
4	30 – 45	0.25
5	> 45	0.01

Factor F_{14}		
Variable	Scale of the attribute	Score assigned
% of the section with slope >30%	100% to 0%	0 a 1

Table 1 (continuación)
SCORING FOR THE FACTORS INCLUDED IN EACH COMPONENT OF THE MULTI-CRITERIA ASSESSMENT

Factor F_{21}	
Category	Score assigned
Abies pinsapo forest	0.69
Woodland	0.31
Others	0.12

Factor F_{31}	
Category	Score
Zones B and C, unrestricted	1
Zone A, with restrictions	0.75

Factor F_{22}		
Category	Maximum distance (m)	Score
Fountain	50	1
Spring	50	1
River source	50	1
Seep point	50	1
Viewpoint	100	1
Unusual trees	50	1
Woodland	100	1
Sinkhole	50	1
Karst	50	1
Snow well	50	0.66
Threshing floor	50	0.66
Farmhouse	50	0.33
Shelter	50	0.33
House	50	0.33
Thermal spring	50	0.33

Source: Prepared by the authors.

3. Criterion 3 (C_3): Management

The management criterion reflects the level of protection afforded to different areas of the natural park. The criterion is defined by a single factor, which in turn depends on a single territorial variable: the zoning of the natural park as described in the Plan for Natural Resource Management for the protected area.

On the basis of the above document, two sectors in the protected area were identified, in which the hiking suitability value varied depending on the degree of protection applied to this activity. Thus, in zones B and C, hiking is unrestricted, provided it is along trails intended for this purpose, and so the suitability value for the hiker is 1 (maximum) (Table 1). In contrast, in protection zone A a hiking permit must be obtained from the corresponding department of the Ministry of Environment. A suitability value of 0.75 is assigned to all the sections passing through protection zone A. This value reflects a degree of suitability that is still high because, in fact, the restriction is almost non-existent; the rules were recently changed to simplify and speed up the approval of hiking activities.

4. Suitability assessment

The criteria for obtaining an overall suitability value were assessed using the distance to the ideal point, reflecting the statistical distance of each case with respect to the ideal situation, in which a score of 1 would be assigned. This distance (calculated as the average of the sum of the squared differences of the score for each criterion with respect to 1, the maximum score), is a measure of similarity and thus is more suitable for our purposes than a mere linear aggregation, since the compensation derived from the use of the arithmetic mean balances situations with different dissimilarity values. Considered as a measure of similarity (in which a distance of 0 from the ideal point would be the ideal point itself, and a distance of 1, its antithesis), the values obtained are inverted when ranking the alternatives in order of suitability, in order to maintain consistency of scores (from 0 to 1, from worst to best) in the procedure as a whole (Equation 4).

$$Suitability = 1 - \left(\sqrt{\sum_{1}^{n} (x_i - p_i)^2} \right)$$

Equation 4: x_i = value of the criterion n (n = 1 to 3) in section i; p_i = ideal point of the criterion n in section i.

The suitability mapping result is illustrated using three intervals, showing in a simplified form the hiking quality of the different sections of the trail in the natural park, as low, moderate or high. The limits of the intervals were calculated from the standard deviation (Table 2). The advantage of this data classification method is that it reveals the variations inherent to the variable in the study area; on the other hand, these intervals are of value only with respect to the study area in question, as they depend on the characteristics of this area. By contrast, the choice of a classification method that could be used to compare different study areas, for example by means of regular intervals, does not discriminate areas of different levels of suitability within the Sierra de las Nieves natural park; accordingly, this option was discarded.

Table 2
CLASSIFICATION OF TRAIL SUITABILITY VALUES FOR HIKING AND CLASS SCORES IN SIERRA DE LAS NIEVES

Degree of suitability	Interval limits	Final suitability class scores
High	$((\overline{X} + ½\ \sigma)$ - Maximum]	(0.49 - 1]
Moderate	$((\overline{X} - ½\ \sigma)$ - $(X + ½\ \sigma)]$	(0.44 - 0.49]
Low	(Minimum - $(\overline{X} - ½\ \sigma\ )]$	(0 - 0.44]

Source: Prepared by the authors.

III. RESULTS

1. Suitability criteria in Sierra de las Nieves

The maps in figure 4 show that the suitability of the trail varies greatly depending on which criterion is applied.

Under Criterion 1, the zones of highest suitability are those located in the central area of the natural park, which is the area most intensively used for hiking. In this central sector, the suitability ranges from high to moderate. The high suitability sections are those on the northern side of the Torrecilla peak, while those to the south are classed as moderate suitability. This variation is strongly influenced by the slope measured in each area, this being steeper on the southern side, which slightly reduces its suitability classification. In any case, this sector is currently most popular for hiking, which in turn is reflected in the Public Use Plan for the natural park, which regulates most of the trails in this area. By contrast, in the southern part of the study area the suitability is highly variable, from high to low. This area contains a high density of trail sections, but their suitability is strongly influenced by the type of trail (path or track). Thus, the sections containing paths are classed as low suitability, while the tracks are classed as high or moderate suitability.

With respect to criterion 2, the higher suitability areas are again located in the central area, mainly where the *Abies pinsapo* density is highest. This landscape element is one of the main attractions for hikers in Sierra de las Nieves, according to the survey for the projects mentioned above. In addition, this sector contains various other resources of interest, such as snow wells, springs, caves and viewpoints. The large number of such resources in other parts of the natural park has no impact on this factor because the suitability criterion is very strongly influenced by the presence of the *Abies pinsapo* forest, as is clear from the survey. Therefore, at present the *Abies pinsapo* zones are considered the real focus of attraction, together with the Torrecilla and other emblematic peaks, in the study area.

Criterion 3 produces a somewhat different result from the other criteria, with the highest level of suitability being located in the zones more distant from the central sector of the natural park. This is because hiking restrictions in the park regulations mainly affect the central sector, in view of the quality of the landscape elements there. On the other hand, in the rest of the natural park there are no restrictions on hiking, which encourages the use of these trails.

Statistically, no correlation was detected between the factors used to evaluate each of the criteria, thereby eliminating errors in the results obtained (Table 3).

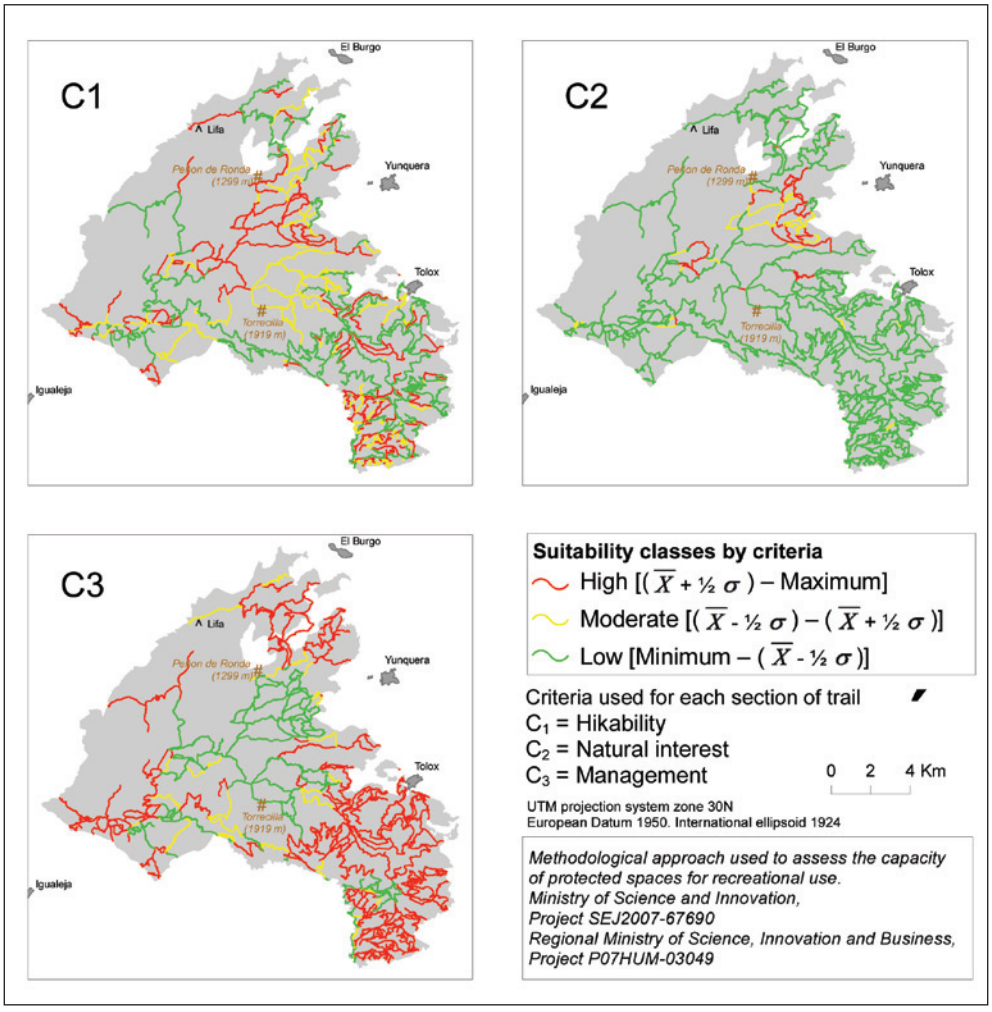
Table 3
STATISTICAL CORRELATION BETWEEN EACH FACTOR OF ANY CRITERION

	Factor F_{11}	Factor F_{12}	Factor F_{13}	Factor F_{14}	Factor F_{21}	Factor F_{22}	Factor F_{31}
Factor F_{11}	1,00						
Factor F_{12}	-0,19	1,00					
Factor F_{13}	0,00	-0,22	1,00				
Factor F_{14}	-0,05	-0,18	0,65	1,00			
Factor F_{21}	-0,12	0,19	-0,05	0,00	1,00		
Factor F_{22}	-0,24	0,08	0,03	0,02	0,09	1,00	
Factor F_{31}	0,35	-0,20	0,04	-0,01	-0,41	-0,16	1,00

Source: prepared by the authors.

All the correlation values are close to zero, except that obtained from F_{13} and F_{14} factors, both related to the slope, but becomes not significant from a statistical standpoint.

Figure 4
SUITABILITY MAPS FOR EACH TRAIL SECTION IN ACCORDANCE WITH THE CRITERION PRESENTED



Source: Prepared by the authors.

2. Suitability map

The network of paths and tracks analysed in the study area contains a total of 785 sections. Each of these was subjected to multi-criteria assessment, carried out automatically in ArcGIS 9.3.1.

The assessment shows that the average suitability of the trail sections in the study area is scored at 0.46 (Table 4), although there are significant deviations from this average value, with some sections producing a final suitability of 0.71 while the minimum value obtained was 0.23.

Table 3
HIKING SUITABILITY VALUES IN SIERRA DE LAS NIEVES

	Paths	**Tracks**	**Total**
Number of sections	327	458	785
Total length (km)	224.3	252.4	476.7
Average length (m)	686	552	608
Longest section (m)	3,344	3,756	3,756
Average suitability value	0.42	0.49	0.46
Extreme suitability values	0.23 – 0.53	0.26 – 0.71	0.23 - 0.71

Source: Prepared by the authors.

When the analysis distinguished between paths and tracks, the latter were found to have a slightly higher suitability, which had a favourable impact on the assessment of the sections in the study area, since nearly 60% of the sections are comprised of tracks.

The mapping result of this suitability assessment of the trail sections in Sierra de las Nieves Natural Park (Fig. 5) shows the suitability to be high in the central area, which is consistent with the values obtained by reference to criterion 1 and 2, but that the suitability is also high in the southern sector of the study area, which in turn reflects the value of this sector for the practice of hiking.

More precisely, it can be seen that the maximum suitability is concentrated at three locations: first, the areas with a large population of *Abies pinsapo*, and access to the Torrecilla peak (as a temporary feature, this sector is particularly attractive when covered in winter snow). Second, the Bohornoque area, in the south, with an attractive tree cover of oaks and less rugged terrain. Third, the area around Nava de San Luis, which is smaller in surface area, with shallow slopes and irregular tree cover. A transition area is the rest of the Nava de San Luis area (adjoining Conejeras and equipped with various recreational facilities) where the trails are few, but very long, and classified as moderate to high suitability.

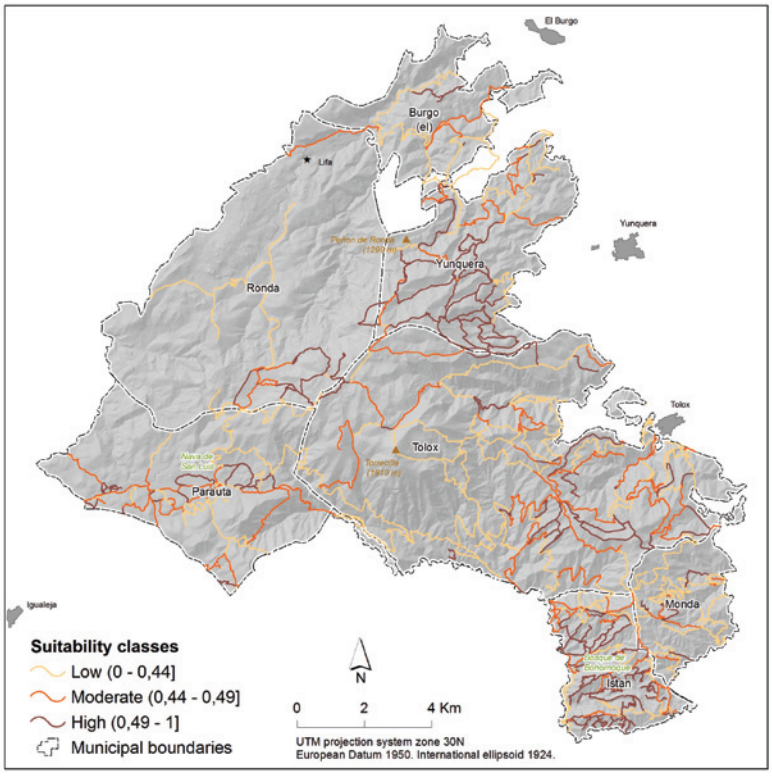
This pattern of suitability locations can be viewed in two ways: one, the possibility of opening up new trails near current ones in order to lighten the hiking traffic there. Another, the possibility of enhancing the recreational use of areas lacking public use trails, something that is in fact foreseen in the Public Use Plan, especially in the southern sector of the park, but not yet put into practice.

At the other extreme, the area classified as least suitable for hiking is located between the above sectors, that is, the area with little tree coverage, located in the sector of the municipality of Tolox between Sierra de las Nieves and the peridotite alignments of the southernmost sector. This fact highlights a problem: how to connect the three sectors classed as most suitable, i.e., Bohornoque, Nava de San Luis and Torrecilla-Yunquera, thereby making the entire park more transitable.

There is a remarkable absence of activity in the large northwestern sector of the natural park, in the area of Sierra Hidalga, partly due to the historical lack of trails in the zone. However, the Lifa area has good potential, as reflected in the section there classed as presenting moderate suitability.

Focusing on trail suitability in terms of the municipalities in which they are located, Figure 4 shows that the towns of Yunquera and Istán offer the greatest suitability for hiking. Yunquera currently has an extensive network of trails included in the Public Use Plan for the natural park. On the other hand, the trails in Istán are considered highly suitable for hiking, but none are included in the Public Use Plan. Parauta and Tolox have an extensive network of trails, with some sections considered to be highly suitable, and these could add value to a large part of the protected area. Monda and El Burgo are in comparable situations; they do not have an extensive network of trails, and those which are to be found are not especially suitable for hiking, although in El Burgo some of the trails do form part of the Public Use Plan, which could provide a pointer for those in the Monda area. Finally, the large municipality of Ronda has hardly any trails in the study area, but certain areas of high suitability could encourage the development of trail sections to enable the connection of others.

Figure 5
HIKING SUITABILITY MAP FOR TRAIL SECTIONS IN SIERRA DE LAS NIEVES NATURAL PARK



Source: Prepared by the authors.

IV. CONCLUSIONS

The choice of the trail section as the unit of analysis of the hiking suitability of the network is an effective solution to the problem addressed, since this type of geographical entity is functional and visible in the territory, and thus establishes a link between the user and the trail.

The methodology, in terms of criteria and mapping sources, offers the advantage of being based on data published by public bodies, which means that it can be used quickly and economically by managers of these natural areas. In this regard, a crucial aspect is that the trail network mapping should be up to date and to the largest possible scale, in order to correct errors resulting from the spatial resolution of the dataset.

Assessing the suitability of trail sections is a tool that will allow managers of protected areas to rearrange the network of trails in the Public Use Plan in order to decongest sectors with problems of saturation and to make known new areas within the natural park, off the beaten track. In our study area, the high suitability of the trail sections located in the southern part of the natural park and which do not form part of the Public Use Plan trail network offer a clear opportunity to enhance the park, through the creation of hiking-friendly trails. The importance of this consideration is heightened by the proximity of a large tourist population in the Costa del Sol, around Marbella, suggesting the possibility of increased development for the municipalities in the hinterland of this protected area.

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