

Spatial analysis of the suitability of olive plantations for wildlife habitat restoration¹

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Abstract

This study adopts a twofold methodological approach to assessing the suitability of olive plantations in mountainous areas for wildlife habitat restoration. Embedding expert judgements through an Analytic Hierarchy Process (AHP) about the effect of specific elements of the landscape on ecological diversity permits the most suitable agricultural areas to be selected by means of Geographical Information Systems (GIS). The case study is the olive (*Olea europaea* L.) plantations of Andalusia (Southern Spain). The results suggest that the edge of major agricultural areas (mostly olive groves), and areas adjacent to Natural Park with oaks would be most suitable for wildlife habitat restoration. These results are in agreement with those of studies carried out by other researchers on ecological diversity, based on either individual or groups of species.

Keywords: AHP; GIS; olive plantations; Spain; habitat restoration

1. Introduction

The restoration of habitats for wild flora and fauna and its coexistence with agricultural activity is one of the main objectives of many environmental programs around the world (United Nations Development Programme, United Nations Environmental Programme, World Bank and World Resources Institute, 2000). Focusing on agricultural fields in the EU, we can identify three main trends that have characterized the recent evolution of European agricultural landscapes (Wolters, 1999):

- Intensification in some Member States of the EU (Central and Eastern Europe).
- Extensification of agricultural lands as a result of the EU's environmental protection programs (intensified after the decoupling of the subsidies proposed by the EU Mid Term Review of the Common Agricultural Policy).
- Abandonment of agricultural land, a particularly important process in Mediterranean mountainous areas.

Mountainous agricultural areas with a high probability of being abandoned could be used for wildlife habitat restoration. However, there is a problem of how to evaluate agricultural land in terms of its suitability for wildlife habitat restoration. The competition between agriculture (particularly intensive agriculture) and wildlife habitats has been pointed out by several authors (Donald et al., 2006; Osinski, 2003; Santelmann et al., 2006; Waldhardt, 2003). The negative influence on wildlife habitats of the agricultural activities through the use of

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agrochemicals and the modification of natural habitats has also been well documented (Pimentel et al., 1992; Sullivan and Sullivan, 2006).

It is clear that some indicators are needed for ecological diversity and wildlife habitat assessments of agricultural areas. Most of the indicators that have been developed to assess biodiversity and ecological diversity refer to species richness and the habitat requirements of particular species (Büchs, 2003; Duelli and Obrist, 2003; Jeanneret et al., 2003; Waldhardt, 2003). On the other hand, the OECD recommends paying attention to man-made objects and their influence on the surrounding habitat (OECD, 1997; 2001). Gilbert et al. (2000) illustrate an original approach to assess the viability of arable land to be transformed into semi-natural habitat using the decision support system similar to the one used in this paper.

A number of ways to include wildlife habitat exist. These include Cost-Benefit Analysis (Bräuer, 2003; Polomé et al., 2005), Geostatistical Probabilistic Modeling (Bayliss et al., 2005), Scenario Modeling (Santelmann et al., 2006) and Multi-Criteria Decision-Making. The latter is the approach adopted in the present study and, within this paradigm, we have utilised the Analytic Hierarchy Process (AHP).

The AHP technique uses expert judgments as inputs for weighing criteria and alternatives (Saaty, 1980). In our study, expert knowledge determines the relative importance of each criterion of the optimising function for the potentiality of habitat restoration. Empirical studies that have used multicriteria evaluation methods for the solution of spatial problems include that of Malczewski (1999), which brought together two approaches developed much earlier: Multi-Attribute Utility Theory (MAUT) and the use of Geographical Information Systems (GIS) as a platform for representing the spatial dimension of the problems. A large number of studies have since adopted Malczewski's approach, including Hctor et al. (2000), Store and Kangas (2001), Tseng et al. (2001), Thirumalaivasan et al. (2003), Ayalew et al. (2005), Strager and Rosenberger (2005), and Neaupane and Piantanakulchai (2006), this last dealing with different fields of landscape assessment process.

As an example of the use of AHP for spatial problems solution, Thirumalaivasan et al. (2003) predicted areas that are more likely than others to become contaminated as a result of activities on or near the land surface. The AHP method computes the ratings and weights of each criterion on the parameters of the model. Then GIS software provides the spatial representation of the optimum solution. Similarly, Ayalew et al. (2005) deal with landslide hazard area prediction using both the AHP and logistic regression techniques. The results compare two susceptibility maps. According to these authors, the AHP map was closer to capturing the reality on the ground than the logistic regression. Strager and Rosenberger (2005) focus on the identification of high-priority areas for land conservation. For this purpose individual stakeholders and expert judgements were combined using the AHP. A recent study by Neaupane and Piantanakulchai (2006) determined landslide hazard zonation but, unlike Ayalew et al. (2005), the authors used the latest modification of AHP known as Analytic Network Process (ANP). This method permits possible interdependences among the criteria of the model to be taken into account.

All of these studies, irrespective of their field of application, share the same methodological approach: the combination of AHP and GIS. The result of this research will allow assessing the potential of restoration of wildlife habitats as a criterion to be included in the decision-making process for the selection of the optimal landscape conservation measures.

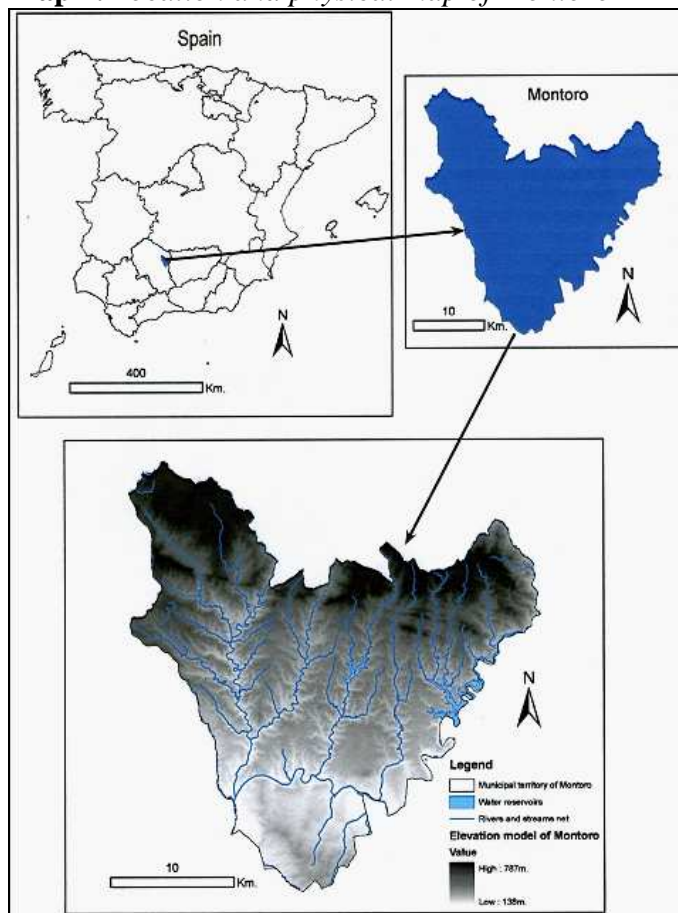
From a practical point of view, the study identifies the more valuable plots of the olive plantations in the area of study that are potentially suitable for the restoration of wildlife habitats. On the methodological side, we have developed a method based on expert knowledge that is capable of identifying potential wildlife habitat areas with relatively small input information requirements, and applied to a particular landscape pattern.

Taking into account the information generated in this study, some policy recommendations can be made about the places most suitable for the restoration of habitats for focal species. In this sense, this methodology can be used to model specific and spatially targeted policy incentives for agricultural lands in environmentally valuable areas.

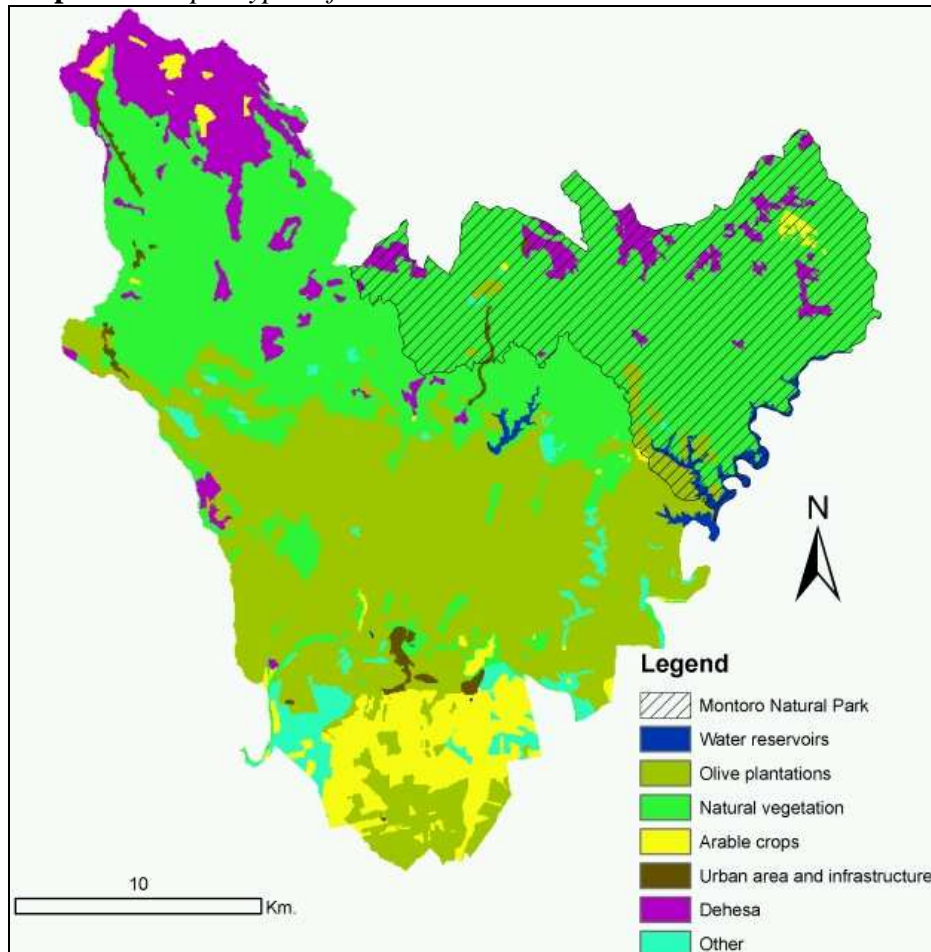
2. The area of study

As Map 1 shows, the municipality of Montoro is located in the province of Cordoba in Southern Spain. The territory enjoys typical Mediterranean continental climate conditions with irregular precipitation distribution during the year (less than 600 mm/year). Montoro was chosen for this study due to the presence of a variety of agricultural ecosystems (pasture, olive groves and annual crops) and natural vegetation near agricultural areas (Map 2 shows the range of land uses). Its 58,103 hectares are divided into olive plantations (34.2%), arable crops (8.1%), forest and natural vegetation (46.1%), *Dehesa* (8.7%), water reservoirs (1.1%), urban area and infrastructure (0,8%) and other land uses (1.0%). The part of the area of the Natural Park Sierra de Cardeña and Montoro is overlapped with other land uses and occupied 26% of the municipal territory of Montoro.

Map 1. Location and physical map of Montoro



Map 2. *Principal types of land use in Montoro*



Note: Dehesa is grassland with scattered trees and a well-developed herbaceous formations (Spanish Society for Pasture Research). These agrosilvopastoral systems are characterized by a savanna-like physiognomy (Martín and Fernández, 2006).

The central and northern parts of Montoro are mostly highlands with steep slopes that make agriculture extremely laborious. For this reason, most agriculture in this region is based on extensive olive plantations and pasture.

3. Methods

The methodology involves three phases: First, an inventory of man-made and natural objects on the territory is drawn up. Then, the AHP method is implemented based on the expert knowledge. Finally, the Geographical Information Systems analysis is used to assess the potential of the study area for wildlife habitat restoration.

3.1. Man-made and natural landscape objects as indicators of potential for wildlife habitat restoration

Some previous studies have used man-made elements as an indicator to delimit landscape protection areas (e.g. Osinski, 2003). Forman and Godron (1986) and Forman (2001) pointed out that the landscape is a matrix of roads, urban areas, natural vegetation, and agricultural plots. Turner (1989) noted the influence of man-made objects on the ecological process (for example road infrastructure reduces dispersal potential of the wildlife species). Some theoretical approaches such as metapopulation theory, the ecology of the landscape and

macroecology (Rosenzweig, 1995; Hanski, 1999) has revealed that the configuration of the landscape has a powerful impact on the diversity of local species. Duelli (1997) thus claims that habitat quality is the most important factor for local species. Such “matrix effects” have been identified by several authors (Jonsen and Fahring, 1997; Miller et al., 1997; Burel et al., 1998; Thies and Tschardt, 1999; Weibull et al., 2000; Dauber et al., 2003).

Although general indicators for all types of landscapes and purposes do not exist (OECD, 2002; Waldhardt, 2003), both natural and man-made factors should be taken into consideration, depending on the local conditions of the landscape matrix and availability of the spatial data. Another important issue is the species under consideration: depending on the focus species selected, as an indicator for the potential of wildlife habitat restoration, the results could vary considerably.

The wildlife species considered in our study were several vertebrate carnivore species² and one bird species³. These species are rare, some of them are on the border of the extinction (Iberian lynx) and quite sensitive to the human presence (Gil-Sánchez et al., 2004; Fernandez et al., 2007). The approach followed in this research is based on the influence of landscape elements, rather than on habitat requirements of focal species. However, the requirements of the focal species are explicitly considered in the approach.

All landscape objects were divided into two groups: “positive” and “negative” according to their influence on the habitat of focus species (Table 1 and 2). This division was made following the literature review and experts opinions.

Table 1. Evaluation of the surrounding influence zone distances for “positive” objects

Landscape objects	Evaluation of the landscape elements surrounding influence zone (m)								
	1=Min	2	3	4	5	6	7	8	9=Max
Water bodies					500-400	400-300	300-200	200-100	<100
Natural vegetation				500-400	400-300	300-200	200-100	<100	Natural veg. structures
Protection of the Natural Park Sierra de Cardeña and Montoro				500-400	400-300	300-200	200-100	<100	Natural Park

Clarifications for Table 1: Water bodies include reservoirs, rivers and streams. Natural vegetation includes natural Mediterranean forest, shrub lands and Mediterranean pastures (dehesa).

Table 2. Evaluation of the surrounding influence zone distances for “negative” objects

Landscape objects	Evaluation of the landscape elements surrounding influence zone (m)								
	1=Min	2	3	4	5	6	7	8	9=Max
Urban areas				900-800	800-700	700-600	600-500	<500	Urban
Roads infrastructure					500-400	400-300	300-200	200-100	<100
High power electricity lines					<100				
Agricultural plots		Low intensification			Moderate intensification		Intensive crops systems		

² Iberian lynx (*Lynx Pardinus*), Wolf (*Canis lupus*), Red fox (*Vulpes vulpes*).

³ Bonelli’s eagle (*Hieraetus fasciatus*).

Clarifications for Table 2: Urban areas include main urban areas in the study area. Road infrastructure includes high speed motorway, motorways and railways. High power electricity lines include main high power electricity lines. Agricultural plots include olive plantations with different level of intensification and arable crops.

In the first group we place all landscape objects that have a positive influence on ecological diversity and wildlife habitat restoration. All natural objects within the landscape matrix are grouped into this first group. Depending on their functions within the landscape matrix, man-made objects can have either a positive (e.g. the Natural Park) or a negative effect (e.g. agricultural plots, buildings, roads and power lines). The Montoro Natural Park is regarded as a positive element since it involves administrative protection from actions that would have negative implications for ecological diversity.

The main model assumption is that both natural habitats (positive landscape object) and man-made elements (negative landscape objects) have a zone of influence. The type of influence varies depending on the landscape object. The element marked as a positive is supposed to enhance the dispersal of the wildlife species, while the negative landscape object impedes the dispersal of the species. This negative influence is more evident for more sensitive species. In addition the intensity of the olive production systems has a negative effect on the adjacent habitat due to the pesticide spraying drift.

3.2. Literature review on influence distance of landscape objects

Guzmán-Álvarez (2004) has developed a model of the potentiality of colonization using a range of distances of between 0 and 500 m as the maximum possible for natural regeneration from existing vegetation. Blab (1993) took a distance of 400-800 m as appropriate for birds, small mammals and flying insects. Knauer (1988) described distances between 100 and 400 m as the longest for an ecological network in agricultural landscapes, while Osinski (2003) regarded a distance of 300 m for the landscape elements as a suitable mean value for setting priorities for landscape protection on a spatial level of the state. The negative influence of road density on wildlife habitats has been well documented by Joly and Myers (2001) within the usage of the indicator of road density.

The selected zones of influence varied from 100 to 900 m, depending on the landscape object concerned. (See Tables 1 and 2 for the range of positive and negative landscape objects, respectively). The values of the different zones of influence were assigned according to the literature review and the expert opinions. A 1 to 9 ordinal scale was adopted for this purpose (Saaty, 1980).

The distances selected for the zones influenced by urban areas (see Table 2) –between 500 and 900 m- are justified by their great impact on surrounding areas (Whitford et al., 2001; Palomino and Carrascal, 2006; Jones and Paine, 2006). For high-tension power lines a distance up to 100 m was considered (Söderman, 2006). The road infrastructure distances are based on the general indicators elaborated by Joly and Myers (2001). Since the evaluation of the potential for wildlife restoration of olive plots is the aim of the study, no buffer zone was created, only an estimate based on the agricultural plantation intensification. Agricultural land was reclassified according to its management type and its influence on ecological diversity and thus on the possibility of restoration. It is often accepted (Duelli et al., 1999; Reidsma et al., 2006) that arable crop systems (cereals), due to its annual soil disturbance, are more harmful to ecological diversity than permanent systems (olive orchards and other tree plantations). Thus, three types of agricultural plots were considered (see Table 2): intensive crop systems (cereals and new intensive olive groves), moderately intensive crop systems (old

olive groves with average yields) and low intensive crop systems (old olive groves with low productivity). The olive groves were classified on the basis of their productivity and tree density maps (both variables positively correlated).

3.3. Analytic Hierarchy Process multicriteria decision-making technique

The Analytic Hierarchy Process (AHP) belongs to the family of multicriteria decision-making techniques. Saaty developed this technique with the aim of supporting arms-reduction negotiations between the USA and the Soviet Union in Geneva (Saaty, 1980). The principal interest of this method lies in the possibility of measuring as tangible relatively intangible commodities during the decision-making process (Saaty et al., 2003). A review of applied studies that have employed this technique can be found in Vaidya and Kumar (2006).

3.3.1. The AHP algorithm description

There are two specific characteristics that distinguish this method from the other methods of this family: the construction of the hierarchy structure of the problem to be solved, and the pair-wise comparisons made between different criteria to weight them with respect to the overall objective. Saaty (1980) recommends a scale of 1-9 for the pair-wise comparisons, where a score of 1 implies similar importance of the criteria being estimated, while 9 indicates an extreme level of importance of one over the other.

If we assume that there are n criteria, and w represents the scores on the 1-9 scale, then the next Pair-Wise Comparison Matrix (or Saaty matrix) can be written:

$$\begin{pmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{pmatrix} \times \begin{pmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{pmatrix} = \begin{pmatrix} nw_1 \\ nw_2 \\ \dots \\ nw_n \end{pmatrix}$$

The same formula in algebraic notation would be: $[A_{(i,j)}] \times [W_{(1,j)}] = [nW_{(1,j)}]$, where A is an $n \times n$ Pair-Wise Comparison Matrix which represents the ratio of ratings to weights, W is the vector of weights of the criteria, and n is the order of the matrix under consideration. The problem to solve is to find the vector of weights W from the A matrix. This kind of problem is quite common in physics and engineering and is known as the nonzero solution of the eigenvector/eigenvalue problem. In spite of the existence of more than one solution to this problem, Saaty and Hu (1998) and Saaty (2003) insist on the application of this method via a system of equations equal to one (Saaty, 1980; Forman and Selly, 2001; Saaty and Vargas, 2000). In the present study we used the MATLAB platform with the free extension of Scott (2001) for the mathematical computation. The ideal mode of AHP (Saaty, 2005) is the approach followed in the simulation.

3.3.2. Checking the consistency of the responses

The above algorithm for the solution of the eigenvector problem is applied only in the case of total consistency of the Pair-Wise Comparison Matrix. In general, however, this condition is rarely met, so the eigenvector problem for the inconsistent case is written as: $[A] \times [W] = \lambda_{\max}[W]$, where, λ_{\max} is the maximum value of the eigenvector of matrix A , and W represents the corresponding weights of the right eigenvector. Normally λ_{\max} is rounded off to n

($\lambda_{\max} \geq n$). The closer the λ_{\max} to n , the more consistent is the judgment recollected previously in the Saaty matrix. Thus, the difference $\lambda_{\max} - n$ could be used as an indicator of the degree of inconsistency (this difference should be zero for a completely consistent matrix). Nevertheless, an alternative kind of measurement known as the Consistency Index (CI) has been proposed (Saaty, 1980; Saaty and Vargas, 2000; Saaty, 2003) . If we define $a_{ij} = (w_i / w_j)d_{ij}$, then:

$$CI = (\lambda_{\max} - n) / (n - 1) = -1 + \frac{1}{n(n-1)} \sum_{1 \leq i < j \leq n} \left[d_{ij} + \frac{1}{d_{ij}} \right],$$

where CI is interpreted as the average inconsistency accumulated in the matrix. In the next step Saaty (1980), Saaty and Vargas (2000) proposes comparing the Consistency Index with the Random Index (RI). This RI is calculated like a CI, but for randomly composed reciprocal matrices with an order from 1 to 15. On the basis of these two indices, the Consistency Ratio (CR) is calculated as $CR = CI/RI$ and, according to Saaty (1980) and Saaty et al. (2003), it should be lower than 0.1. This means that the inconsistency of the responses should not exceed 10%. An inconsistency between 0% and 10% can be regarded as normal. In cases where the CR is higher than 10% the responses should be revised in detail and the evaluation questions must be repeated until the $CR < 0.1$.

In this study six experts in the field of ecology and focal species from the Montoro Natural Park authorities (one expert), the University of Cordoba (two experts from the department of Botany, Ecology and Plant physiology), the Agricultural and Training Research Institute of Andalusia (two experts) and the National University of Dnipropetrovsk (Ukraine) (one expert) were interviewed according to a standard AHP questionnaire and asked to estimate the importance of the selected landscape elements on the recovery of agricultural land. The experts were selected based on either their knowledge on the study area or the focal species requirements. There are several methods of aggregating individual judgments⁴; in this case we use the aggregation of individual priorities by Geometric Mean method (Forman and Piniwati, 1998).

3.3.3. Establishing positive and negative priorities in the AHP

Originally, the AHP evaluated the ranking of a few well-defined alternatives. Later, with the development of GIS methods, Carver (1991) and then Malczewski (1999) suggested applying Multicriteria Decision Analysis to the solution of the spatial problems. With this method, the linear additive function is accepted as an acceptable approximation to reality (Saaty, 1980;

Malczewski, 1999) and takes the form: $V_i = \sum_{i=1}^{i=m} w_i U_i$, where, in our case, V_i is a relative value

of the potential for wildlife restoration in each territorial unit; w_i represents the experts weighting of the landscape matrix object represented by spatial layers; U_i represents the values of each class of the landscape objects.

In our study we found it necessary to incorporate negative priorities in the AHP model. Originally the AHP technique did not consider negative priorities, and when they were found, they were incorporated in the models as small positive priorities. But it was observed that this kind of procedure led to some reversals of rankings in the results (Millet and Schoner, 2005).

⁴ The example of questionnaire and the divergences between the experts' answers are in the Annex.

Utilization of the Bipolar AHP (BAHP) is one possible way of dealing with negative priorities. Recognition of the natural zero concept is an obligatory condition of the BAHP procedure. As Stevens (1946) comments, the real ratio scale has a natural zero that can be interpreted as *lack of magnitude*. Saaty and Ozdemir (2003) advocate utilization of the negative priorities to deal with the costs and risks and the zero in the same mode. Since the *Expert Choice* software package that provides solution of the AHP/ANP problems does not deal with negative figures, forcing to the researcher to rethink its problem in a positive mode, we handle the problem without employing this routine.

In order to avoid the undesirable bias from the consideration of negative priorities as small positive numbers, we thus included the negative and positive priorities in the same model. Saaty and Ozdemir (2003) describe the theoretical backgrounds of this approach, while Millet and Schoner (2005) propose some practical ways to do it. Briefly, the technique that allows the possibility of incorporating the negative priority involves utilizing the AHP ideal mode (Saaty, 2005). This technique separates the positive and the negative priorities into two hierarchical structures that are added at the end of the procedure. The weight of each hierarchy is reached through the ratio of relative priorities. The ratio of relative priorities can be defined as "the absolute value of the relative preference of the extreme priorities values under each criterion" (Millet and Schoner, 2005, p. 3170). In some AHP cases, the separation of the positive and negative priorities into two hierarchies is not possible, since some criteria attain both positive and negative values (for example the observer's visual preference). In such cases, it is recommended to employ both negative and positive numbers in the same hierarchy. Since such cases did not occur in our study, we separated the positive and negative landscape objects into two hierarchies.

3.3.4. The sensitivity analysis

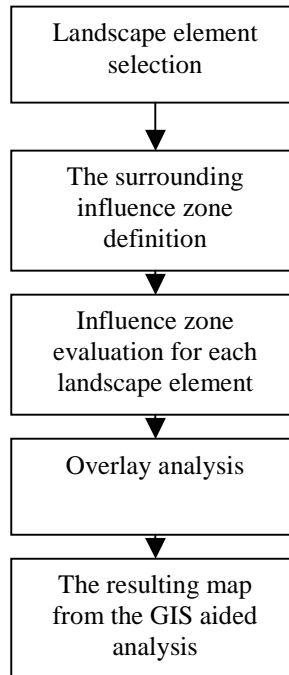
Performing a sensitivity analysis is recommended as a mean of checking the stability of the results due to the subjectivity of the expert judgments (Mészáros and Rapcsák, 1996). The most common method is to modify the weightings obtained from the experts. The assumption of equal weightings is also used for this purpose. The maps obtained from the sensitivity analysis are included in the Results section.

3.4. GIS-aided analysis

The analysis of the area of study on a territorial basis involves the use of GIS, which is defined as an information system for the management and analysis of geographical information, and the geographical information as an abstraction or representation of the real world (landscape) (Santiago, 2005).

The GIS software used as a platform for the representation, management and analysis of the spatial information was ArcGis 9.1. The input data were: land use map (1999; 1:50,000) corresponding to the study area (EGMASA, 2001); aerial monochrome orthophotos (2001-2002; 1:5000) and color orthophotos (2005; 1:10,000); yield map of the olive plantations (2004; 1:25,000); road infrastructure map (1999; 1:25,000). The materials were provided by the Cartography Service (Junta de Andalucía, 2004, 2005). All geographical materials are represented in European Datum 1950, Zone 30N (Spain and Portugal). Several trips to the study area were made with a GPS device, in order to check and if necessary, correct, the accuracy of the geographic information. Figure 1 shows the structure of the spatial problem to be solved.

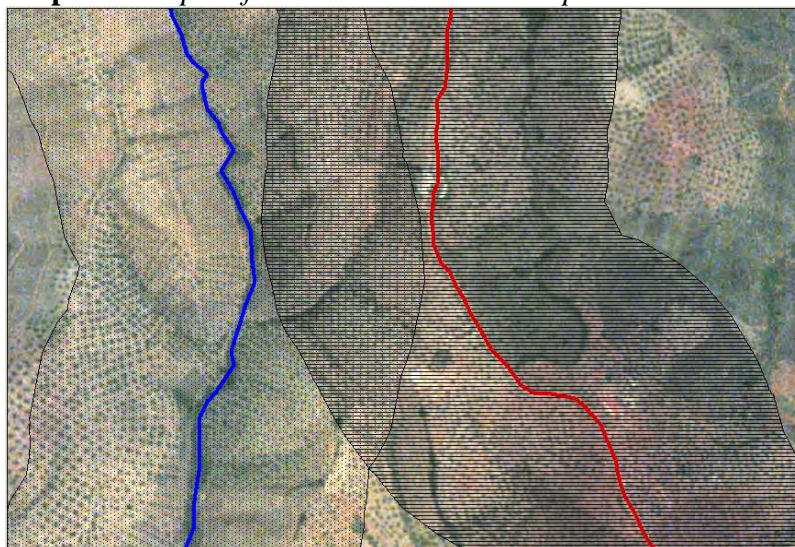
Fig. 1. *The structure of the spatial problem to be solved*



The second phase of the GIS analysis involves the definition of the size of the zone of influence. The distance (or size of the influenced zone) depends on the particular qualities of each landscape element. A decreasing influence as distance increases was assumed. A distance of 100 m was selected as the smallest possible due to the accuracy limitations of the cartographic information.

The third phase of the GIS analysis consists of the map layer overlays produced by the raster calculations from either the shape format or directly in raster mode. The type of geographical information data and the type of analysis determined the choice of format. The result is presented in raster format with a cell size of 10 m. An example of the methodology employed is depicted in the Map 3, with two layers (one river and one road), and one class (area of influence of 200-300 m) per layer.

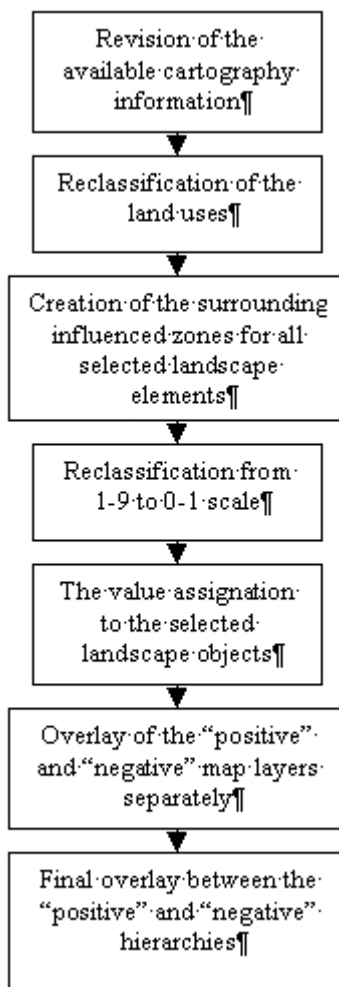
Map 3. *Example of the AHP-based landscape evaluation*



In this example of olive plantation landscape evaluation, there is an interaction of two landscape elements: a river (blue line) and a motorway (red line). Each landscape element has its own area of influence (dotted area for the river and striped area for the motorway). The interaction is marked with stripes and dots. In order to simplify the example, we assume an area of influence of 200-300 m (unlike the simulation model which considers decreasing areas of influence) for both elements (river and motorway). According to Tables 1 and 2, both rivers and motorways have values of 7 on the expert scale. This value is equivalent to a normalized value of 0.75 (see Table 3). Considering a ratio of relative priorities for positive and negative objects, 0.405 and 0.595, respectively (see Section 4.1) and the weight of rivers and roads, 0.33 and 0.27, respectively (see Table 4 and 5), their inclusion in the additive AHP function yields an interaction factor of $0.41*(0.33*0.75) - 0.59*(0.27*0.75) = -0.018$, with the negative sign indicating the overall negative effect of motorway on the potential for wildlife restoration.

As Figure 2 shows, the first step in the cartographic analysis is verify the accuracy of the geographical information. For this purpose the input maps and aerial photos were compared. On the basis of recent aerial photographs, an additional highway and an urban area were added, and some corrections to the size of olive groves were taken into account.

Fig. 2. Algorithm of map overlay analysis



The next step was the reclassification of the information presented in the land-use map. All existing land use types were classified into four groups: natural vegetation areas, agricultural lands, urban areas, and reservoirs and lakes. Other land occupants such as rivers, streams and roads were considered as line landscape structures.

We used the new land use map of the study area to generate the zones of influence surrounding the selected landscape elements. This operation was carried out through the ordinary routines of ArcGIS 9.1 called “buffer creation”.

For the AHP implementation it was necessary to normalise the values assigned to classes of each layer, on the basis of the following the formulae:

$$X_{normalised} = \frac{X_{raw} - X_{min}}{X_{max} - X_{min}}$$

where $X_{normalised}$ is the normalized rank value; X_{raw} is the raw rank value in the ordinary scale from 1 to 9; X_{min} is the minimum value of the scale utilized; and X_{max} is the maximum value of the scale utilized. The results appear in Table 3.

Table 3. *The results of the normalization from the ordinary 1 to 9 scale*

Old values	1	2	3	4	5	6	7	8	9
New values	0	0.125	0.250	0.375	0.500	0.625	0.750	0.875	1.000

The AHP ideal mode was implemented using the normalized values. The evaluation of classes for each layer makes the procedure more flexible and, at the same time, helps to avoid the possible irregularity in the results produced by using the “distributive” mode of the AHP technique, that is, the *rank reversal* phenomenon that sometimes occurs (Saaty, 1994; Millet and Saaty, 2000). The selection of the AHP mode has specific implications for spatial modelling using GIS: In the assessment of the territory each layer has a different number of classes to be evaluated. According this procedure, therefore, layers with more classes tend to reduce the value of each class since the total always equals one. To resolve this limitation, the ideal mode of AHP takes this irregularity into account. Thus, in the present study the expert judgements determine the value of each spatial layer (see Tables 4 and 5), then each class within the layer is given a value according to Tables 1 and 2, and this value is finally normalized in accordance with the weights of Table 3, where the sum is not 1 but a decreasing value according to the 1-9 scale.

For example, the layer of water bodies, according to the AHP expert evaluation, has a value of 0.3332 (see Table 4). This layer has five classes (see Table 1), with a range of relative importance between 5 and 9. The first class (500-400 m) is assigned a relative importance of 5; therefore, according to Table 3, this class has a weighting of 0.500. The final weight of this class on this layer is calculated by multiplying $0.3332 \times 0.500 = 0.1666$. However, the same class (500-400 m) on the layer of natural vegetation is weighted $0.2647 \times 0.375 = 0.0993$.

4. Results

4.1. The hierarchy of the problem and expert evaluation

As noted above, the positive and negative landscape objects were processed separately (Tables 1 and 2). Following the recommendations of Saaty and Ozdemir (2003) and Millet

and Schoner (2005). Six experts were then asked for their evaluation of the importance of the landscape objects in terms of its influence on the ecological diversity and wildlife habitat restoration. The aggregated judgements of the experts are presented in Table 4 for the positive landscape elements and Table 5 for the negative elements (see Annex for the elicitation procedure and experts' judgements).

Table 4. *Aggregated matrix of the experts' evaluation for the positive landscape objects*

	Water bodies	Natural vegetation	Natural Park area	Weights
Water bodies	1	1.21	1/1.16	0.333
Natural vegetation	1/1.21	1	1/1.58	0.265
Natural Park area	1.16	1.58	1	0.402

CR=0.0015; CI=0.0078; λ_{\max} =3.0016

Table 5. *Aggregated matrix of the experts' evaluation for the negative landscape objects*

	Urban areas	Roads	Agricultural plots	High power electricity lines	Weights
Urban areas	1	2.61	7.86	7.98	0.591
Roads	1/2.61	1	3.91	4.83	0.270
Agricultural plots	1/7.86	1/3.91	1	1.82	0.082
High power electricity lines	1/7.98	1/4.83	1/1.82	1	0.057

CR=0.0181; CI=0.0161; λ_{\max} =4.0483

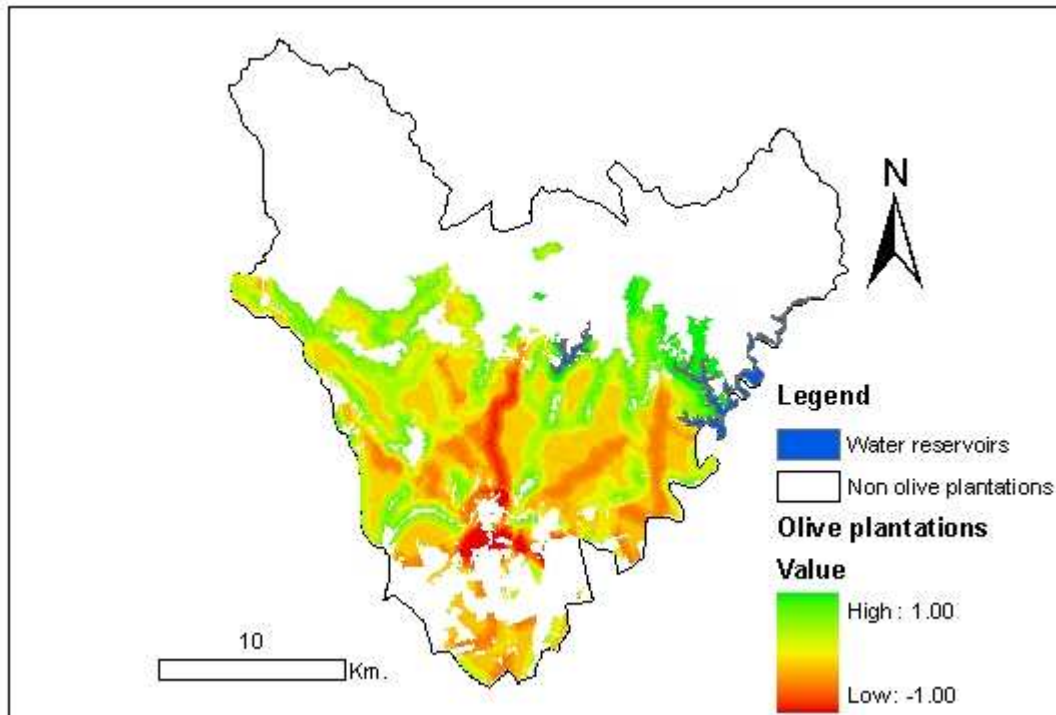
As Table 4 shows, Natural Park territory was evaluated as a more important landscape element with a 40% weighting, followed by Water Bodies with 33%. Natural Vegetation obtained the lowest weighting (27%). However, the maximum difference between weightings (less than 7%) suggests the absence of extreme preferences among objects.

On the negative side, Urban Areas, with a weight of 59%, was the most important element among the negative landscape objects (see Table 5). The next most important element was Road Infrastructure, with a weighting of 27%. Agricultural Plots (8%) and High-tension Power-lines (6%) were evaluated as less important as far as potential for restoration was concerned. Considering the absolute value of the relative preference of the extreme priorities 0.591 and 0.402 (see Table 5 and Table 4, respectively) the weight of the positive hierarchy is $0.402/(0.591+0.402)=0.405$, whereas for the negative hierarchy the value equals $0.591/(0.591+0.402)=0.595$.

Once each class has been assigned a value that depends on the layer on which it is located, the next phase of analysis consists of the calculation of the territorial values of the positive and negative hierarchies. This overlay analysis is provided via the linear weighted sum recommended by Saaty (1980) for classic AHP cases, and by Malczewski (1999) for Multicriteria Analysis in GIS, as discussed above.

The final phase overlays both the negative and positive areas of influence using the map algebra calculation in a raster layers analysis. Since the analysis considers negative priorities some parts of the resulting map have negative values. These values can be interpreted as implying a very low potential for wildlife restoration in this territory, due to the strong influence of negatively weighted human factors. The final map values range between -1.568 and 1.333. In order to compare scenarios in the sensitivity analysis and to make interpretation easier, the scale has been transformed into a more familiar -1, +1 scale.

Map 4. *The resulting map of evaluation of wildlife habitat restoration potential*



As Map 4 shows, the olive orchards close to the natural objects such as natural vegetation, water bodies (rivers, streams and reservoirs) and the Natural Park yield high positive values, indicating their relative suitability for wildlife habitat restoration.

4.2. Sensitivity analysis

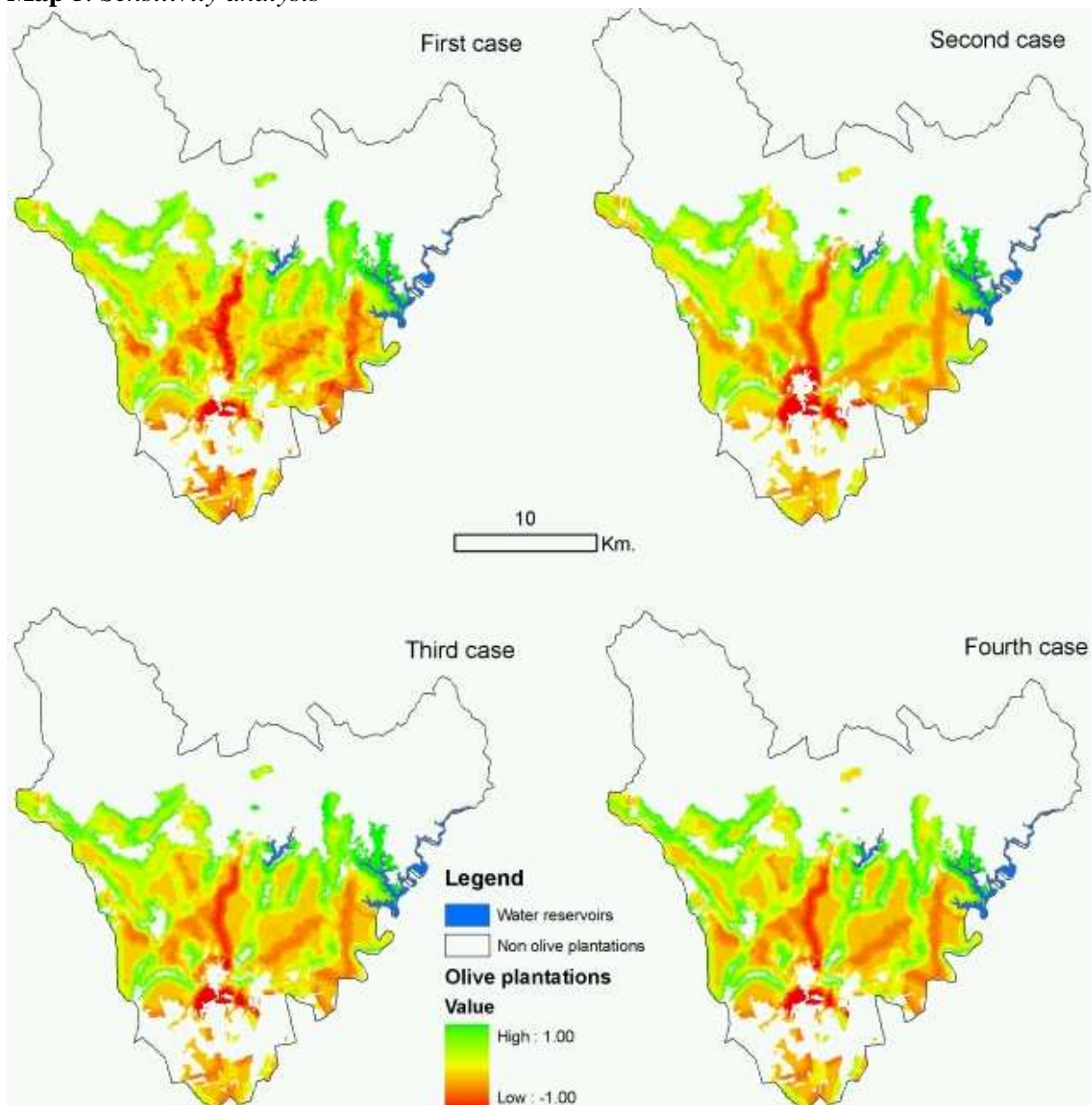
It is recommended in any Multicriteria Analysis that a sensitivity analysis aimed at answering the question “what if” should be performed. In this study the analysis addresses the question of the relative stability of the suitability maps vis-à-vis changes in the inputs. Another use of the sensitivity analysis would be to evaluate different territorial development scenarios. In our case, for example, it might analyse the effect of cancelling the Natural Park protection or assess the effects of a stronger influence of negative landscape objects. Among many possible scenarios, we selected four types of changes in the model (see Map. 5):

- Equal importance between the factors in each hierarchy (this would imply three weights of 0.3333 each in Table 4, and four weights of 0.2500 each in Table 5). This scenario is provided purely in order to check the stability of the model.
- The negative landscape objects are assigned greater importance than the positive ones ($w_n=0.7$; $w_p=0.3$). This sensitivity analysis assumes that negative landscape objects have a greater influence on the wildlife habitats ($w_n=0.7$) than the positive ones ($w_p=0.3$). These weights are transformed into 1 and 0.43, respectively, through the ideal mode of AHP.
- Among the positive objects’ hierarchical structure we switch the weights of natural vegetation and the Natural Park.
- The model omits the influence of the Natural Park protection.

The objective of the last two cases of the sensitivity analysis is twofold: First, to take into account the uncertainties and disagreements revealed by the experts during the AHP

evaluation. Second, to assess the effect of the environmental protection policy related to the Sierra of Cardeña and Montoro National Park.

Map 5. *Sensitivity analysis*



According to these four maps, it is reasonable to accept the stability of the model, since the changes observed in the potential for restoration of wildlife habitats of certain areas maintain the trend depicted in the initial model.

5. Discussion

Due to competition between human activities and wildlife for the same habitats in mountainous areas of Andalusia, it is important to be able to identify the most suitable areas for wildlife restoration now that the viability of many olive-growing areas is at stake. Although most studies claim that there is a lack of generalized models of ecological diversity and that it is impossible to apply the same indicator in different spatial-temporal scales (Waldhardt, 2003; Jeanneret et al., 2003), many studies offer the selection of suitable places

for either a particular species or for a group of species with similar habitat requirements, subject to a spatial-temporal scale (Store and Kangas, 2001; Pedersen et al., 2004; Van der Horst and Gimona, 2005).

The method adopted in this study is based on the consideration of the habitat requirements of several wild species and its relations with landscape matrix elements, whose theoretical background rises from Forman's (2001) land mosaic theory and the OECD studies on human influence on the environment ("man-made objects" indicators).

Geographical Information Systems play an important role in our study as a platform for the preparation, management and representation of spatial information. Once more, GIS have proved to be a valuable tool for any study at landscape level. Combining the potential of GIS with the AHP multicriteria analysis enables us to understand the potential value of the olive grove landscape for wildlife habitat restoration.

The concept of boundaries as a crisp or fuzzy concept is an important topic of discussion in landscape ecology. We assume that in real life there are no clearly defined limits for wildlife habitats. This is why we approximate the boundaries utilized in the model to a soft or fuzzy pattern. This was done by creating zones of influence for landscape elements bordering particular areas.

The major contribution of the presented approach is the consideration of the negative priorities in the AHP spatial model through the distribution of landscape objects into positive and negative hierarchies. In introducing the negative priorities we avoided possible errors that might have appeared as a result of transforming negative values into small positive priorities.

The model offered here can be easily modified and has relatively small input data requirements. This enables the model to be implemented in other parts of the world, always bearing in mind the conditions that apply to the specific site concerned. Furthermore, its results could be used as input for other types of analysis.

It is interesting to report some similarities between the results obtained in this study and those provided by Van der Horst and Gimona (2005), who used multicriteria spatial analysis to determine the most suitable territories in agricultural areas for the implementation of action plans for biodiversity. Unlike the present study, in which we analyse the potential of the area for the wildlife habitat restoration, these authors combine the requirements of 15 species as map layers, weighted according to the importance of each species. However, the results of both studies emphasise the importance of the edge zones of major agricultural areas, the riparian zones (in our case their natural vegetation) and areas adjacent to mature pinewoods (in our case the Natural Park with its oaks) as having the highest potential for wildlife habitat restoration.

Albeit the split of the landscape objects into positive and negative elements is a simplification of the complexity of their influence on the wildlife habitats, it seems a reasonable approximation in order to assess the possibility of restoration of agricultural lands with limited data availability. Likewise, the classification of forest, shrub and pasture into the same group ("natural vegetation") has the same purpose. We acknowledge that simplicity of these assumptions and relatively general nature of the input data. Notwithstanding, this approach can be used to identify *a priori* those areas for habitat restoration for generalist species in areas where proximity to human structures is a most important component of habitat

suitability. Also it can be used to assist in the finding of the areas that would be unsuitable for restoration (for example for the species highly sensitive to the human presence).

Other issue is the consideration of the low intensive agricultural plots into the group of negative objects: some authors claim that low intensive agricultural areas are very important for the preservation of wild species. Being that true by comparison with more intensive production systems, most of these areas were Mediterranean forests and transformed into olive plantations due to the production linked subsidy. Now that the subsidy has been decoupled, it seems more appropriate for the wildlife habitat to return to their original state.

Another issue worth to be commented refers to the subjectivity of the experts' opinions. Although their answers showed clear divergences, the Geometric Mean aggregation method (Forman and Peniwati, 1998) proved to overcome this limitation, as the sensitivity analysis seemed to suggest.

In addition to the sensitive analysis, we checked the validity of the results we selected at random eight plots that, according to the suitability map (Map 4), obtained the highest score. The visual assessment of these plots confirmed their suitability in terms of the non-existence of negative objects and the presence of positive ones.

Finally, the combination of the model presented here with the models based on empirical data for key species habitat suitability is an interesting line for future research. Other lines might involve utilization of non-linear functions such as multiplicative AHP. Consideration of the interdependences and feedback between the model criteria with the negative priorities via Analytic Network Process would be worth pursuing in future studies.

6. Conclusions

The present study provides a methodological approach to assessing the suitability of agricultural lands for habitat restoration. This methodology combines cartographic data with expert judgments about the effects of specific elements of the landscape on wildlife habitats.

The evaluation of potential is applied empirically to the olive groves of Montoro in Andalusia in southern Spain through a combination of AHP and GIS. The first technique provides weightings of the elements of the landscape for the spatial analysis based on defining areas of positive and negative influence for each matrix element. The GIS technology aggregates the layers of elements in order to determine the most suitable areas for wildlife habitat restoration.

From a methodological point of view, the use of the ideal mode of AHP avoids the bias that arises from the weighting of elements in each layer when the number of elements differs in individual layers. Consideration of negative priorities instead of their transformation into small positive priorities also gives the model more internal consistency and produces more accurate results that are in accordance with the preferences revealed by the experts. Also, the data requirements of this approach are less rigorous than those of classical statistical models based on historical data.

The sensitivity analysis indicates that the model is stable on the basis of the results of the four alternative scenarios considered. The simulation carried out in the study identifies the edges of major agricultural areas (mostly olive groves), areas of natural vegetation and areas

adjacent to Natural Park with oaks as being most suitable for wildlife habitat restoration. These results have similarities to those obtained by other researchers on ecological diversity, based on either individual or groups of species.

Finally, we must acknowledge the limitations of this analysis. The rather simple input data on species requirements makes this study a prior approach to a further analysis to spot suitable areas for focal species. Therefore, this approach is not a replacement for more careful analyses based on species-habitat associations and the proposed configuration and spatial extent of those habitats in a restored landscape.

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