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Restoration of abandoned agricultural lands toward habitats for umbrella species

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Abstract

This study analyzes the suitability of agricultural lands with risk of abandonment for restoration to suitable habitats for animal species of conservation interest. As a case study, the main focus was on olive plantations (*Olea europaea* L.) of mountainous areas of Southern Spain and the Iberian lynx (*Lynx pardinus* Temminck, 1827). The method weighs the judgement of experts on the effect of landscape elements on the habitat *via* an analytic hierarchy process and spots areas most suitable for restoration through geographical information systems. The results suggest that the edge of major agricultural areas and areas with natural vegetation adjacent to the Natural Park of Sierra de Cardeña and Montoro would be most suitable for restoration of the lynx habitat. The precise location of olive groves suitable for restoration are discussed, as revealed by experts' decision-making processes. The main interest of the study relies on the potential of the method to combine territorial analysis with biological requirements of endangered species to facilitate their dispersal.

Additional key words: analytic hierarchy process, AHP, GIS, *Lynx pardinus*, olive groves, Spain.

Resumen

Restauración de zonas agrícolas abandonadas para hábitats de especies de interés

El presente estudio analiza la idoneidad de zonas agrícolas con riesgo de abandono para su restauración como hábitat de especies animales de interés. Como caso de estudio se considera las plantaciones olivareras (*Olea europaea* L.) de montaña del sur de España y el lince ibérico (*Lynx pardinus*). La metodología pondera la opinión de un grupo de expertos sobre el efecto que los diferentes elementos del paisaje tienen sobre el hábitat del lince, integrándose posteriormente en un sistema de información geográfica. Los resultados sugieren que las zonas olivareras lindantes con el Parque Natural de la Sierra de Cárdena y Montoro y zonas con vegetación natural existente serían las más adecuadas para su restauración. Si bien la exacta localización de las zonas más adecuadas está sujeta a discusión, como demuestran las divergencias en la opinión de los expertos, el interés principal del estudio radica en la potencialidad del enfoque metodológico, el cual combina el análisis territorial y requerimientos biológicos específicos, para la conservación y dispersión de especies de interés.

Palabras clave adicionales: España, *Lynx pardinus*, plantaciones de olivar, proceso analítico jerárquico, sistema de información geográfica.

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Abbreviations used: AHP (analytic hierarchy process), AR (asphalted roads), CAP (Common Agricultural Policy), CI (consistency index), CR (consistency ratio), EU (European Union), GIS (geographical information system), GV (grass vegetation), ILWIS (Integrated Land and Water Information System), NP (natural park).

Introduction

Recently EU agricultural and environmental policy has been orientated toward changes in European landscape structure. In some countries this has led to agricultural intensification (Central and Eastern Europe). In other countries it has led to agriculture becoming more extensive (this was intensified after loss of subsidies implemented by the EU Mid Term Review of the Common Agricultural Policy, CAP). It also led to agriculture being abandoned on low productive uplands (Mühlenberg and Slowik, 1997; Wolters, 1999). This latter process is important in Mediterranean upland olive (*Olea europaea* L.)-growing systems.

Conversely to what could be expected, spontaneous abandoning of olive plantations without any control measures may not lead to an improved the wildlife habitat (Henle *et al*., 2008). Further, the impact, of the process on the visual quality of the landscape is not clear (Höchtl *et al*., 2005).

This study addresses the question of which agricultural areas are most suitable for wildlife habitat restoration. The European Union's Council Directive 92/43/EEC on conservation of natural habitats of wild flora and fauna (Habitat Directive, EEC, 1992) obliges all member states to conserve and restore key habitats and species. The approach proposed in this study focuses on one key species or "umbrella species", the Iberian lynx (*Lynx pardinus*). The Iberian lynx is included in the Annex of Habitat Directive 92/43/EEC as a priority species. Currently the Iberian lynx is the most seriously endangered species of all the felids, is recognized as critically endangered by the World Conservation Union (IUCN, 2002), and as the most threatened carnivorous species in Europe (Nowell and Jackson, 1996; Delibes *et al*., 2000; Guzmán *et al*., 2004). It is on the brink of extinction due to a low total population and a highly fragmented distribution (Rodríguez and Delibes, 1992, 2002). Its distribution is restricted to the Iberian Peninsula.

The recent trend to abandon agriculture in mountain areas has not improved the lynx's habitat. The dense shrubs that occupy abandoned agricultural land are a very poor habitat for rabbits (*Oryctolagus cuniculus* L.) the main prey of lynx. Thus, restoration measures in abandoned olive groves should be carefully planned to meet lynx habitat requirements (Palomares *et al*., 2001; Fernández *et al*., 2006): restoration of dense shrub patches to 40-50% of the total surface; preservation of the old growth bush species; control and avoidance of human or natural disturbance (fire, clearance, hunting). Long-term conservation of restored areas should be guaranteed. Other wild species that could benefit from this type of habitat restoration are: wild boar (*Sus scrofa* L.), red deer (*Cervus elaphus* L.) and red fox (*Vulpes vulpes* L.) as mammal species with similar habitat requirements. Among scrubland and forest species that could benefit from the restoration are: strawberry tree (*Arbutus unedo* L.), mastic (*Pistacia lentiscus* L.), Kermes oak (*Quercus coccifera* L.) and tree heath (*Erica arborea* L.); Holm oak (*Quercus rotundifolia* L.), Portuguese oak (*Quercus faginea* L.), cork oak (*Quercus suber* L.) and sessile oak (*Quercus pyrenaica* L.). This last species is only recorded at the Natural Park of Sierra Cardeña and Montoro. Substantial diversity increase only occurs a long time after agricultural activities cease.

The aim of this paper is to present an original method of approach that combines the analytic hierarchy process (AHP) (Saaty, 1980; Malczewski, 1999) and geographical information system (GIS) technology, to spot suitable agricultural areas for wildlife habitat restoration. Consideration of the requirements of the Iberian lynx as a species example highlights the potential of this approach for policy makers. However, this is a simplified analysis of lynx requirements and the influence of the landscape elements on its survival. An accurate result map for the lynx would require more precise information on these aspects.

Study area

As Figure 1 shows, the municipality of Montoro is located in the Province of Cordoba in southern Spain, and lies between 4º33'; 4º9' W and 38º16'; 37º57' N and has a variety of agricultural ecosystems (pasture, olive groves and annual crops) and forest/shrub natural vegetation near the agricultural areas. Elevations range from 140 m to 790 m a.s.l. Of the area 58,103 ha (34.2 %) are in olive groves. The reminder is in arable crops (8.1%), forest (17.5%), scrubland (28.7%), *dehesa*[1] and other pastures (8.7%), water reservoirs (1.1%), urban area and

[1] *Dehesa* is grassland with scattered trees and well-developed herbaceous formations (Spanish Society for Pasture Research). This agrosilvopastoral system is characterized by a savannah-like physiogronomy (Martín and Fernández, 2006).

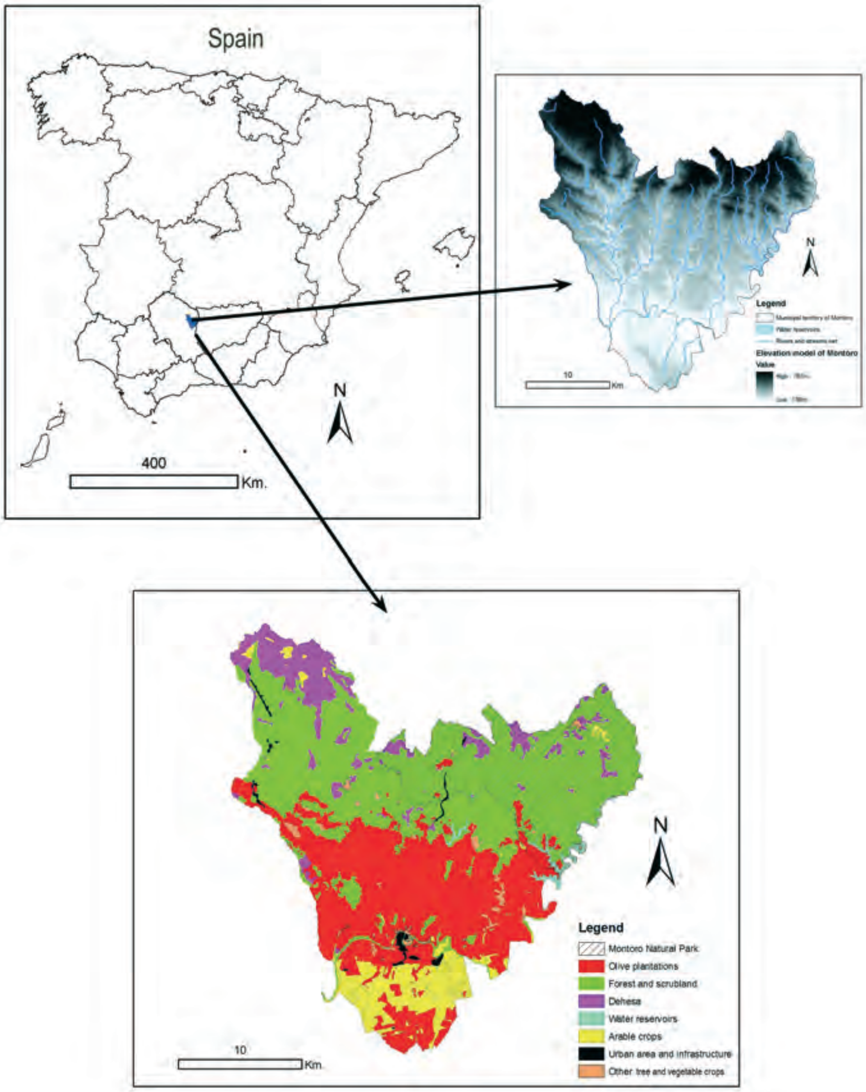

Figure 1. Location, physical and land use maps of Montoro (Córdoba).

infrastructure (0.8%) and other land uses (1.0%). The Natural Park of Sierra Cardeña and Montoro occupies 26% of the municipality.

The central and northern parts of Montoro are mostly highlands with steep slopes that make agriculture difficult and expensive. For this reason, most agricultural production in this region is based on extensive olive groves and pasture.

The study area adjoins the lynx core population located in the Sierra Cardeña and Montoro. Previous studies have suggested that neighbouring areas of this park potentially meet the requirements of the lynx (Junta de Andalucía, 2004a; Fernández *et al*., 2006). However, both proximity but and habitat structure are essential to use olive groves for lynx dispersal (Palomares *et al.,* 2000).

Methods

The method used involved three phases:

- first, an inventory of Iberian lynx habitat requirements was drawn up;
- then, the AHP method was implemented based on experts' knowledge;
- finally, GIS technology was used to assess the potential of the study area for Iberian lynx's habitat restoration.

Selection of landscape elements related to Iberian lynx habitat requirements

The main causes that have brought the Iberian lynx to the border of extinction are habitat alterations and removal, a reduction in the number of rabbits (the main lynx's prey) and human activity, such as illegal hunting and traps (Rodríguez and Delibes, 1990; Delibes *et al*., 2000). In this study, the main focus is habitat alteration and, according to several studies (Delibes *et al*., 2000; Junta de Andalucía, 2004a), the elements and their influence area included in the analysis are (Table 1):

-Considering the influence of each landscape element, *urban areas* clearly have a negative impact on the lynx habitat since they impede species dispersal species and increase the risk of human disturbance (Whitford *et al*., 2001; Jones and Paine, 2006; Palomino and Carrascal, 2007). This landscape factor was therefore treated as a constraint (non-compensatory criteria) and areas closer than 2 km from urban areas, as a tentative distance, were excluded from the evaluation.

-*Sealed roads* have a negative impact due to the risk of being run over (Ferreras *et al*., 1992; González-Oreja, 1998) and potential limitation of movement on fenced roads. These two aspects drove the classification of roads into three groups. It was considered that an influence zone of 1 km was less desirable for all types of roads (see Figure 2a). Further, reflecting higher traffic density on the first two types of sealed roads a 500 m-wide strip on both sides of the road was taken for the first type of motorway and of 250 m for the second type as constraints (non-compensatory criteria). Such areas had the lowest relative value (red areas on the map of results). As Figure 2a shows, the further the distance from a road the higher the positive effect (higher utility value in the map). However, a stable and maximum standardized value of 1 in this case is reached at 1 km from the road. At this distance the negative influence of a road is assumed to be exhausted.

-All olive groves were classified according to the presence or absence of grass cover. Olive groves with grass cover were considered suitable habitats (value of 1), while those without grass were regarded as potentially less suitable habitats (value of 0). Albeit this is a circumstantial temporal fact, olive groves with grass cover were pesticide free, in most cases. They are controlled

Table 1. Influence of landscape objects on lynx habitat requirements

Landscape objects	Remarks
Urban areas	Main urban areas situated in the study area. A negative effect is expected on the surrounding area of 2 km due to disturbances from human activities. Treated as a non-compensatory criterion (excluded from restoration).
Sealed roads	Motorway (two lanes each way, fenced road): 0 - 500 m on both sides is a non-compensatory criterion. From 500 m to 1000 m there is a decreasing negative effect. From 1000 m zero effect. Main sealed roads (single lane each way, fenced roads): Similar for 0 - 250 m, 250 - 1000 m and beyond 1000 m. Other sealed roads (non-fenced): 0 - 1000 m, decreasing negative effect; >1000 m, zero effect.
Olive groves with or without vegetation cover	Represents the study area subject of the evaluation, consists on a mosaic of agricultural area with different type of agricultural practices (more or less intensive with or with out grass cover). A positive effect is expected.
Currently existing vegetation formations: • Edges between scrubland and pasture, • Mediterranean forest, • Scrubland, • *Dehesa* and other pastures.	Non-linear decreasing positive effect is expected.
Natural Park of Sierra de Cardeña and Montoro	The positive influence of the Natural Park is considered to be up to 19 km.
Water bodies (stream, rivers, reservoirs)	Streams, rivers and reservoirs. 0 - 1000 m, decreasing positive effect; >1000 m, zero effect

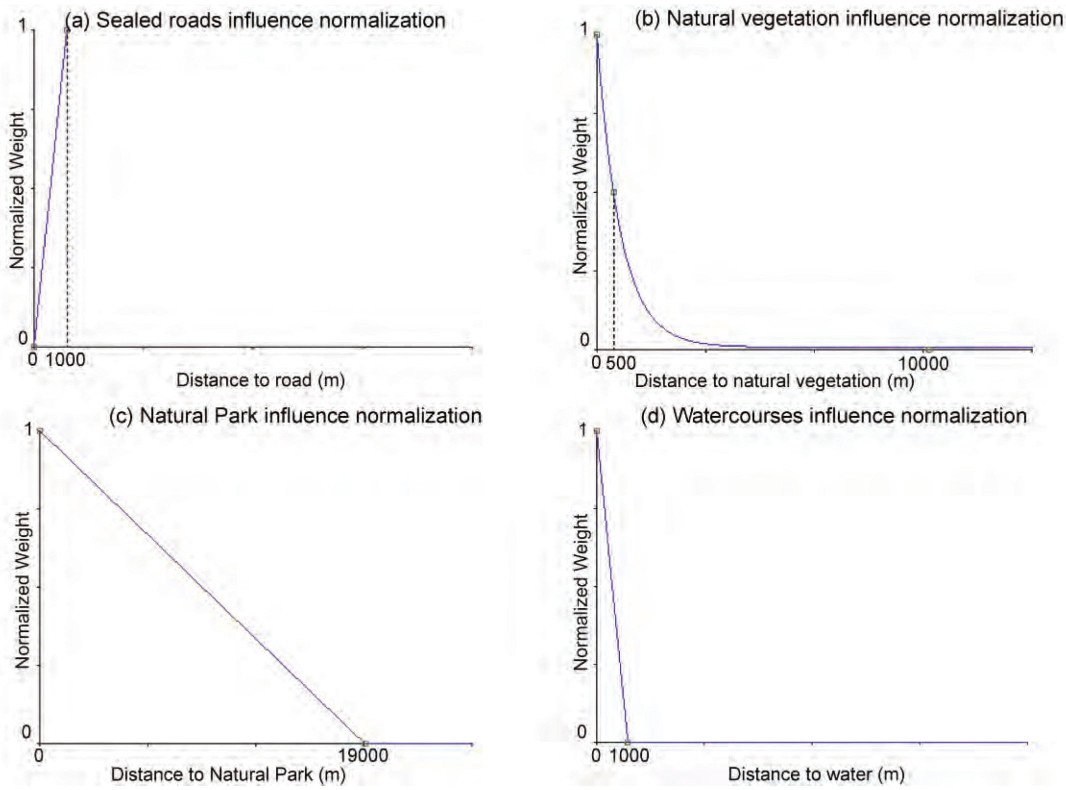

Figure 2. Priority functions. The figure depicts the procedure for normalization of distances for each landscape object on a scale from 0 to 1 via the priority functions, a necessary requirement of the analytic hierarchy process multicriteria evaluation.

by either ruminants or machines, and provide food for rabbits. These factors make them more suitable than groves without grass cover.

-Natural vegetation considered was Mediterranean forest (it included riparian vegetation), scrubland, *dehesa* and other pasture and borders between scrubland and pasture. The pinewoods of the Sierra Cardeña and Montoro, near the border of the olive groves, were excluded from the natural vegetation group due to their poor suitability as a lynx habitat (Palomares *et al*., 2001). The importance of each type of vegetation was studied by Fernandez *et al*. (2003), who concluded that the borders between scrubland and pasture are the most suitable places (58% importance), followed by scrubland (29%), *dehesa* and pasture (9%) and forest vegetation (4%). The underlying aspects in considering the influence zone of natural vegetation are:

- The minimum home range size for one adult animal.
- The dispersal and colonization potential of the species.
- The positive influence at the edges of scrubland and pasture which benefit the rabbit population.

Detailed information on home range size and social organization can be found in Ferreras *et al*. (1997), Gaona *et al*. (1998), Delibes *et al*. (2000) and Palomares *et al*. (2001). With regard to the first factor, Delibes *et al*. (2000) pointed out: “adult lynx usually occupy stable home ranges that measure between 4 and 20 km^2”. They also conclude that the size of the home range generally depended on the rabbit population density. Similar results are presented by Palomares *et al*. (2001). For example, in the Doñana National Park the average home range for a female is 12.6 km^2 where the rabbit density is low (Ferreras *et al*., 1997), and 5.3 km^2 where the rabbit density is high (Palomares *et al*., 2001). In Sierra Morena the home range size of an adult female was 5.4 km^2 (Delibes *et al*., 2000). The smallest area that might be worth restoring should therefore be in agreement with this requirement.

Despite a lack of studies on lynx dispersal in the Andujar and Cardeña-Montoro Natural Parks, according to Ferreras *et al*. (2004), based on a study in the Doñana National Park, the dispersal potential of lynx was estimated as 38 km from their birth place territory. Due to the proximity of the study area to the lynx’s population core (see Figure 3), this criterion did not present a limitation. This priority function is shown in Figure 2b, in which the value decreases as the distance to existing vegetation patches increases. At 500 m the function reaches a normalized value of 0.5, from 500 m to 10 km, approximately the border of the study area, it gradually decreases to 0.

-A further important landscape object that was considered in the evaluation was the influence of the Cardeña and Montoro Natural Park (NP). Legislation protects wild animals in general and the Iberian lynx in particular (BOJA, 2003). The park can therefore be regarded as a suitable habitat and its enlargement would therefore be desirable.

Due to a lack of studies on the effect of such land use on lynx habitat, reliance was placed on the opinion of experts on this point. Their answers did not give a unanimous decision on this influence, but the general idea was that the protection of the park enhances species dispersal. Since the lynx population core is situated in the northeast of the Montoro Municipality (see Figure 3), as Rodríguez and Delibes (1992) stated, and a dispersal potential of 38 km is assumed, the lynx would need about half of that to cross the park, giving a migration potential from the border of 19 km. Figure 2c shows the priority function for the area of influence of the Natural Park. As can be seen utility decreases in value as distance from the Natural Park increases. The minimum value is reached at 19 km. Although the linearly decreasing function is a simplification of reality, it meets the suggested monotonically decreasing criterion of the exponential decreasing function found in Rodríguez and Delibes (2003).

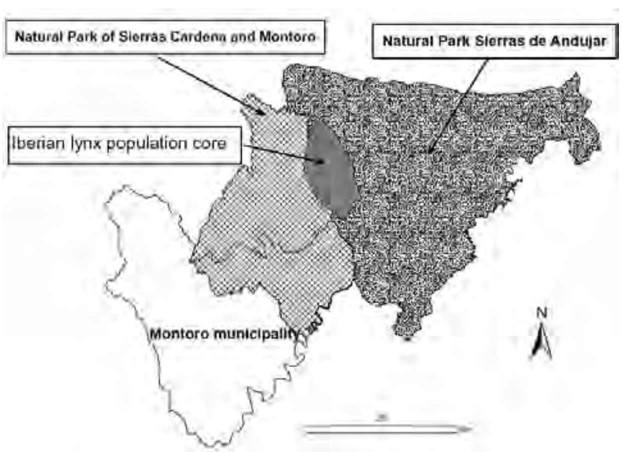

Figure 3. Map of the core lynx population in the Natural Parks of Cardeña and Montoro and Sierra de Andujar.

-The final landscape objects considered in the model were watercourses. Areas adjacent to watercourses have important ecotones represented by the interface of riparian vegetation and adjacent areas (Malanson, 1993; Naiman and Decamps, 1997). Areas adjacent to watercourses can be used as green corridors that allow migration of wild species (Naiman *et al.*, 1993; Shields *et al.*, 2003). These authors suggest a general distance of 1 km as the positive area of influence. The model uses this figure for the lynx case (Figure 2d).

Some of the well-known lynx requirements were not proposed to the experts for their ranking (i.e. rabbit abundance, den structure, human disturbance). However, most of them were indirectly considered due to their relationship with the other landscape elements. Thus, rabbit abundance is partially included in the model with the higher suitability of borders between scrubland and pasture. Likewise, human disturbance is related to the proximity of urban areas and roads, both included in the analysis. By accepting this simplification, the AHP decision exercise remained within recommended limits.

Analytic hierarchy process multicriteria decision-making technique

The AHP algorithm description

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

If it is assumed 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 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 be solved is to find the vector of weights W from the A matrix. This kind of problem is 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; Saaty and Vargas, 2000; Forman and Selly, 2001). In this study the MATLAB platform is used with the free extension of Scott (2001) for mathematical computation. The ideal mode of AHP (Saaty, 2005) is the approach followed in the simulation.

Checking response consistency

The above algorithm for solution of the eigenvector problem is applied only in the case of total consistency of the Pair-Wise Comparison Matrix. Generally, 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} is to n, the more consistent is the judgment recollected previously in the Saaty matrix. Thus, the difference λ_{max}-n could be used as an indicator of the degree of inconsistency (the difference should be zero for a completely consistent matrix). Alternatively, the Consistency Index (CI) and the Consistency Ratio (CR) have been proposed as consistency indicators (Saaty, 1980, 2003; Saaty and Vargas, 2000). Both of them must be lower than 0.1. This means that the inconsistency of the responses should not exceed of 10%. An inconsistency of between 0% and 10% can be regarded as normal. In cases where CR > 10% the responses should be revised in detail and the evaluation questions repeated until CR < 10%.

It is generally accepted that a linear additive function as an approximation of reality (Saaty, 1980; Malczewski, 1999): $V_i = \sum_{i=1}^{i=m} w_i U_i$, where, in this case, V_i is a relative value of the potential for wildlife restoration in each territorial unit (in this case is each cell of 10 x 10 m); w_i represents the experts' weighting of the landscape matrix object represented by spatial layers and U_i represents the values of each class of landscape objects.

The AHP questionnaire and aggregation of decisions

The opinion of ten experts on Iberian lynx behaviour and agricultural landscape management were collected[2] using a typical AHP questionnaire (see example in the annex). Their professional profiles are:

- Experts 1, 4 and 5: Technicians involved in the LIFE restoration programme[3].
- Experts 2 and 3: Researchers on agricultural landscape management.
- Expert 6: Member of the Plant Biology Department, University of Cordoba and participant in the LIFE LINCE programme.
- Expert 7: Former director of the Cardeña and Montoro National Park.
- Expert 8: Environmentalist and participant in the LIFE LINCE programme.
- Experts 9 and 10: Biologists researching Iberian lynx.

At the start of the personal interview the objectives of the study and the definition of each landscape object were presented. After obtaining the weight for each landscape object (see "Description of the AHP algorithm") each expert was interviewed again and asked: "Do you agree with the relative weight attached to each landscape object from your answers?" if he/she agreed the weights were used. In the case of a disagreement, the questionnaire was repeated, and the results re-confirmed.

There are several methods for dealing with group decision-making (Forman and Peniwati, 1998; Jankowski and Nyerges, 2001). Due to discrepancies in the experts' opinions, the Aggregation of Individual Priorities by Geometric Mean method was chosen (Forman and Peniwati, 1998, p.168; Aull-Hyde *et al*., 2006).

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[2] Some additional potential candidates for evaluation were discarded during an initial personal interview after because they had little experience of the topic.

[3] European project LIFE 02 NAT/E/8609 "Recuperación de las poblaciones de lince ibérico en Andalucía" (Restoration of Iberian lynx populations in Andalusia).

Sensitivity analysis

Performance of a sensitivity analysis is recommended to check the stability of the results due to subjectivity in the experts' judgments (Mészáros and Rapcsák, 1996). The most common method is to modify the weight of the objects obtained from the experts. The assumption of equal weights is also used for this purpose. The maps obtained from the sensitivity analysis are presented in the results section.

Geographic Information System - aided analysis

Databases and software

The GIS software used as a platform to represent, management and analysis of the spatial information was ArcGIS 9.1 and ILWIS 3.4[4] (Integrated Land and Water Information System). The spatial multi criteria evaluation was carried out in ILWIS 3.4. SMCE module. 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 colour orthophotos (2005; 1:10,000); olive grove productivity maps (2004; 1:25,000) and a road infrastructure map (1999; 1:25,000). Materials were provided by the Andalusian Autonomous Government Cartography Service (Junta de Andalucía, 2004b, 2005). All geographical materials are represented in European Datum 1950 30N (Spain and Portugal). Several trips to the study area were made with a GPS device, to check, and if necessary, correct the accuracy of the geographic information.

Obtaining the resulting map through overlay analysis

The first step in the cartographic analysis was to verify the accuracy of the geographical information. To do this input maps and aerial photographs were compared. Based on recent aerial photographs, new highway and urban areas were added, and some corrections to the size of olive groves were taken into account.

The next step was to reclassify the information in the land-use map. All existing land use types were classified into four groups: natural vegetation areas, olive groves, urban areas, and reservoirs. Natural vegetation areas were subdivided into four classes (Table 1). Other land use, such as rivers, streams and roads, were treated as linear landscape structures. Considering the objective of the study, agricultural land use which did not involve olives was not analyzed. Olive groves were reclassified according to management type i.e. with or without grass cover).

A hierarchy structure with five criteria, four sub-criteria for natural vegetation and four constraints (Table 1) was built. The reclassified land use map of the study area was used to generate zones of influence surrounding selected landscape elements (except olive groves). This operation used the ordinary routines of ILWIS 3.4 called "distance calculation". Once all "distances" had been calculated the method continues standardizing each criterion via priority functions (see Figure 2). The next operation was the assignment of weights to each landscape element. Finally, it is performed a raster overlay analysis to obtain the result map, in which the index value for each pixel is calculated.

The 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 results are presented in raster format with a cell size of 10 m.

Results

Divergence among weights obtained from the experts' answers

The weight attached to each landscape element derived from the experts' answers and the aggregation through the geometric mean is shown in Figure 4.

As expected, there were some differences in the experts' weights. Compared with the geometric mean, both biologists (Experts 9 and 10) place a lower weight on the proximity to sealed roads and a higher weight on existing natural vegetation. The experts involved in the lynx LIFE project (1, 4, 5, 6 and 8) had a greater disparity in their responses. Overall, the experts can be grouped into two categories: Experts 2, 3, 4, 7 and 8, who assigned a very high importance to the influence of sealed roads (at least 37%) and the others, who assigned great importance to the influence of the current vegetation types (at least 41%).

The most important landscape objects were: natural vegetation structures (32%), proximity to sealed roads

[4] ILWIS 3.4 Open is open software developed at ITC (Enschede, Netherlands) and is freely available from www.itc.nl.

(28%), the proximity to the Natural Park (18%) and proximity to watercourses (14%). Olive groves, with vegetation cover, had the lowest weight (8%).

Figure 4 shows, the Consistency Ratio (CR) for some of the experts was greater than recommended (0.1). To validate the weights obtained from the experts with a high CR the following verifications were implemented:

i) all experts were interviewed again and asked to confirm the weights obtained from their answers. In the case of disagreement the interview was repeated. Only confirmed weights were used in the subsequent analysis.

ii) The aggregation of judgements via the geometric mean was provided and subsequently the CR of this aggregated matrix was calculated (CR = 0.003). This suggests that the CR of the aggregated matrix was acceptable and the weights obtained could be used in the analysis (Aull-Hyde *et al*., 2006). The use of weights obtained from the experts was justified, it is implemented the verification procedure to all experts with CR higher than 0.1.

The red spot in the centre of the resulting map (Figure 5) is the urban area and is regarded as a constraint (non-compensatory criteria). The red lines passing through the map represent two motorways that have high traffic levels. The maximum suitability value in the study area was 0.92, the minimum was 0 and the mean was 0.46 (on a 0 - 1 scale). The green on the map represents areas suitable for the implementation of restoration measures. All are situated to the North of the motorway A-IV. Some suitable areas are too small (< 2,000 ha) for supporting lynx breeding (the model does not take into account a minimum area size). In these cases, their connection through habitat management could be useful for enlarging the existing Andújar-Cardeña population.

As the divergence in the opinions of the experts raised a considerable uncertainty about the reliability of the result, it was decided to perform a sensitivity analysis on the results.

Sensitivity analysis

A sensitivity analysis is recommended in any multicriteria analysis. It is aimed at answering the question "what if". In this study what is questioned is the stability of the suitability map with respect to the weight of landscape elements. From many possibilities, four types of changes in the model were selected:

i) Equal importance given to all landscape elements. This scenario would be equivalent to assumption of a zero value of the parameters in the regression analysis to check the model utility.

ii) The weights of Expert 4 instead of the geometric mean. This expert assigned the highest impor-

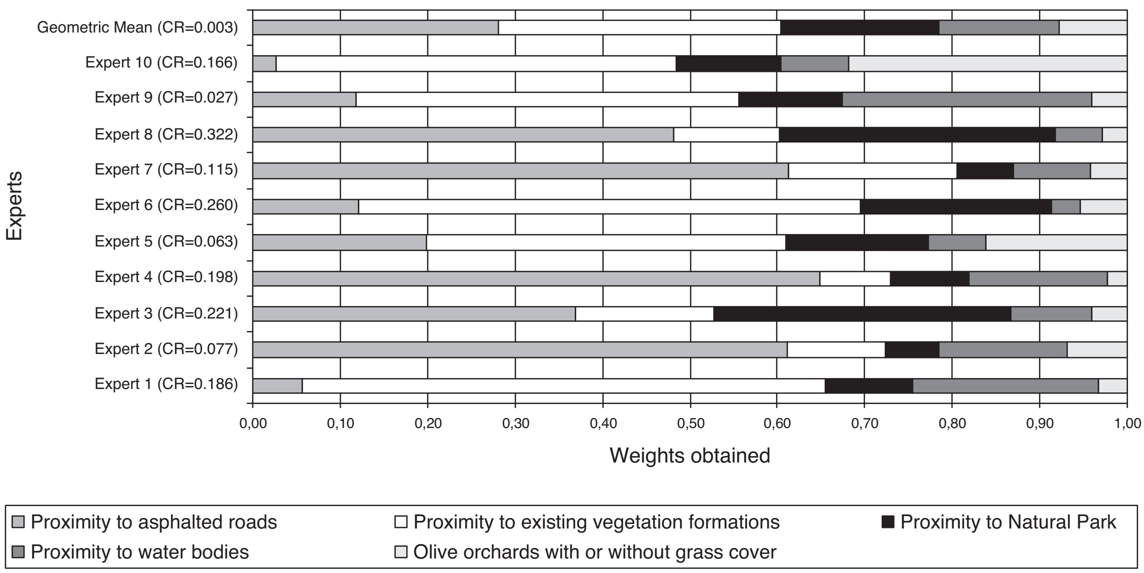

Figure 4. Divergences among experts' landscape element evaluations. CR is the Consistency Ratio. It is obtained from Saaty matrices composed by the experts' answers.

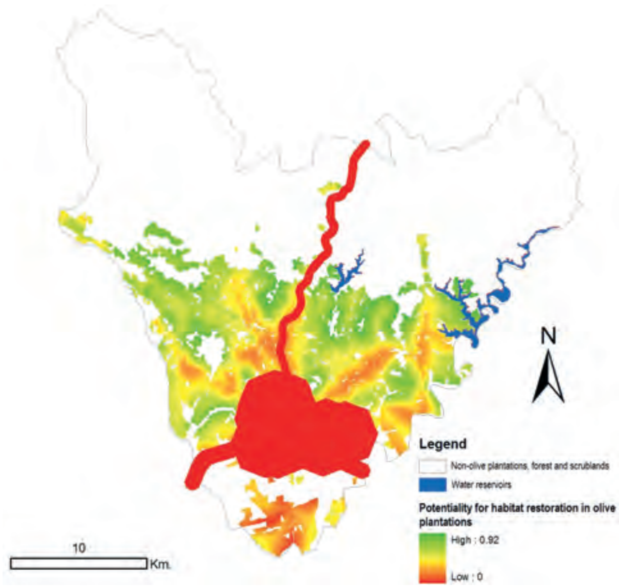

Figure 5. Evaluation of Iberian lynx habitat restoration potential for olive groves. On the map, red indicates low suitability in olive groves for habitat restoration, yellow intermediate and green high suitability. The results are represented as a continuous data. There are no cut-off points, the closer the value is to 1 the more suitable the area for restoration.

tance to sealed roads (0.65) and can be considered as a representative of the first group of experts (2, 3, 4, 7 and 8).

iii) The weights of Expert 10 instead of the geometric mean. This expert assigned high importance to the influence of existing vegetation formations (0.46) and can be considered as a representative of the second group of experts (1, 5, 6, 9 and 10).

iv) The influence of Natural Park was omitted. This scenario arises from some doubts expressed by some experts about the adequacy of including this element.

Comparing the first scenario, some similarities were found with the results map (Figure 6). Assigning an equal weight to all elements (Figure 6a) produced a higher area suitable for restoration, in the northwest, North-centre and north-eastern part of the map. Considering the alternative weights provided by the group of experts that place high importance to sealed roads (Figure 6b), the map, logically, is more restrictive in and around the roads but the overall analysis shows a higher percentage of land suitable as a lynx habitat. Conversely, the weights corresponding with the expert that put n first place the influence of the existing vegetation formations (Fig 6c) gave a much lower area suitable for restoration. The last map (Figure 6d), omitting the influence of the park, suggested, as did some of the experts that this element was of little importance in the analysis.

Discussion

The mountain olive groves of Montoro are a low-input agricultural system that could easily be returned to their natural state. This would improve habitat quality for wild species in general and for the Iberian lynx in particular. The latest reform of the EU CAP opens up the possibility of returning part of agricultural land (olive groves, in this case) to its natural state. However, identification of areas that could be potentially valuable as a wildlife habitat is an important exercise at the local scale.

Although most studies claim 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), others offer a selection of suitable places for either a particular species or for a group of species with similar habitat requirements, subject to a spatiotemporal scale (Store and Kangas, 2001; Pedersen *et al.*, 2004; van der Horst and Gimona, 2005).

This research adopted the latter methodology and evaluated olive groves in Montoro as a possible habitat for Iberian lynx. The location of the Montoro olive groves near one of the two last population cores of the Iberian lynx justifies consideration of the requirements of this wild species which is on the brink of extinction. In doing this the methodology moves from the wildlife habitat approach to the use of one umbrella species: the Iberian lynx. Simberloff (1998) raised questions about the use of flagships and keystones species for ecosystem conservation. Notwithstanding, this an indicator cannot be generalised to cover all Andalusian olive groves due to the special characteristics of the study area (its proximity to the main lynx population). For this reason, other indicator species should be used to generate similar evaluations for other areas.

The approach adopted in this study could be of use in programmes of lynx reintroduction, particularly in areas where experimental data are scarce. Identifying an indicator species of local importance, such as the Iberian lynx in this case, would enable the approach suggested here to be extended to any European territory. Mechanisms for offering social and economic incentives to regenerate optimal habitats for lynx, or other wild species, could be introduced.

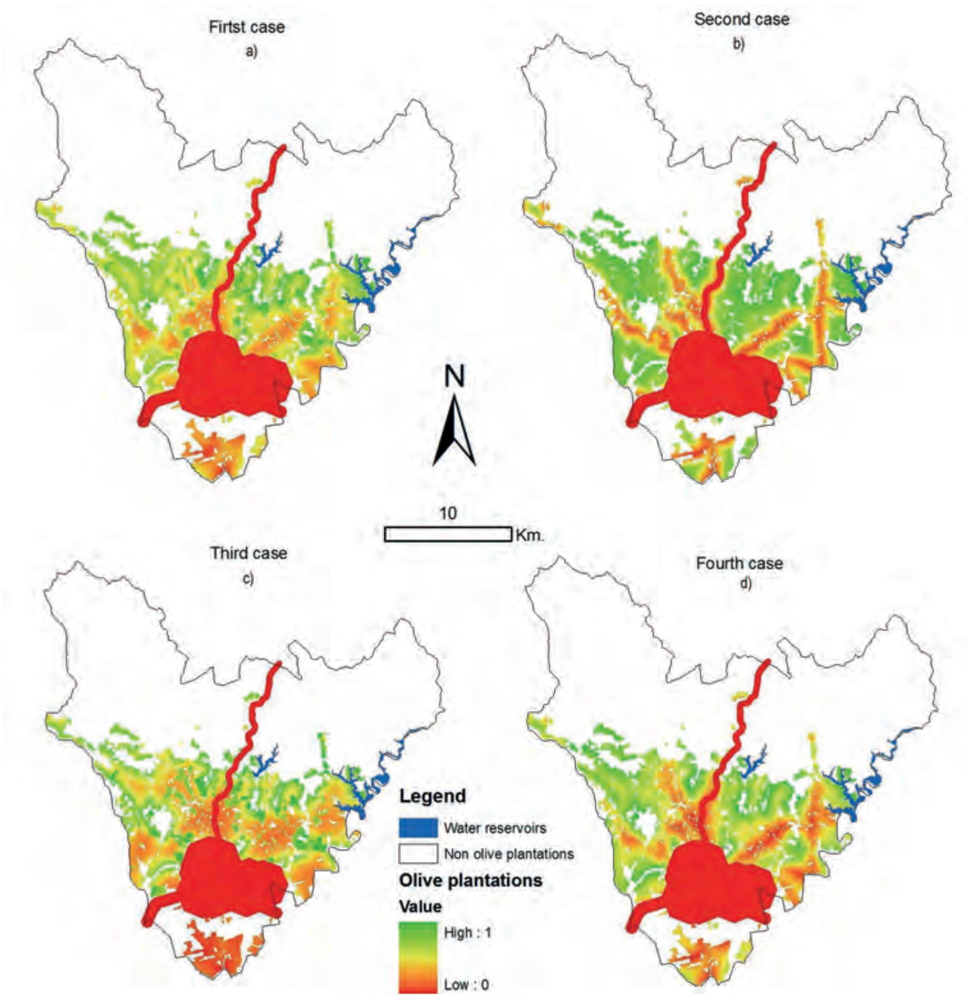

Figure 6. Sensitivity analysis maps. The results of four types of change are represented. a) First case: equal importance of all landscape elements; b) Second case: weights of Expert 4 were used instead of the geometric mean; c) Third case: weights of Expert 10 were used instead of the geometric mean; d) Fourth case: the influence of the Natural Park was omitted.

There are some similarities between the results obtained here and those of van der Horst and Gimona (2005), who used multicriteria spatial analysis to determine the most suitable territories in agricultural areas for implementation of action plans to promote biodiversity. Unlike this study, these authors combine the requirements of 15 different species as map layers, weighted according to the importance of each species. However, the results of both studies emphasise the importance of edge zones of major agricultural areas, riparian zones (in this case the natural vegetation) and areas adjacent to natural pinewoods (in this case Mediterranean forest and shrub lands) as having the highest biodiversity potential.

Geographical Information Systems data played an important role in this study as a platform for the preparation, management and representation of spatial information. Once more, GIS have proved a valuable tool for studies at landscape level. Combining the potential of GIS with the AHP multicriteria analysis enabled us to understand the potential value of the olive grove landscape for ecological restoration.

Limitations of the proposed approach

Regardless of the advantages discussed above, the approach proposed here has some limitations. Among these was the omission of the presence of rabbits, which is one of the most important criteria for the Iberian lynx (Palomares *et al.,* 2001; Rodríguez and Delibes 2004; Fernández *et al.,* 2006). As a substitute for this criterion the model considered the interface (edges) between scrubland and pastureland as a variable included in the "natural vegetation" group (Palomares, 2001). Another important point is fragmentation of potentially suitable areas for restoration in the results map where lynx would probably not survive (Palomares *et al*., 2000). However, since lynx requirements are probably more restrictive, these isolated spots could be suitable for other wildlife.

A further important issue is the choice of landscape variables. Various studies have considered a wide range of landscape variables (Cadenas *et al*., 2004; Junta de Andalucía, 2004a; Fernández *et al*., 2006, 2007). The variables in this study were selected based on the characteristics of the olive groves and the limited number of variables that the AHP method recommends. As a result the experts were not allowed to include additional variables aimed at enriching the analysis.

The result of the sensitivity analysis is also interesting. As pointed out in the Results section, there was significant divergence among the expert opinions. Because of this the effects of these differences were calculated via sensitivity analysis. This analysis illustrated the limitations of the expertise-based approach. In this case the limitation was the high dependency of the result from experts' opinions. In future studies this uncertainty could be addressed via fuzzy logic methods.

A further important issue is the quality and resolution of available digital layers. The land use map used had a 1:50,000 spatial resolution. Other digital layers had either a 1:25,000 or 1:10.000 spatial resolution. This means that allowed spatial errors were from 10 to 50 m or even 100 m in some layers, therefore, the results should be treated with caution.

Considering all previous limitations, it is recommended that the use of this approach be a preliminary, general, large-scale assessment of potential candidate sites for habitat restoration. Quantitative and empirically-based analysis of habitat suitability should be the primary guide for restocking and reintroduction of Iberian lynx populations. Further research is needed to refine both the possibility of obtaining more consistent decisions about the influence of the different landscape elements on habitats and an extended analysis of species requirements, in this case the Iberian lynx, to improve the biological soundness of the results.

Final remarks

The model presented in this study is completely open to changes or additions and has relatively small input data requirements. This enables it to be implemented into other ecosystems, always bearing in mind the conditions that apply to the specific site. Further, its results could be used as input for other types of analyses.

A combination of the model presented here with models based on sample data for species habitat suitability would offer an interesting line for future research, as well as the use of non-linear functions (multiplicative AHP), and consideration of the interdependences and feedback between the model criteria and negative priorities via an analytic network process.

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Annex

Pairwise comparison and relative importance (1=both factors have the same importance; 9=absolute dominance of one factor) and calculation of weights for one expert.

P1	Proximity to sealed roads (SR)	**X**
	Presence of grass vegetation cover in olive groves (GV)	

1	2	3	X 4	5	6	7	8	9

P2	Proximity to sealed roads (SR)	
	Areas influenced by a combination of Mediterranean forest, scrublands and pasture (VF)	**X**

1	2	3	X 4	5	6	7	8	9

P3	Proximity to sealed roads (SR)	
	Protection of Natural Park of Sierra de Cardeña and Montoro (NP)	

X 1	2	3	4	5	6	7	8	9

P4	Proximity to sealed roads (SR)	**X**
	Distance to watercourses (streams, rivers and reservoirs) (WA)	

1	2	X 3	4	5	6	7	8	9

P5	Presence of grass cover in olive groves (GV)	
	Areas influenced by a combination of Mediterranean forest, scrublands and pasture (VF)	**X**

1	2	3	4	5	6	*X* 7	8	9

P6	Presence of grass cover in olive groves (GV)	
	Protection of the Natural Park of Sierra de Cardeña and Montoro (NP)	**X**

1	2	3	X 4	5	6	7	8	9

P7	Presence of grass cover in olive groves (GV)	
	Distance to watercourses (streams, rivers and reservoirs) (WA)	**X**

1	2	3	4	5	X 6	7	8	9

P8	Areas influenced by a combination of Mediterranean forest, scrublands and pasture (VF)	**X**
	Protection of the Natural Park of Sierra de Cardeña and Montoro (NP)	

1	2	3	X 4	5	6	7	8	9

P9	Areas influenced by a combination of Mediterranean forest, scrublands and pasture (VF)	**X**
	Distance to watercourses (streams, rivers and reservoirs) (WA)	

1	X 2	3	4	5	6	7	8	9

P10	Protection of the Natural Park of Sierra de Cardeña and Montoro (NP)	
	Distance to watercourses (streams, rivers and reservoirs) (WA)	**X**

1	2	X 3	4	5	6	7	8	9

Calculation of weights for these pairwise comparisons

	AR	GV	VF	NP	WA	Weights
AR	1	4	1/4	1	1/3	0.1182
GV		1	1/7	1/4	1/6	0.0410
VF			1	4	2	0.4376
NP				1	1/3	0.1182
WA					1	0.2850

C.R.=0.0267