

**FUZZY MODELLING TO IDENTIFY AREAS OF HIGH CONSERVATION VALUE FOR
RAPTORS: EFFECTIVENESS OF THE NETWORK OF PROTECTED AREAS OF
ANDALUCÍA (SPAIN)**

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VALUE FOR RAPTORS: EFFECTIVENESS OF THE NETWORK OF
PROTECTED AREAS OF ANDALUCÍA (SPAIN)

by

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Abstract

Raptors in Spain face severe threats like illegal hunting and poisoning. Serious population declines of raptors have been reported in Andalucía (South of Spain) over the last decades making imperative the evaluation of the effectiveness of the network of protected areas for raptors' conservation. In this study fuzzy modelling was used to identify gaps in the network of protected areas of Andalucía. Environmental favourability models were obtained for the raptors breeding in Andalucía. Favourability predictions were used to calculate diversity attributes (richness, rarity and vulnerability) within a fuzzy logic framework. The correlation of diversity attributes was evaluated and used to assess their surrogacy in conservation planning. Effectiveness of the network was assessed by a fuzzy degree of disprotection that reduces the uncertainty arising from the use of arbitrary thresholds and targets in gap analyses. Results showed that richness, rarity and vulnerability of raptors are positively correlated in Andalucía, and serve as surrogates of each other in conservation planning. The network of protected areas of Andalucía is effective for the protection of raptors' diversity attributes, although it is more effective in protecting rarity and vulnerability than richness and it is not effective in protecting steppe nesting raptors. Areas where both overall richness and steppe raptors' richness are high are proposed as conservation priorities to overcome the gaps encountered.

Keywords: raptors, gap analysis, fuzzy modelling, degree of disprotection, steppe nesting raptors, Andalucía

Resumen

Las aves rapaces afrontan graves amenazas como la caza ilegal y el envenenamiento. Serios declives poblacionales han sido reportados en Andalucía (sur de España) en las últimas décadas, haciendo imperativa la evaluación de la efectividad de sus áreas protegidas para conservar las rapaces presentes en su territorio. Un análisis de vacíos (“Gap analysis”) fue hecho haciendo uso de la lógica difusa para encontrar fallos en la red de áreas protegidas de Andalucía. Modelos de favorabilidad ambiental fueron obtenidos para todas las rapaces reproductoras de Andalucía. Las predicciones de favorabilidad de estas especies fueron usadas para calcular atributos de diversidad como riqueza, rareza y vulnerabilidad dentro del marco de la lógica difusa. La efectividad de las redes fue evaluada a través de un grado de desprotección difuso que reduce la incertidumbre proveniente del uso de umbrales y objetivos arbitrarios en los análisis de vacíos. Los resultados mostraron que riqueza, rareza y vulnerabilidad están positivamente correlacionadas en Andalucía, y sirven como sustitutas la una de la otra al momento de planear para la conservación. La red de áreas protegidas de Andalucía es efectiva para la protección de la diversidad de las rapaces, aunque es más efectiva para proteger rareza y vulnerabilidad que riqueza, y no es efectiva en la protección de las rapaces esteparias. Áreas donde la riqueza de rapaces en general y la riqueza de rapaces esteparias en particular son altas son propuestas como prioridades de conservación para superar los vacíos encontrados.

Palabras clave: rapaces, análisis de vacíos, lógica difusa, grado de desprotección, rapaces esteparias, Andalucía

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1. Introduction

The conservation status of raptors worldwide is a concern (Chancellor and Meyburg, 2004). Raptors are especially sensitive to environmental degradation and are good indicators of the biological richness and environmental conditions of an area (Bildstein, 2001). In Spain, until the 70's raptors were subject to intense human persecution; raptors were believed responsible for reducing the availability of prey for hunting activities. This persecution caused serious declines in raptors' populations (Donázar and Fernández, 1990, González et al., 1990). Although all raptors are now legally protected in Spain, its persistence is still uncertain. Human disturbance, road construction, electric fences, power lines, resource overexploitation, agricultural intensification and wind turbines are some of the major threats that raptors currently face in Spain (SEO/Birdlife, 2010).

Given the delicate situation of raptors, careful conservation planning should be undertaken to assure their persistence. Networks of protected areas are fundamental conservation measures for the persistence of species (Chape et al., 2008), but in many cases even if they cover a considerable percentage of a territory they fail to achieve conservation goals. Globally, 11.5% of the land territory was, by the year 2004, under protection, but as pointed out by Rodrigues et al.(2004), the global network of protected areas is far away from assuring the persistence of biodiversity since not even all species of terrestrial vertebrates, the most studied species, are included. The evaluation of the effectiveness of protected areas for biodiversity conservation is a fundamental step in conservation planning (Margules and Pressey, 2000) because it entails a clear definition of conservation targets, it allows the identification of targets that are already met by the network and targets that have not been met and that should be priorities for future conservation investments. Gap analysis is a commonly used method for doing this evaluation (Jennings, 2000).

1.1. Gap analysis-evaluating the effectiveness of protected areas and setting priorities

Gap analysis is basically an overlay of areas of high conservation value with the network of protected areas (Jennings, 2000). Gaps are encountered when a certain target (for example 10% of the species rich areas or minimum area for a viable

population) is not met by the network. The gaps are set as conservation priorities for future protected areas.

There are a number of criteria that have been used to identify areas of high conservation value: species richness, rarity, vulnerability, risk to habitat loss, ecosystem or species representativeness, processes maintaining biodiversity, minimum area for viable populations and dispersal zones (Chape et al., 2008). The criteria used depend on the conservation objective and are intrinsically subjective (Richardson and Whittaker, 2010).

In the case of specific taxa, such as raptors, a simple approach to a gap analysis has been to identify if all the species are represented in the network of protected areas. A species would be considered represented if a protected area overlaps any portion of its mapped distribution (Rodrigues et al., 2004) or if a specific percentage of its distribution is under protection (Araújo et al., 2007). Diversity attributes such as richness, rarity and vulnerability have also been extensively used to evaluate networks of protected areas (Maiorano et al., 2006, Sanchezfernandez et al., 2008, Rey Benayas and De la Montaña, 2003, Estrada, 2008b).

A network of protected areas may be representing well areas with high species richness, but may be failing to include areas where rare or vulnerable species are present. The importance of incorporating rarity into a gap analysis, in addition to species richness, is that species with smaller range sizes are more likely to be left out of a network of protected areas and previous research have found that rare species do not necessarily occur in the most rich areas (Prendergast et al., 1993). Including a measure of diversity of vulnerable species becomes important, since these species are the ones of most conservation concern (Rodrigues et al., 2004).

Gap analyses have been frequently performed based on species distribution maps derived by museum collections and expert knowledge (Rodrigues et al., 2004, Williams et al., 1996). Such distribution maps may be biased by different sampling efforts over the study area (e.g. more species encountered within protected areas given that they have been researched more) making it difficult to infer the most suitable areas for a species. Nevertheless, the development of techniques for modelling the distribution of species has recently opened new ways of approaching gap analyses (Townsend Peterson and Kluza, 2003). The relatively recent field of conservation biogeography encloses this development. Conservation biogeography, as described by Whittaker et al. (2005), deals with the incorporation of biogeographic models, methods and analysis to solve problems related to

biodiversity conservation. Species distribution models lay at the core of conservation biogeography (Richardson and Whittaker, 2010).

1.2. Species distribution models and Favourability function for Gap analysis

To account for the possible bias in distribution maps, species distribution modelling is now a common methodological approach, and an important step in conservation planning and management (Richardson and Whittaker, 2010). Several methods are now available for modelling the distribution of species (Hegel et al., 2010). Generalized Linear Models (GLM's), a commonly used technique, relates environmental variables with the presence or absence of a species (Guisan and Zimmermann, 2000). The output is a probability of presence of the species in each unit over the study area. Advantages and disadvantages of this method have been discussed by Guisan and Zimmermann (2000).

GLMs produce continuous outputs, ranging between 0 and 1, which represent the probability of occurrence of the species in an area. Commonly this continuous output is transformed into a discrete (present-absent) prediction based on a predefined threshold (0.5 for example) (Guisan and Zimmermann, 2000). Although useful, this transformation results in an information loss; the areas with the highest probability values are no longer distinguishable. Additionally, probability values obtained with GLMs are not comparable between species with different prevalence (presence-absence ratio) (Jiménez-Valverde et al., 2009). The favourability function (Equation 1) proposed by Real et al. (2006a) solves this problem by removing the influence of the prevalence. A favourability value higher than 0.5 means that the probability of presence is higher than it would be expected by the prevalence. Several examples of studies can be found that have incorporated the favourability function to GLM (Estrada, 2008a, García-Ripollés et al., 2005, Farfán et al., 2009b, Niamir, 2009, Vargas et al., 2006, Duarte et al., Farfán et al., 2009a, Barbosa et al., 2009).

$$F = \frac{\frac{P}{(1-P)}}{\frac{n_1}{n_0} + \frac{P}{(1-P)}}$$

Equation 1. The Favourability function. P is the probability value, n_1 is the number of presences and n_0 is the number of absences

The use of favourability as a raw number and not transformed into a present/absent category yields another advantage. It does not depend on a predefined probability threshold that may cause great uncertainty when calculating properties such as richness. For example, if richness is calculated using presence-absence predictions, it is possible that high values of richness appear in areas in the periphery of the distribution of one species and the next since they are overlapping (Loiselle et al., 2003). It could be that neither one of the species is present in the area but the threshold chosen is not the appropriate one. An estimation of richness based on raw favourability values solves this problem. This approach has been referred to in the literature as fuzzy modelling and it has been shown to be useful for performing gap analysis and identifying important conservation areas (Estrada et al., 2008). The incorporation of species distribution modelling in the process of doing a gap analysis and the use of the favourability function means that protected areas can now be evaluated not only on the basis of presence/absence of species but based on those areas that are highly favourable for them.

1.3. Fuzzy modelling

Fuzzy logic acknowledges that there are objects that cannot be clearly defined as belonging to one category or the other, but that have a degree of membership to a category (Zadeh, 1965). An area where a species is present is not completely favourable or unfavourable for the species. Thus, fuzzy logic provides a good framework to work with favourability values. For a species, the favourability value of an area is the degree of membership of that area to the fuzzy set of favourable areas for the species (Estrada et al., 2008). Based on favourability values, for groups of species, diversity indices such as richness (Estrada et al., 2007), rarity (Real et al., 2006b) and vulnerability have been derived.

Estrada et al. (2008) proposed the following equations. The richness of an area (j) is the sum of the favourability values of all the species (Equation 2). Rarity can be calculated for each species, but also for an area when considering more than one species simultaneously. The species rarity (Equation 3) is the inverse of the sum of its favourability values over the entire study area. The rarity of an area (Equation 4) is the sum, for all species, of the species rarity weighted by the favourability of that species in that location. The vulnerability of an area (Equation 5) is a weighted sum of the vulnerabilities of the species based on the favourability values of each species in that specific location. The vulnerability of each species is commonly based on a predefined classification such as the IUCN Red List Categories.

$$FRich_j = \sum_{i=1}^n (F_{ij})$$

Equation 2. Fuzzy richness of the pixel j . F_{ij} is the favourability value of the species i in the pixel j .

$$Rar_i = \frac{1}{\sum_{j=1}^p F_{ij}}$$

Equation 3. Species rarity.

$$FRar_j = \sum_{i=1}^n (F_{ij} * Rar_i)$$

Equation 4. Fuzzy rarity of the pixel j .

$$FVuln_j = \sum_{i=1}^n (V_i * F_{ij})$$

Equation 5. Fuzzy vulnerability of the pixel j . V_i is the weight given to the raptor species i based on its vulnerability status.

1.4. Correlation and overlap of conservation criteria

Studying the pair wise correlations of diversity metrics aids to identify the best conservation criteria to include in a gap analysis. For example, if richness correlates positively with rarity, it can be used as a surrogate to identify conservation priorities according both to richness and rarity, making conservation more efficient. In addition to pair wise correlations, it is important to study the spatial overlap of conservation criteria. The overlap of areas with high values of more than one attribute also helps to identify conservation priorities (Orme et al., 2005). Previous studies have investigated the correlation and overlap of conservation criteria reaching different conclusions.

At a global scale Orme et al.(2005) concluded that different diversity metrics should be used for conservation prioritization, since hotspots of species richness, threat and endemism do not coincide geographically. For the case of birds, hotspots of species richness were found mainly in tropical upland regions, that present high diversity of habitats, and hotspots of endemism were found in large islands or archipelagos that

allowed allopatric speciation. Threat hotspots were thought to be a consequence of the interaction of factors promoting diversity and anthropogenic pressures.

At a continental scale, Gaston and Blackburn (1996) found that, for birds of America the number of threatened species was positively correlated with overall number of species and its variability was significantly explained by number of rare species. There may be two explanations for richness and vulnerability correlating: areas high in richness may be subjected to a higher number of threats and species in rich areas may be more vulnerable to threat (Gaston and Blackburn, 1996). Given that Blackburn and Gaston (1996) found, within the same study in America, that areas with high richness have a smaller mean of species' range sizes and species with small geographic ranges have been found to be associated with a high extinction risk (Purvis et al., 2000), support is given for the second explanation of richness and occurrence of threatened species being highly correlated.

At a local scale and in a study spanning birds and other different taxa, Prendergast et al. (1993) found that in Britain many rare species fall outside the richest areas. Supporting this finding, but restricted only to birds, Williams et al. (1996) found that in Britain richness and rarity hotspots are not correlated. These results are explained by the level of fragmentation of nature areas in Britain and the spatial resolution used: at coarser resolutions patterns of richness and rarity are thought to coincide better (Prendergast et al., 1993, Curnutt et al., 1994). In a study in Britain and South Africa Lennon et al. (2004) found that patterns of richness were better explained by the distribution of common species than by the distribution of rare ones, suggesting that overall species richness can tell little about the richness patterns of the rare species.

Particularly in Spain Rey Benayas (2003) found a significant correlation between vulnerability and rarity of nesting birds in Spain but did not find significant correlations between richness and rarity or between richness and vulnerability. In Andalucía, Estrada (2008b) reported that areas of high conservation value, according to fuzzy richness, fuzzy rarity and fuzzy vulnerability, have similar distribution, although measures of overlap or correlation were not obtained.

The diverse conclusions reached by different authors working with different taxa at different scales and resolutions, highlights the importance of evaluating the correlation and overlap of conservation criteria for the specific case of raptors in Andalucía.

1.5. Predefined thresholds and the importance of fuzzy modelling

Predefined thresholds and quantitative conservation targets are commonly incorporated into gap analyses. Diversity attributes, such as richness are transformed so that areas can be defined as rich or not, for example by assuming as rich only the top 5% of spatial units (Williams et al., 1996). A diversity attribute is considered protected if, for example, at least 20% of its total coverage is protected (Estrada, 2008b). Even more, since gap analysis are based in spatial units that do not necessarily coincide with the boundaries of the protected areas, the protected status of the cell or spatial unit is derived using a threshold, such as more than 50% of the cell falling within a protected area. The selection of the threshold and of the target is often arbitrary and is in many cases driven by policy rather than evidence (Svancara et al., 2005).

Until now fuzzy modelling has only been used to derive richness, rarity and vulnerability from fuzzy sets of favourability, thus avoiding the uncertainty of setting a threshold on the species' favourability values (Estrada et al., 2008). Fuzzy modelling has not been used to avoid the uncertainty arising from the remaining thresholds used to produce the outcomes of the gap analysis, although it provides the appropriate framework for doing so. Here an index is derived that does not rely on predefined thresholds to transform favourability or diversity values or to define the protection status of the grids given the network of protected areas. The mentioned index has been named Degree of Disprotection (DD).

Commonly a gap analysis yields a crisp outcome: a species or a diversity attribute is either protected or not, in reality it has a degree of protection and a resulting degree of disprotection. The emphasis is given here to the degree of disprotection because of its practicality. In order to visualize conservation priorities we want to map those areas with the highest degree of disprotection instead of those areas with the highest degree of protection. A detailed explanation of the Degree of Disprotection is given in the methods (Section 3.5.3).

Measuring a degree of disprotection yields another advantage, particularly in regions of the world like Andalucía in the South of Spain, that have large areas under protection but where there is still the need to prioritize conservation actions. Under a target based gap analysis, a target could already be met by the network of protected areas, but there are no means of measuring its effectiveness beyond the threshold. The degree of disprotection provides more information and avoids subjectivity in the choices of thresholds and targets.

1.6. Gap analyses in Spain

Previous studies have performed gap analyses in Spain. Rey Benayas (2003) identified areas of high conservation value based on vertebrate diversity and reported that 70% of these are included in natural protected areas. They used an index of biodiversity that combined species richness, rarity and vulnerability based on presence/absence data of species in UTM grids of 50x50 km and vulnerability categories of the International Union for Nature Biodiversity (IUCN). Araújo et al. (2007) assessed the effectiveness of the protected areas of the Iberian Peninsula to conserve terrestrial biodiversity. The results show that animal and plant species were well represented in the network, but for the case of amphibians, reptiles, birds and gymnosperms the representation of species was not better than it would be expected by chance.

Traba et al. (2007) identified hotspots of steppe birds in the Iberian Peninsula and the Balearic Islands using a combined index of richness, rarity and vulnerability derived directly from the Atlas of breeding birds of Spain (Ministerio de Medio Ambiente, 2010) in a 10x10 km grid resolution. The research concluded that Natural Protected Areas (NPAs) have a low coverage of the hotspots (less than 2%) whilst Special Protected Areas (SPAs) have higher coverage (45%).

Specifically for raptors, López-López et al. (2007) evaluated the network of protected areas of the Valencian community in Spain for the conservation of the Bonelli's eagle (*Hieraetus fasciatus*). They concluded that SPA's and Important Bird Areas (IBA's) are insufficient to protect the Bonelli's Eagle given the low percentage of highly suitable areas falling within the protected areas.

1.7. Gap analyses in Andalucía

The Mediterranean basin, where Andalucía is located, is considered one of the top 25 hotspots of biodiversity in the world and one of the most vulnerable ones given the extent of primary vegetation remaining (4.7%) (Myers et al., 2000). Andalucía has the largest network of protected areas in Spain. 19,35% of the territory of Andalucía is under protection, representing 29,8% of the protected areas in Spain (Consejería de Medio Ambiente, 2006).

In Andalucía gap analyses have been performed for all vertebrate species on a 10x10 km resolution (Estrada, 2008b). Estrada (2008a) used atlas presence/absence data to model the distribution of species and, based on favourability predictions, obtained fuzzy values for richness, rarity and vulnerability that were used as basis for the gap

analyses. The conclusion was that the network of protected areas of Andalucía is well distributed when setting as target the inclusion of 20% of the areas with the highest diversity values.

A gap analysis specifically for raptors has not been done for Andalucía. Such gap analysis is needed to evaluate how effective the network of Andalucía is for the conservation of the raptors present in its territory and to set conservation priorities for the future. Given the bias that protected areas commonly have (e.g. located in unfertile or inaccessible areas) it is important to evaluate the network not only in terms of conserving diversity attributes but also in terms of how well is representing raptors with different nesting habitats. In Andalucía raptors can nest in forests, cliffs or steppes. The steppe nesting raptors are commonly found nesting in cropland given the transformation that the steppe habitat has suffered. Land suitable for cropland is less likely to be included in protected areas given its economical utility.

2. Research problem, objectives, questions and hypothesis

2.1. Research problem

Given the threats raptors are facing in Andalucía it is important to evaluate the network of protected areas of this region by doing a gap analysis. No previous studies have evaluated the network of protected areas of Andalucía for their effectiveness in protecting raptors.

The use, in gap analysis, of untransformed favourability predictions reduces the uncertainty produced by the use of predefined thresholds and allows comparability between species with different prevalence. Conservation priorities can then be identified not only on the basis of the presence or absence of the species, but also on the degree of favourability of the area for it. Environmental favourability predictions were obtained for all breeding raptors in Andalucía and used as basis for the gap analysis.

Sometimes is not possible for a network of protected areas to cover places that are highly favourable for all species because of social or economical constraints. Mechanisms for making conservation as effective as possible must be developed. Diversity indices such as richness, rarity and vulnerability should be calculated in order to identify areas of high conservation value and hence, of conservation priority. The degree of correlation of diversity attributes aids at identifying how suitable is one diversity attribute as surrogate of the others, hence providing evidence on how to make conservation more efficient. The present research models richness, rarity and vulnerability based on favourability predictions and evaluates how these diversity attributes of raptors are correlated in Andalucía.

Protected areas, being declared for many different reasons, may protect disproportionately different attributes of raptors. For example, protected areas may be covering areas rich in species rather than high in rarity or covering more habitats of cliff nesting rather than steppe nesting raptors. Furthermore, different networks (i.e. EENNPP “Espacios Naturales Protegidos” and Natura 2000) may have differences on the percentage of areas of each conservation value that are under its protection. Commonly, predefined thresholds and arbitrary targets have been used to assess the effectiveness of protected areas. The present research proposes a fuzzy degree of disprotection of species and diversity attributes that does not rely on thresholds or subjective targets to evaluate the effectiveness of networks of protected areas. Using

this fuzzy degree of disprotection, gaps in the protected areas are identified and suggested as conservation priorities for raptors in Andalucía.

2.2. Objectives

2.2.1. Overall objective

Identify gaps in the network of protected areas of Andalucía (Spain) for the protection of raptors.

2.2.2. Specific objectives

- a. Assess if there is a relationship between fuzzy values of pairs of diversity attributes in Andalucía and its significance.
 - Richness and rarity
 - Richness and vulnerability
 - Vulnerability and rarity
- b. Evaluate if there are differences in the degree of disprotection of diversity attributes of raptors: richness, rarity and vulnerability in Andalucía.
- c. Evaluate if there are differences in the degree of disprotection of species with different nesting habitat: forest, cliff or steppe.

2.3. Research questions

2.3.1. Overall research question

Which are the gaps in the network of protected areas of Andalucía (Spain) for the protection of raptors?

2.3.2. Specific research questions

- a. Is there a relationship between pairs of conservation criteria? The pairs that will be considered are:
 - Richness and rarity
 - Richness and vulnerability
 - Vulnerability and rarity
- b. Is the network of protected areas of Andalucía disprotecting in a higher degree a particular diversity attribute of raptors in Andalucía: richness, rarity or vulnerability?
- c. Is the network of protected areas disprotecting in a higher degree forest, cliffs or steppe nesting species?

2.4. Hypothesis

Hypothesis a:

Richness and rarity

Ho: The correlation between richness and rarity is not significant.

Ha: Richness and rarity are positively correlated.

Rarity and Vulnerability

Ho: The correlation between rarity and vulnerability is not significant.

Ha: Rarity and vulnerability are positively correlated.

Richness and vulnerability

Ho: The correlation between richness and vulnerability is not significant.

Ha: Richness and vulnerability are positively correlated.

Hypothesis b:

Ho: Richness, rarity and vulnerability have similar degrees of disprotection.

Ha: Richness has the lowest degree of disprotection.

Hypothesis c:

Ho: Forest, cliff and steppe species do not have significantly different degrees of disprotection.

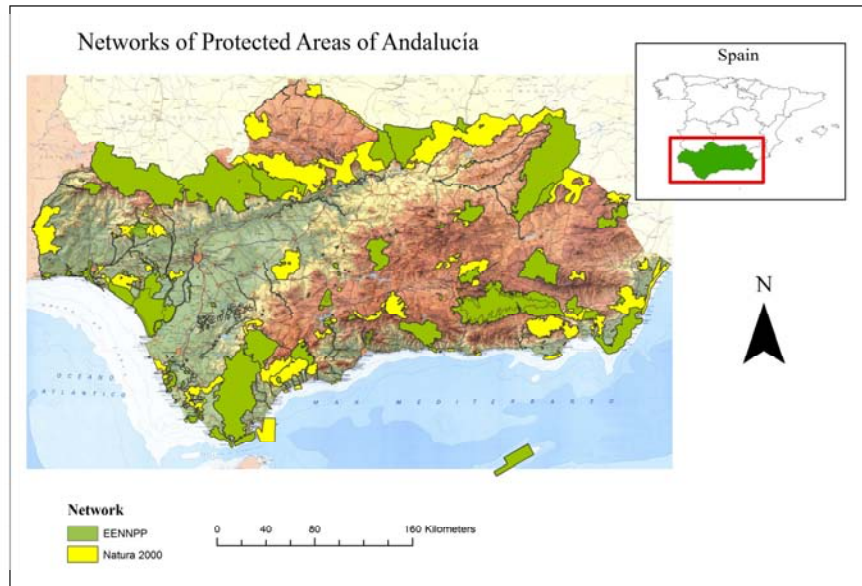
Ha: Steppe species have a significantly higher degree of disprotection.

Steppe species are associated with agricultural areas which are commonly not under any protection figure. Highlands which are normally not as suitable for agriculture are normally the first areas to be declared as protected.

3. Methods

3.1. Study area

Andalucía (Map 1), with an extent of 87.600 km², is located in the South of the Iberian Peninsula. It is an autonomous community of Spain and entails 8 provinces. The climate is Mediterranean and presents a strong gradient of rainfall (from 1800 to 170 mm per year). The altitude varies from sea level up to 3.500 m in the case of the Sierra Nevada (Granada).



Map 1. Map of Andalucía and the national (EENNPP) and Natura 2000 network of protected areas.

The east of Andalucía is mountainous; the Pennibetic and Subbetic mountain ranges are located there. The aridity is very high in most of this part of Andalucía, except for the coast between Almeria and Algeciras where the weather is subtropical. Contrastingly, the west part of Andalucía is flat and has a higher precipitation, reason why the Guadalquivir valley is very fertile.

Mediterranean forests, mountain systems and Iberian steppes are characteristic habitats of this region. The sclerophyllous vegetation is widely distributed, characterised by hard, small leaves suitable for extremely dry conditions.

The network of protected areas of Andalucía RENPA (Red de Espacios Naturales Protegidos de Andalucía) includes protection figures such as: European Diploma, EENNPP (Espacios Naturales Protegidos), Geoparks, Ramsar sites, World heritage sites, Natura 2000, Biosphere reserves and SPAMI (Spatial Protected Areas of Mediterranean Interest). The EENNPP and the Natura 2000 networks were evaluated in the present study. The Natura 2000 network includes 63 Special Protection Areas for Birds (SPAs) and 195 Sites of Community Interest (SCI). These SCI's are in the first stage to become Special Areas for Conservation (SACs) (Junta de Andalucía, 2010).

3.2. Data preparation

3.2.1. Species data

Data on presences and absences of nests of all the breeding raptors in Andalucía (see Appendix 1) was obtained from the Atlas of reproductive birds of Spain (Ministerio de Medio Ambiente, 2010). The data is represented in UTM grids of 10x10 km. *Pandion haliaetus* and *Pernis apivorus* were not included in the modelling. The reproductive population of *P. haliaetus* is considered extinct in Andalucía, only the wintering population remains and is considered vulnerable (Junta de Andalucía, 2001). *P. apivorus* only has two reports of occasional reproduction in Andalucía (Ministerio de Medio Ambiente, 2010). In total 20 raptor species were included. Given that there are 975 UTM cells of 10x10km in Andalucía, each species had 975 records of presence/absence.

3.2.2. Protected areas

The EENNPP and Natura 2000 networks (explained in section 3.1) are the ones evaluated with the present study. Based on shapefiles of these networks, raster files of 10 km resolution were created with values between 0 and 1 representing the portion of each pixel under protection. This is referred to as P_j and represents the degree of protection of the pixel.

3.2.3. Environmental data

Environmental variables were grouped according to the following categories: topography (1), water availability (2), energy availability (3), productivity (4), climatic stability (5), human activity (6) and land cover (7) (see Appendix 2 for the sources, units and details about the environmental variables).

To avoid geometric inaccuracies all environmental variables were set to the coordinate system: ED 1950 UTM zone 30, re-sampled to match the 1x1 km UTM grids, and clipped to the extent of Andalucía. The matching to the 1x1km UTM grids means that when the variables are aggregated to 10x10km they coincide perfectly with the 10x10km grids on which the species data is available. In the case of the variables that had originally a resolution of less than 1x1 km they were aggregated using the mean. Based on the 1x1 km rasters, further aggregations using the mean were done to obtain all variables at a 10x10 km resolution matching the species data (Figure 1).

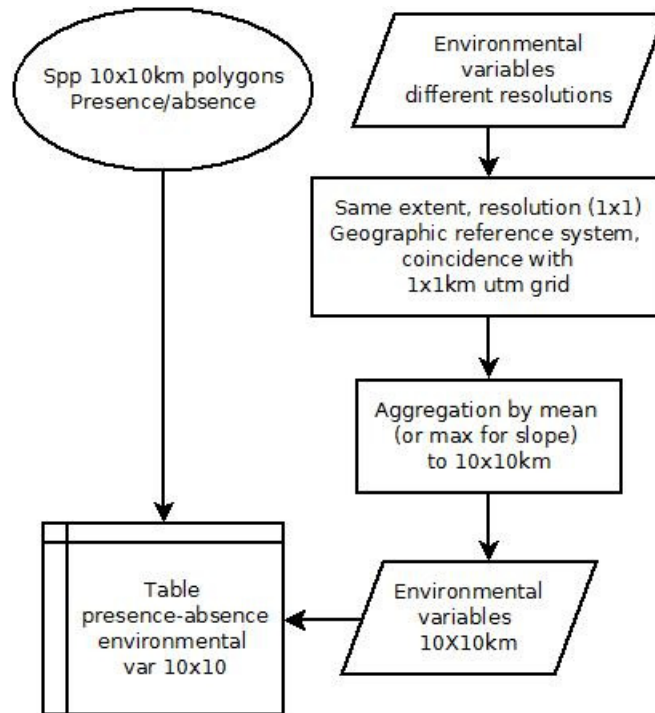


Figure 1. Approach to obtain the data table to be used in modelling.

Slope, aspect, south and west exposure, and land cover were derived using ArcGIS following these methods:

Slope was derived from the 30 m DEM using the SLOPE function in ArcGIS. The 30x30m slope map was resampled to 100x100m and this was aggregated using the mean and the maximum into a 10x10 km raster.

For **aspect** aggregation of the 30x30 m raster would not make sense because it would require an average or majority filter. So aspect was directly derived from the 10x10 km DEM. Aspect was not incorporated as a variable in the modelling process, it was only used to calculate south and west exposure.

South and west exposures were derived separately from the 10x10 km aspects. South exposure (Table 1) ranges from 0 to 180, where 0 means an area oriented to the north and 180 an area oriented to the south. West exposure (Table 2) ranges from 0 to 180, where 0 means an area oriented to the east and 180 an area oriented to the west. In both case a flat area gets a value of 90.

Table 1. Conversion made from aspect to South exposure. The following conditional function was used in ArcGIS: con (aspect <= -1, 90, con (aspect <= 180, aspect, 360 - aspect))

Aspect	Formula
-1	90
0 -180	South exposure = Aspect
180 - 360	South exposure = 360 - aspect

Table 2. Conversion made from aspect to West exposure. The following conditional function was used in ArcGIS: con (aspect_10 <= -1, 90, con (aspect_10 <= 90, 90 - aspect_10, con ((aspect_10 > 90 & aspect_10 <= 270), aspect_10 - 90, 450 - aspect_10)))

Aspect	formula
-1	90
0 -90	90 – Aspect
90 -270	Aspect – 90
270 - 360	450 - Aspect

The **land cover variables:** Artificial, forest, agricultural, shrubland and wetland percentage were calculated based on the 2006 Corine land cover (originally of 250 m resolution) (European Environment Agency, 2010). The Corine land cover categories included in the classes used here are presented in Appendix 3. To get the 10x10km land cover variables, first the raster was resampled to a resolution of 200 m. By reclassifying to 0 and 1 a raster for each land cover class was created. The 200x200m rasters were aggregated by sum with a factor of 50 to get the number of 200x200m cells inside each 10x10 km cell. From this number the percentage coverage of each land cover in each cell was obtained.

3.3. Selection of environmental variables

A variable selection was performed in order to reduce problems arising from collinearity and in order to assure ecological relevance given the species modelled (Figure 2). Spearman correlation coefficients were calculated among pairs of all the environmental variables (Spearman, 1987). If the correlation was higher than 0.8 then a choice was made between the variables according to their ecological relevance (Jiménez-Valverde and Lobo, 2006, Real et al., 2008). Subsets of variables were formed for groups of raptors depending on the resident or breeding status in Andalucía and on their nesting habitat. Different subsets were obtained for: resident forest, resident cliff, resident steppe, breeding forest, breeding cliff and breeding steppe species. (See Appendix 1 for the breeding status and nesting habitat of each species modelled).

Collinearity tests (Mansfield and Helms, 1982) were performed for all subsets. For variables with VIF values higher than 10 choices were made, based on the knowledge of the ecology of the species, about which variables to include or exclude.

For species that are only present in Andalucía during the breeding season, variables related to winter, such as temperature of the coldest month or NDVI in winter, were not taken into account. Depending on the nesting habitat, choices were made among the land cover variables available.

The number of environmental variables used for modelling was reduced in the case of species with very few records of either presence or absence to avoid over fitting. The minimum number of variables recommended to be used for each species is reported in Appendix 1 as well as the amount of variables used. This minimum number recommended follows the rule of thumb of Harrell et al.(1996) that states that the maximum number of variables should be the category with the fewest records (presences or absences) divided by 10.

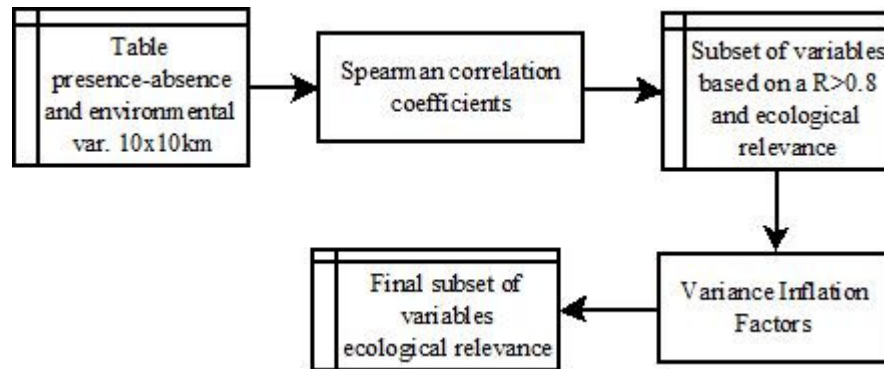


Figure 2. Method to obtain subsets of environmental variables.

3.4. Environmental favourability models for all the raptor species breeding in Andalucía.

Generalized linear models were obtained for each species using the software R with the library BIOMOD. Polynomial logistic regressions were performed for all species using a forward step wise procedure based on the AIC criteria. A modification of the probability function was used: the favourability function (Equation 1 in section 1.2).

Two evaluation measures were obtained AUC (Area under the Receiving Operating Characteristic Curve) (Metz, 1978) and Cohen's kappa (Cohen, 1960). The threshold independent evaluation of the models was done by splitting the data 10 times, 70% for calibration and 30% for validation. AUC scores were obtained for each run and an average score of all runs was obtained. Nevertheless, to avoid biased predictions, the definitive predictions were made with the full set of data and an AUC score was reported for the full run as well. The AUC is threshold independent and assesses the discrimination power of the models. A model that discriminates perfectly gets a value of 1 and one that predicts no better than chance gets a value of 0.5. Since the aim is to identify areas of high conservation value, it is important to select the model that minimizes the false-positive errors (Loiselle et al., 2003).

Kappa scores differ if obtained with probability or favourability values. To avoid the effect of different prevalence, the kappa score was calculated with a threshold of 0.5 based on favourability values. Specificity, sensitivity, false positive and false negative errors were calculated based on the same threshold and favourability values.

For each model the importance of each variable was obtained. The BIOMOD library performs this calculation by randomizing each variable a number of times, making a new prediction and recording the correlation between the new prediction and the standard one. The higher the correlation, the less important the variable. The

reported variable importance is 1 minus the correlation and for this reason it is not a relative measure of the importance of each variable among the whole set of variables (e.g. the sum of the variable importance for all variables included in the model is different from 1). The randomizing procedure was set to run 5 times for each variable. A flow chart of the methods is presented in Figure 3.

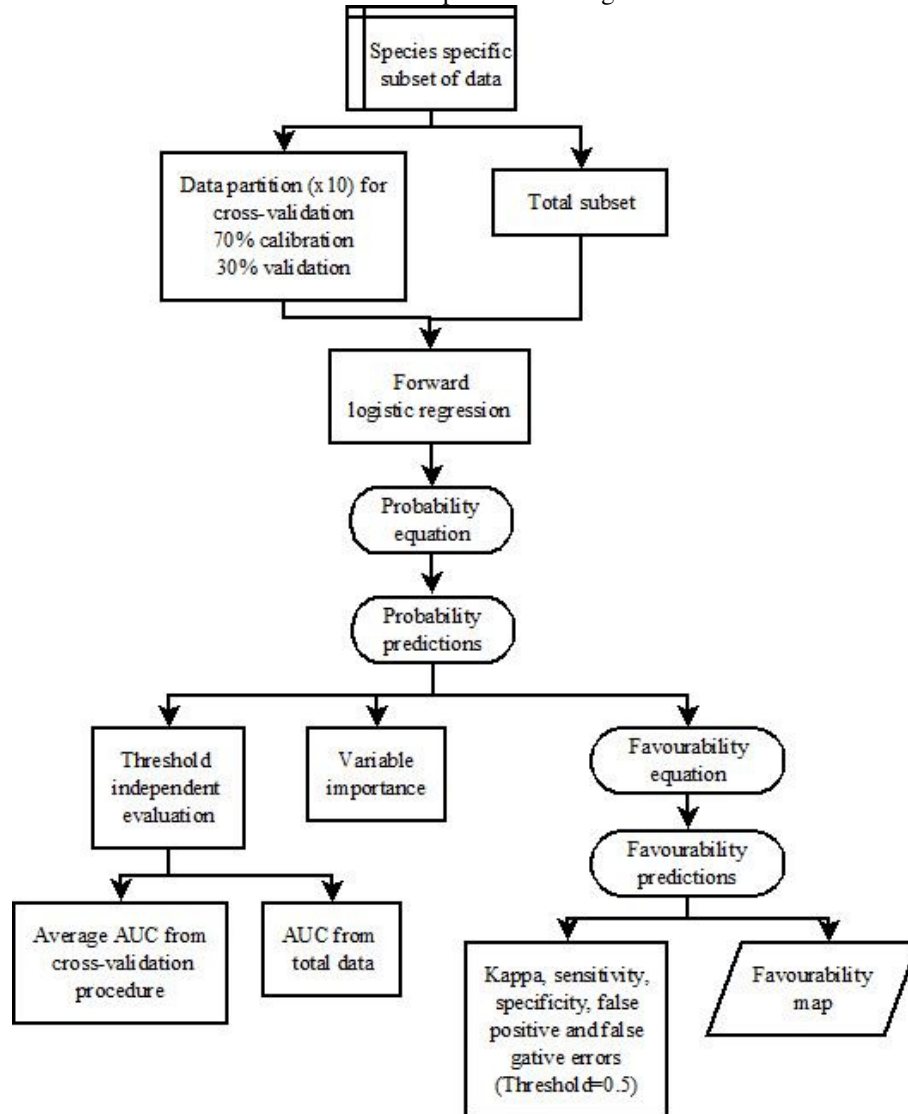


Figure 3. Flow chart of method applied for the generalized linear model of each species and for the evaluation procedure.

3.5. Fuzzy modelling

3.5.1. Richness, rarity and vulnerability

The methods proposed here are based on the methods used by Estrada et al. (2008) and Real et al. (2006b). The favourability values were predicted for the entire study area. The resulting favourability values were not converted to presence/absence predictions. Instead, fuzzy values were used to calculate diversity attributes of raptors in Andalucía. For each species a rarity value was obtained (Equation 3) and for each pixel in Andalucía richness (Equation 2), rarity (Equation 4) and vulnerability (Equation 5) were calculated. Equations can be found in section 1.3. The values of the diversity attributes were normalized by dividing by the maximum value in the study area. A flow chart of the fuzzy modelling and data analysis is found in Figure 4.

A species can be considered rare on the basis of its low population size, small range, and specific habitat needs. In this research species are considered rare only on the basis of its range size. Vulnerability for each species was based on the classification presented in the Red list of Threatened Vertebrates of Andalucía (Junta de Andalucía, 2001). Numerical weights are given to each species depending on its category of vulnerability (Table 3); species that are not vulnerable get a value of 0 to assure that the index only considers vulnerable species.

Table 3. Weights given to the vulnerability status

Status	Weight
Critically endangered	16
Endangered	8
Vulnerable	4
Near threatened	2
Least concern	1
Data deficient	1
Not evaluated	0

(Equation 7-9) under the EENNPP and the Natura 2000 networks was obtained. The difference between the degree of disprotection of EENNPP and of Natura 2000 is referred here as **Gain** and shows how much the Natura 200 network improves protection.

In the case of rarity, richness and vulnerability, the fuzzy degree of disprotection is calculated in the same way, but based on the normalized values. The fuzzy degrees of protection are standardized between 0 and 1 by dividing by the sum of the favourability values. This allows comparison among degrees of disprotection from different diversity attributes. The pixel value of disprotection for species and for diversity attributes was used to visualize areas with different degrees of disprotection.

$$DD_i = \frac{\sum_j^p (F_{ij} - (F_{ij} * P_j))}{\sum_{j=1}^p F_{ij}}$$

Equation 6. Degree of disprotection of the species i (over the entire study area). F_{ij} is the favourability for the species i in the pixel j . P_j is the proportion of the cell cover by a protected area.

$$DD_{FRich} = \frac{\sum_j^p (FRich_j - (FRich_j * P_j))}{\sum_{j=1}^p FRich_j}$$

Equation 7. Degree of disprotection of richness (total for the study area).

$$DD_{FRar} = \frac{\sum_j^p (FRar_j - (FRar_j * P_j))}{\sum_{j=1}^p FRar_j}$$

Equation 8. Degree of disprotection of rarity (total for the study area).

$$DD_{FVuln} = \frac{\sum_j^p (FVuln_j - (FVuln_j * P_j))}{\sum_{j=1}^p FVuln_j}$$

Equation 9. Degree of disprotection of vulnerability (total for the study area.)

To answer the research question C a one-way ANOVA and a Tukey test were performed to check for significant differences in the degree of protection of species with different nesting habitats: forest, cliff or steppe.

4. Results

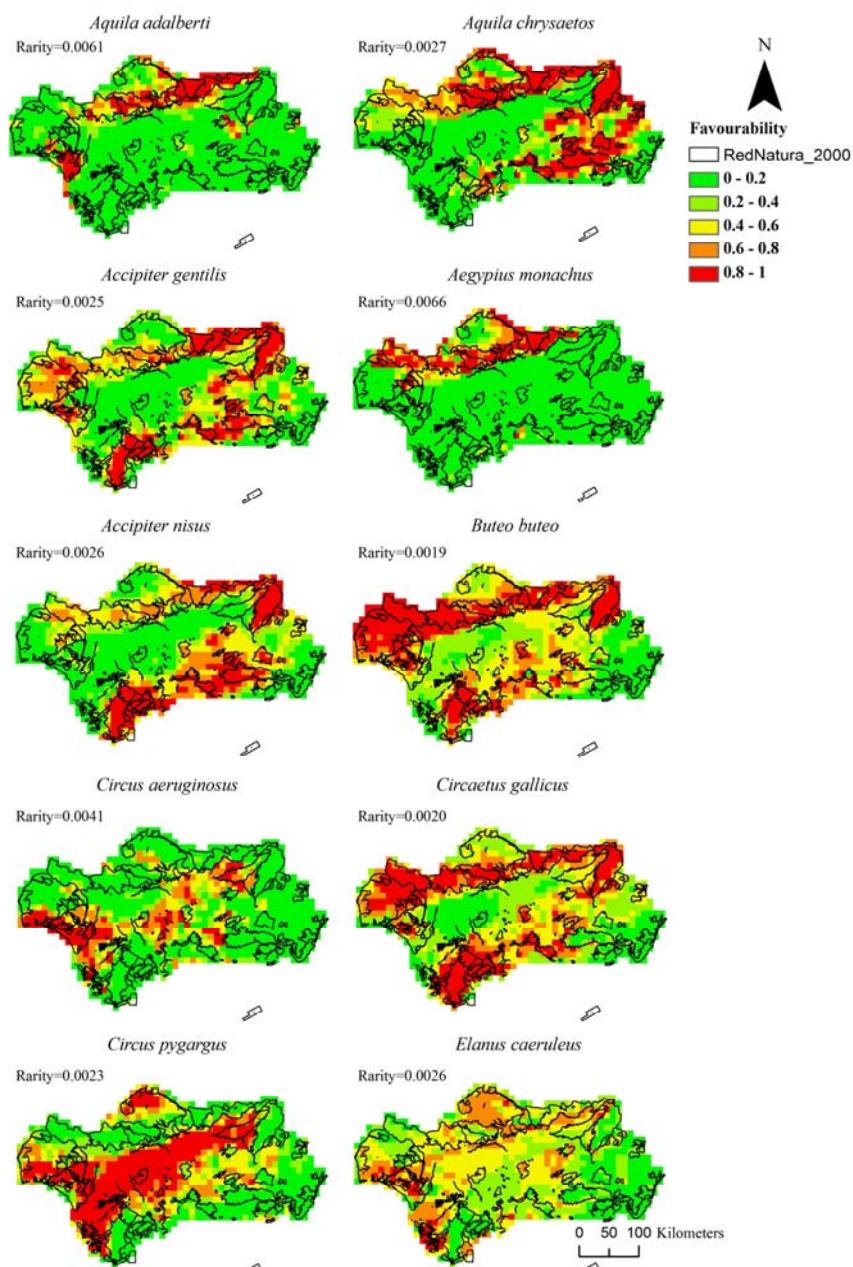
4.1. Environmental favourability models

Models were obtained for all raptor species breeding in Spain, except for *Pandion haliaetus* and *Pernis apivorus*. These two species had very few presences recorded. The predicted favourabilities over Andalucía for each raptor are shown in Map 2. *E. caeruleus*, *F. subbuteo* and *F. tinnunculus* were the species with the lowest average AUC scores (less than 0.75) after the cross-validation procedure (Table 4). Kappa scores of less than 0.4 were found for the same species and for *A. monachus*, *N. percnopterus* and *M. milvus*. The kappa scores were calculated from favourability values and using a threshold of 0.5.

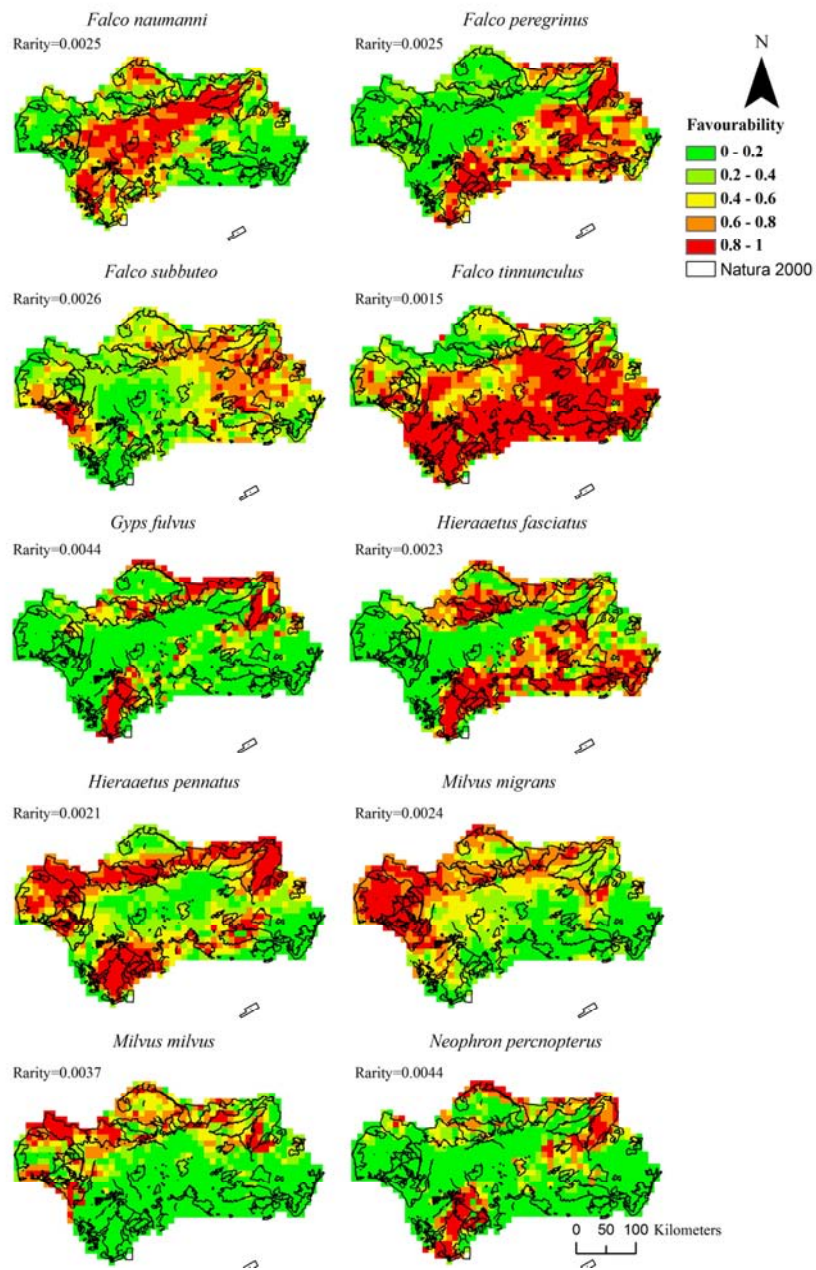
Variables related to water availability, energy availability, climatic stability and land cover for most of the species had the highest importance. Topographic variables were more important for cliff nesting and forest nesting raptors than for steppe nesting ones. Variables included in the categories of productivity and human activities were among the least important variables in most models. Nevertheless, for steppe nesting species distance to cities and distance to roads were variables explaining their occurrence, although not with a high importance. See Table 5 for the results of the variable importance for each species modelled.

Table 4. Evaluation results of the favourability predictions. Average of AUC scores of cross-validation runs, AUC score for the final model, and Kappa, specificity, sensitivity, false negative and false positive errors calculated from favourability values using a threshold of 0.5.

Species	Cross-validation AUC	AUC	Kappa (Fav.) (0.5)	Spec. (0.5)	Sens. (0.5)	False negative errors (0.5)	False positive errors (0.5)
<i>A. adalberti</i>	0.883	0.970	0.464	0.886	0.949	0.051	0.11
<i>A. chrysaetos</i>	0.903	0.922	0.636	0.819	0.868	0.132	0.18
<i>A. gentilis</i>	0.826	0.869	0.481	0.771	0.754	0.246	0.23
<i>A. monachus</i>	0.918	0.965	0.295	0.858	0.921	0.079	0.14
<i>A. nissus</i>	0.849	0.882	0.510	0.778	0.799	0.201	0.22
<i>B. buteo</i>	0.786	0.846	0.483	0.787	0.712	0.288	0.21
<i>C. aeruginosus</i>	0.878	0.939	0.453	0.833	0.907	0.093	0.17
<i>C. gallicus</i>	0.817	0.843	0.520	0.772	0.749	0.251	0.23
<i>C. pygargus</i>	0.871	0.907	0.637	0.809	0.839	0.161	0.19
<i>E. caeruleus</i>	0.619	0.762	0.090	0.666	0.688	0.313	0.33
<i>F. naumanni</i>	0.780	0.857	0.508	0.762	0.796	0.204	0.24
<i>F. peregrinus</i>	0.844	0.880	0.526	0.775	0.814	0.186	0.23
<i>F. subbuteo</i>	0.677	0.785	0.210	0.725	0.724	0.276	0.27
<i>F. tinnunculus</i>	0.780	0.882	0.318	0.837	0.782	0.218	0.16
<i>G. fulvus</i>	0.873	0.953	0.520	0.866	0.900	0.100	0.13
<i>H. fasciatus</i>	0.850	0.895	0.585	0.867	0.213	0.163	0.23
<i>H. pennatus</i>	0.805	0.864	0.526	0.772	0.755	0.245	0.23
<i>M. migrans</i>	0.800	0.845	0.498	0.747	0.797	0.203	0.25
<i>M. milvus</i>	0.825	0.914	0.354	0.795	0.856	0.144	0.20
<i>N. percnopterus</i>	0.800	0.936	0.356	0.825	0.923	0.077	0.17



Map 2. Favourability maps for all breeding raptors of Andalucía. The rarity of each species is presented. Black lines are representing the borders of the Natura 2000 protected areas.



Continuation Map 2.

Table 5. Variable importance of the favourability models. See section 3.6 of the methods for explanation on how it was calculated. A symbol – is used for variables that were not used to initialize the model. A variable receives a value of zero when it was not incorporated to the final model after the step wise procedure.

Category	Variable	Breeding forest			Breeding cliff			Breeding steppe		
		H. pennatus	C. galliicus	M. migrans	F. subbureo	N. Ferenopierus	F. natumanni	C. l.	F. natumanni	C. l.
Topography	Alt	0.128	0.186	0.736	0.000	0.312	0.124	0.000	0.000	0.000
	Max slope	0.030	0.000	0.000	0.228	0.000	0.000	0.000	0.000	0.000
	South exp	0.000	0.000	0.000	0.000	0.087	0.000	0.000	0.000	0.000
	West Exp	0.000	0.000	0.000	0.072	0.000	0.000	0.000	0.000	0.000
Water availability	Annual Prec	0.363	0.000	0.578	0.000	0.744	0.000	0.000	0.000	0.000
	Prec Driest Month	0.433	0.000	0.463	0.000	0.265	0.000	0.000	0.000	0.000
	Prec Warmest Quarter	0.058	0.095	0.000	0.256	0.402	0.000	0.000	0.000	0.000
	Runoff	0.000	0.000	0.204	0.340	0.662	0.218	0.000	0.000	0.000
Energy availability	Max Temp Warmest Month	0.064	0.103	0.000	0.328	0.198	0.088	0.000	0.000	0.000
	Min Temp Coldest Month	0.109	0.000	0.000	0.192	0.202	0.087	0.000	0.000	0.000
	Mean Temp Wettest Quarter	0.045	0.035	0.129	0.216	0.000	0.030	0.000	0.000	0.000
	Solar rad	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Productivity	Prec	0.112	0.000	0.078	0.000	0.433	0.000	0.000	0.000	0.000
	Temp Seasonality	0.175	0.055	0.258	0.000	0.450	0.000	0.000	0.000	0.000
	Air humidity	0.000	0.000	0.000	0.000	0.182	0.105	0.000	0.000	0.000
	Cont index	0.000	0.000	0.000	0.000	0.073	0.027	0.000	0.000	0.000
Climate stability	Days with prec >=0.1 mm	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Dst to cities	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Dst to water	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Dst to roads	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Land cover (%)	Agric land	0.000	0.000	0.066	0.000	0.100	0.126	0.000	0.000	0.000
	Artif land	0.152	0.098	0.048	0.000	0.084	0.000	0.000	0.000	0.000
	Forest land	0.035	0.141	0.122	0.269	0.000	0.129	0.000	0.000	0.000
	Shrubland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Human activity	Wetland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ndvi winter	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ndvi summer	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ndvi spring	0.082	0.000	0.052	0.166	0.000	0.064	0.000	0.000	0.000
Total # of input variables		18	18	18	18	16	21			

Category	Variable	Resident forest				Resident cliff			
		B. buteo	A. adalberti	A. monachus	H. fasciatus	G. fulvus	F. peregrinus	A. c.	
Topography	Alt	-	-	0.429	0.824	-	0.27	-	1.02
	Max slope	0	0	0.201	0.139	0.041	0.041	0.01	0.01
	South exp	0	0.124	-	0.02	-	0	-	0.052
	West Exp	0	0.06	-	0	-	0.029	-	0
Water availability	Annual Prec	0.209	0.381	0.341	0.306	-	0.143	-	0.36
	Prec Driest Month	-	-	-	-	-	-	-	-
	Prec Warmest Quarter	0.136	0	-	-	-	-	-	-
	Runoff	0.147	-	-	-	0	0.075	-	0
Energy availability	Snow days	0.064	0.342	-	0.03	-	0.072	-	0
	Max Temp Warmest Month	0.151	0.78	-	0.312	-	0.401	-	0.147
	Min Temp Coldest Month	0	0.463	-	-	-	-	-	-
	Min Temp Coldest quarter	-	-	-	-	-	-	-	-
Productivity	Mean Temp Wettest Quarter	0	0.314	-	-	0	0.225	-	0.098
	Solar rad	0.06	0.23	-	-	0	-	-	0
	ET actual	-	-	-	-	-	-	-	-
	Isothermality	0	-	-	0.12	-	0.251	-	0.082
Climatic stability	Temp Seasonality	-	-	0.34	-	-	-	-	-
	Prec Seasonality	0.315	0.427	-	0.572	-	0.726	-	0.523
	Air humidity	-	-	-	-	-	-	-	-
	Cont index	-	-	-	-	-	-	-	-
Human activity	Days with prec >=0.1 mm	0.179	-	-	0.024	-	0	-	0
	Dst to cities	-	-	-	-	-	-	-	-
	Dst to water	-	-	-	-	-	-	-	-
	Dst to roads	-	-	-	-	-	-	-	-
Land cover (%)	Agric land	0	-	-	0.3	-	0.194	-	0.298
	Artif land	-	-	-	0.017	-	0.126	-	0
	Forest land	0.106	0.364	0.067	0.037	0.026	0.026	0.018	0.021
	Shrubland	0.033	-	-	0	-	0	-	-
Productivity	Wetland	-	0.072	-	-	-	-	-	-
	Ndvi winter	0.07	-	0.471	0	0	0	0	0
	Ndvi summer	0.021	0.064	0.578	0	0	0	0	0
	Ndvi spring	-	-	-	-	-	-	-	-
Total # of input variables		20	14	7	19	19	19	19	19

4.2. Fuzzy models of diversity: Richness, rarity and vulnerability

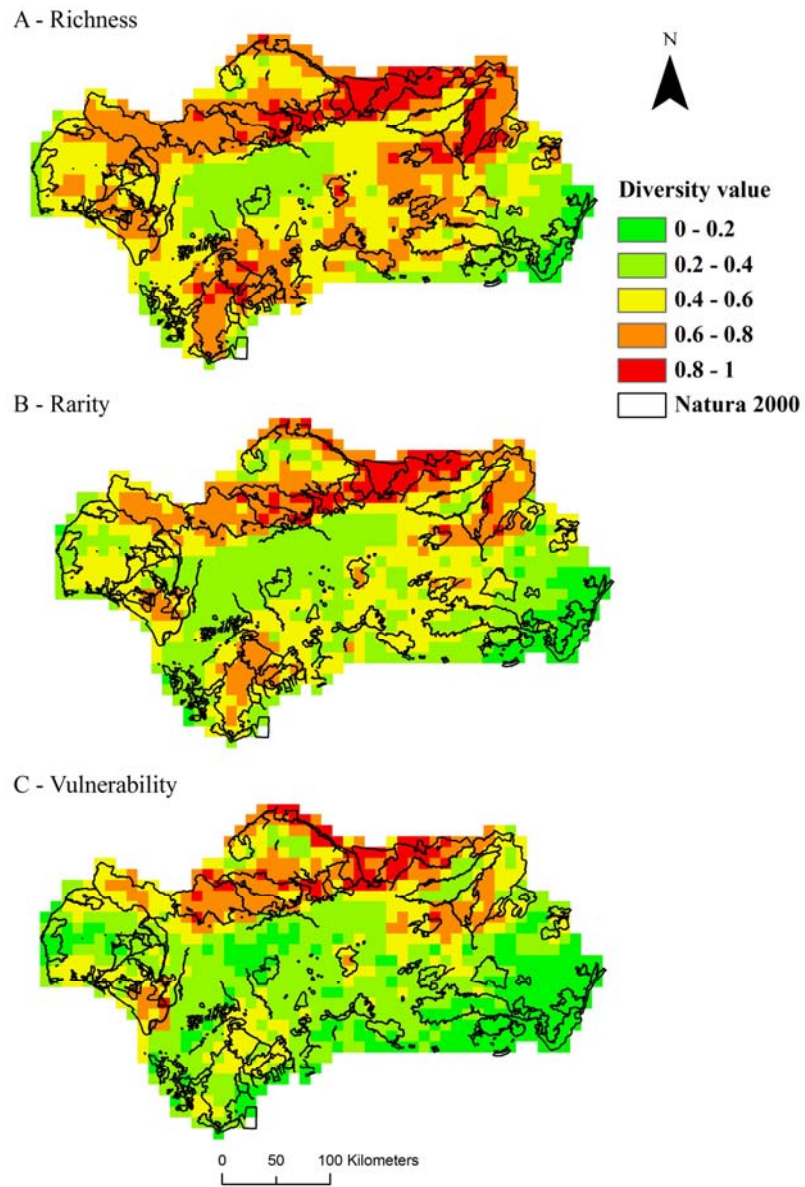
The species with the highest rarity were *A. monachus*, *A. adalberti*, *N. Percnopterus*, *G. fulvus* and *C. aeruginosus* (Map 2). All of this species except for *C. aeruginosus* are either cliff or forest nesting species. *C. aeruginosus* is associated with wetlands.

High values of all richness, rarity and vulnerability (at the pixel level) were found in the northern part of Andalucía in the Sierra Morena Mountains and in the mouth of the Guadalquivir River. Additionally, high values of both richness and rarity were encountered in the South-West of Andalucía in the Sierra de Ronda and the Campo de Gibraltar and in the South-East of Jaen in the Cazorla Sierra (Map 3).

The total sum of each diversity attribute over Andalucía is higher for richness, followed by vulnerability and rarity (Table 6). These values were used to standardize the degree of disprotection of the diversity attributes.

Table 6. Sum of the diversity values over all pixels for richness, rarity and vulnerability. These values were used to calculate the degree of disprotection as part of Equations 7, 8 and 9.

Diversity attribute	Sum of Diversity values over all pixels
Richness	536.6284
Vulnerability	368.5593
Rarity	239.2444



Map 3. Richness, rarity and vulnerability at the pixel level of raptors in Andalucía.

4.3. Correlation of richness, rarity and vulnerability

As answer to research question *a'* all pairs of diversity attributes of raptors in Andalucía are significantly and positively correlated according to the Pearson's correlation coefficient (Table 7). The scatter plots between diversity attributes (Figure 5) show that for most of the pixels vulnerability is lower than rarity and rarity lower than richness. The relation between richness and vulnerability is the one that deviates the most from a linear one (Figure 8B). For pixels with values of richness between 0.4 and 0.8 the corresponding vulnerability values range between 0.2 and 0.6.

Given the fact that most pixels have values of vulnerability and rarity lower than richness the few pixels that have a high value of richness but an even higher value of vulnerability of rarity are particularly important in terms of conservation. Map 4 shows the areas where either vulnerability or rarity is higher than richness. These areas are mainly located in the north of Andalucía in the Guadalmez and Zujar Rivers, the Alto Guadiato region, the "Sierra de los Santos", and south east of the "Sierra de Cardeña" and Montoro.

Table 7. Pearson's correlation coefficient between the diversity attributes

Diversity attribute		Richness	Vulnerability	Rarity
Richness	Pearson	1	0.8225*	0.9714*
	Sig.		0.0000	0.0000
Vulnerability	Pearson		1	0.9137*
	Sig.			0.0000
Rarity	Pearson			1
	Sig.			

*significant at the 0.01 level (2-tailed)

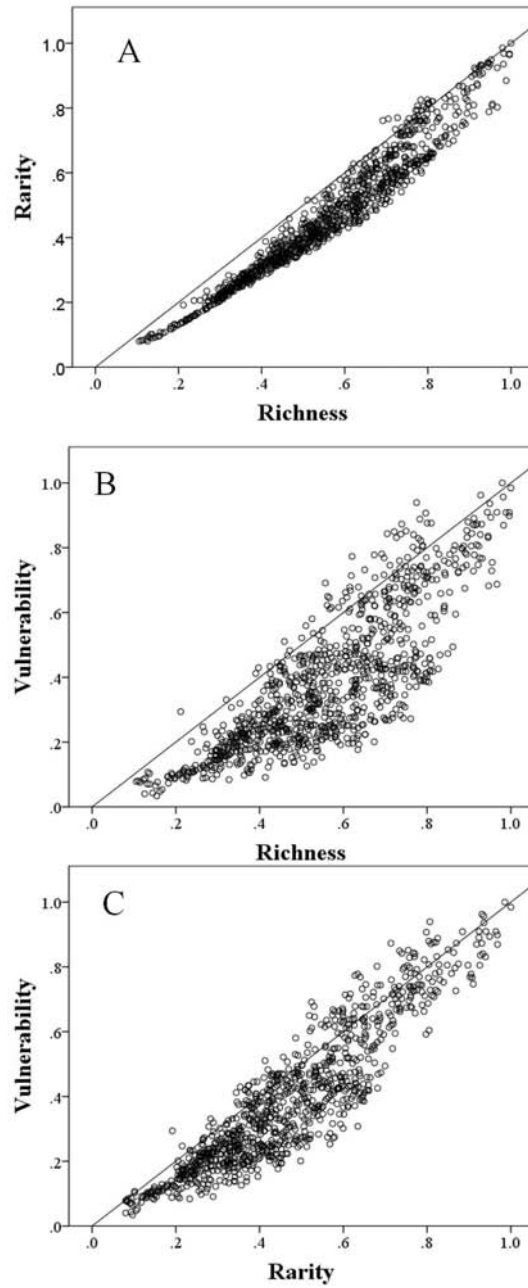
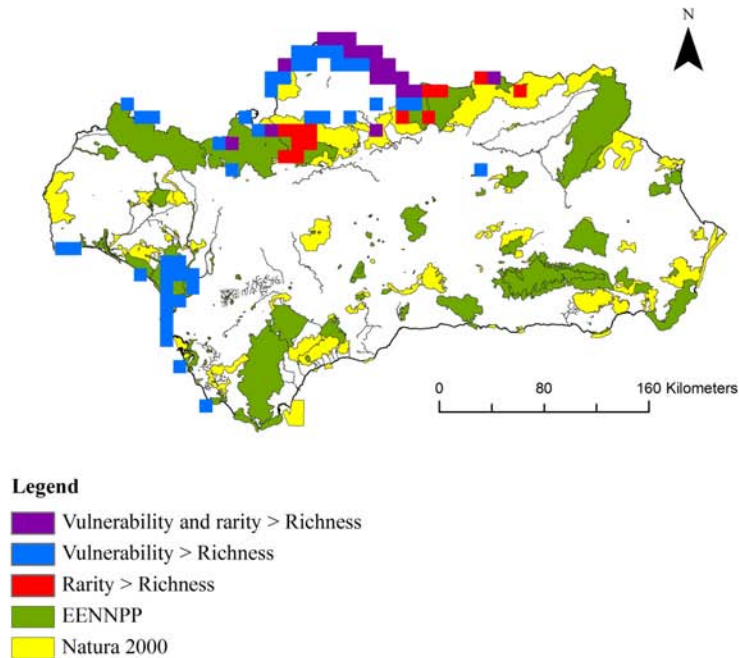


Figure 5. Scatter plots of diversity attributes. Richness and rarity (a), richness and vulnerability (b) and rarity and vulnerability (c).

Areas where rarity and vulnerability are higher than richness



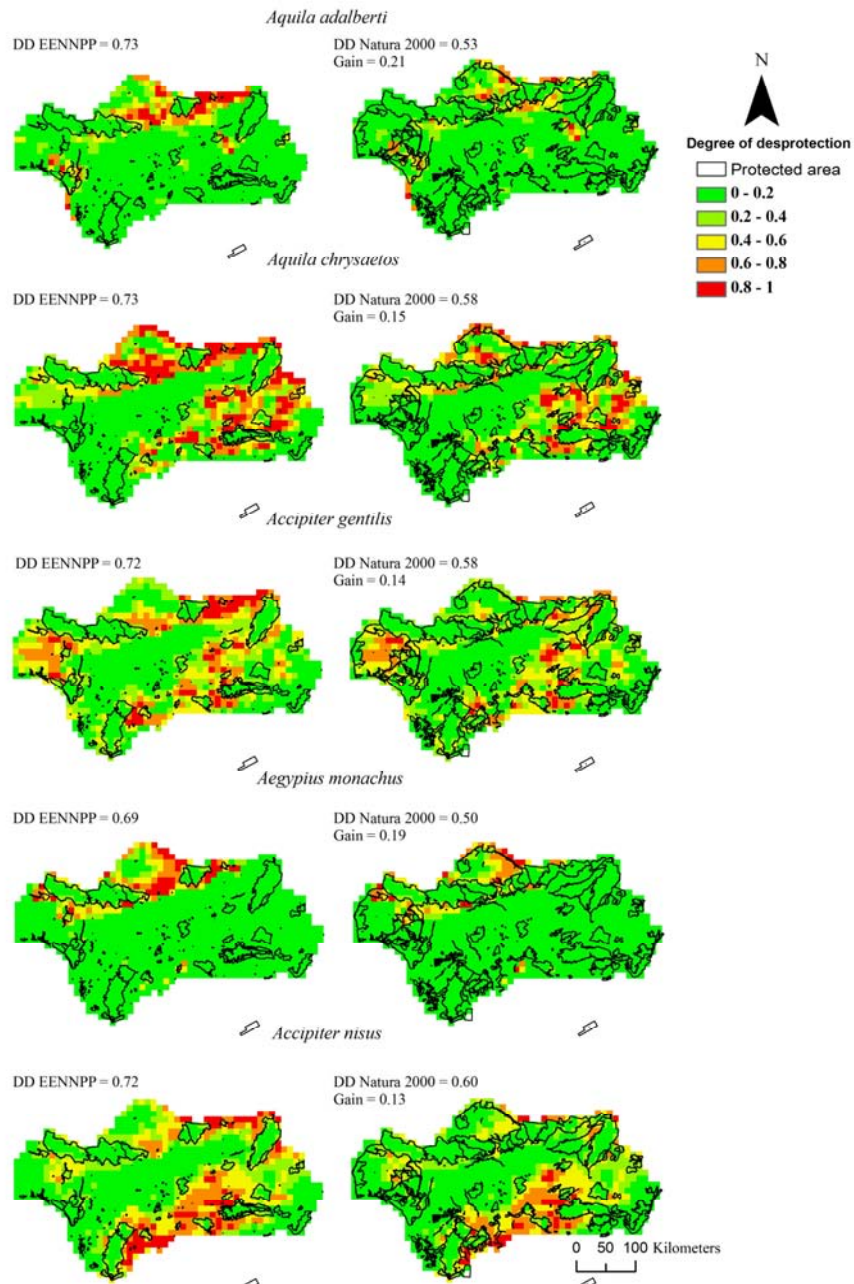
Map 4. Localization of pixels with higher values of vulnerability than richness and pixels with higher values of rarity than richness. The shapes of the networks of protected areas are used as background.

4.4. Fuzzy degree of disprotection

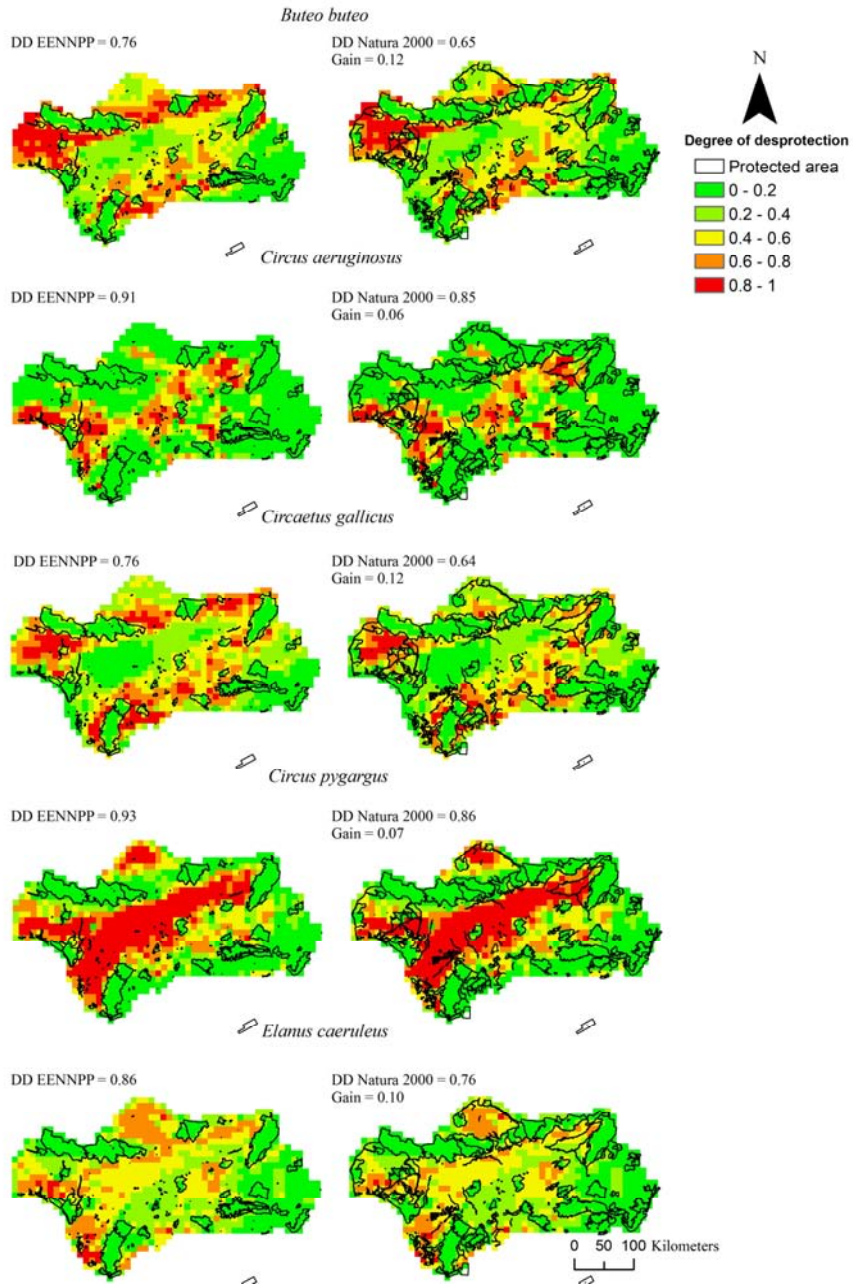
4.4.1. Species level

The species with the highest degree of disprotection were *C. pygargus*, *C.aeruginosus*, *F. naummani* and *E. caeruleus* under the two networks of protected areas (Map 5). For all species the degree of disprotection is less under the Natura 2000 network. In average all raptors have a degree of disprotection of 0.66 ranging from 0.52 in *G. fulvus* to 0.86 in *C.pygargus* under the Natura 2000 network.

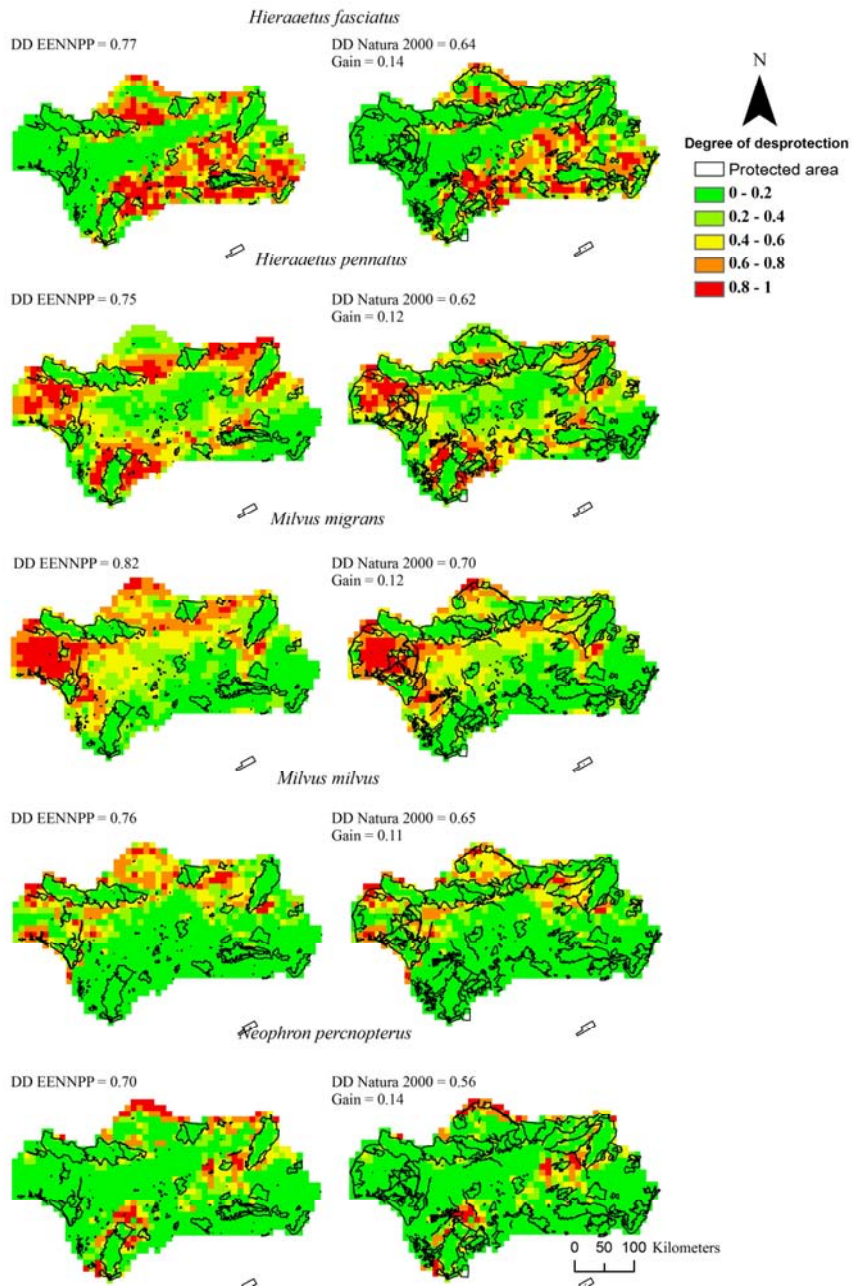
The three species with the lowest degree of disprotection under the EENNPP network (*A. monachus*, *G. fulvus* and *A. adalberti*) are the ones that have the highest gain in protection under the Natura 2000 network (Map 5).



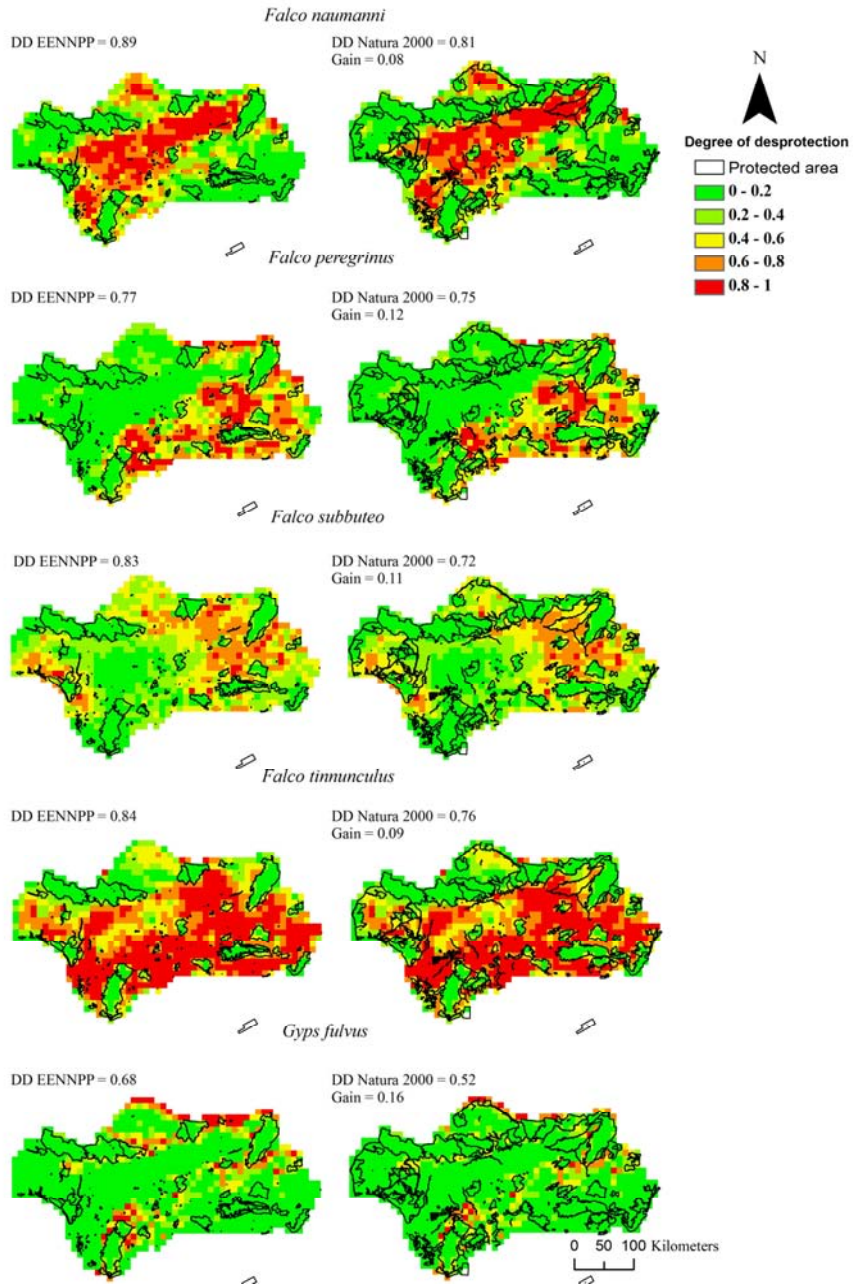
Map 5. Maps of degree of desprotection for each species under the EENNPP and Natura 2000 networks.



Continuation Map 5.



Continuation Map 5.



Continuation Map 5.

In reference to research question ‘c’, the ANOVA test (Table 8) showed significant differences in the degree of disprotection of forest, cliff and steppe raptors. Specifically, the Tukey test showed that steppe nesting raptors are significantly more disprotected than forest or cliff species (Figure 6 and Appendix 4). Steppe raptors presented a degree of disprotection of 0.888 under EENNPP and of 0.809 under Natura 2000 network.

Table 8. Analysis of variance of the degree of disprotection of raptors with different nesting habitats. * significant at the 0.01 level.

ANOVA oneway	F	Sig.
Degree of disprotection EENNPP	22.312	0.00002*
Degree of disprotection Natura 2000	19.157	0.00004*

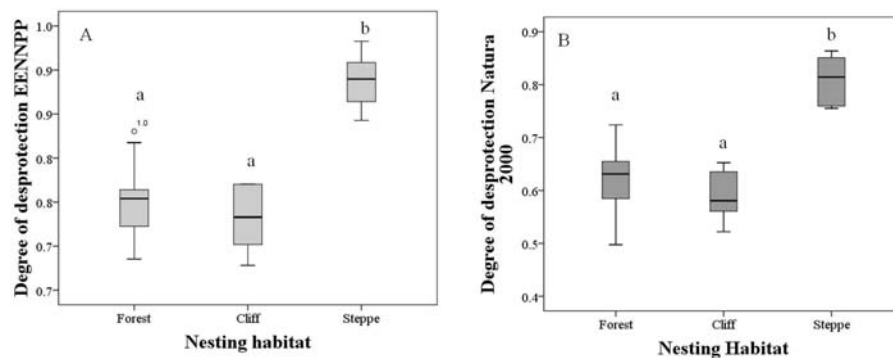
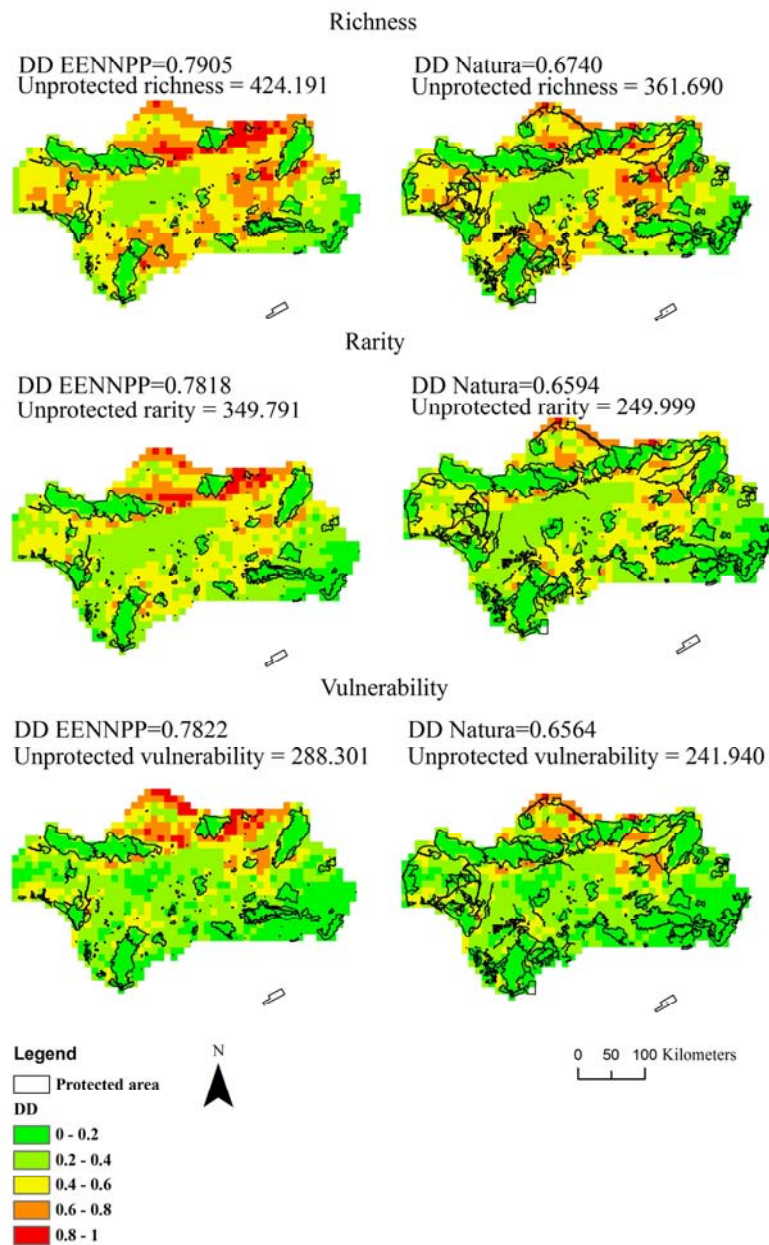


Figure 6. Box-plots of degree of disprotection and nesting habitat for the EENNPP (A) and Natura 2000 (B) networks. a and b are groups according to a significant difference in the degree of disprotection. For detailed results see Appendix 4.

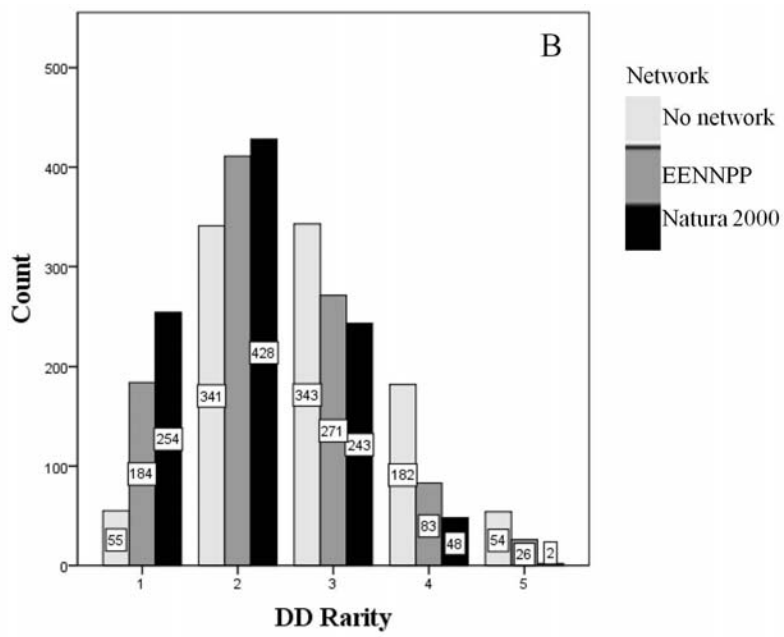
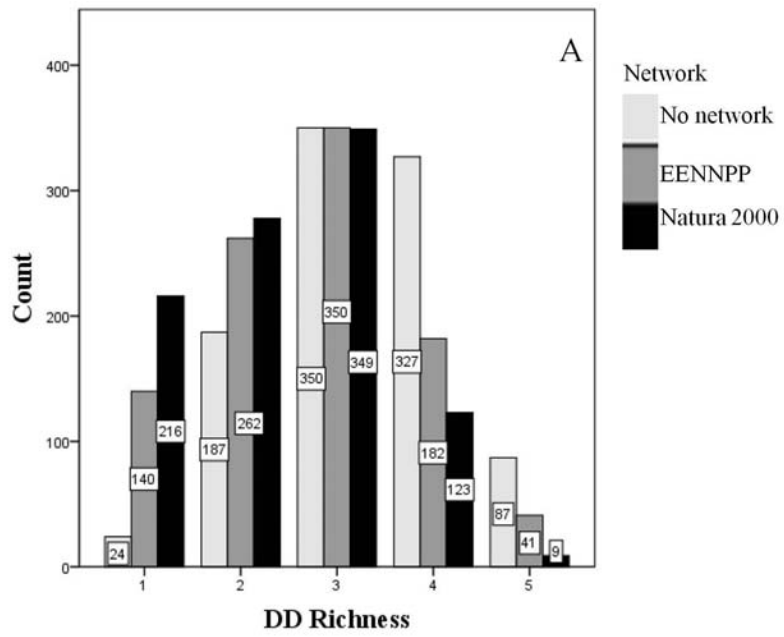
4.4.2. Diversity level

Answering research question ‘b’, it was found that richness had a higher degree of disprotection than vulnerability and vulnerability had a higher degree of disprotection than rarity (DD Richness > DD Vulnerability > DD Rarity) under the EENNPP network (Map 6). Under the Natura 2000 network, rarity had a higher degree of disprotection than vulnerability, and richness remained as the one with the highest degree of disprotection (DD Richness > DD Rarity > DD Vulnerability). With the implementation of the Natura 2000 network the gain in protection for richness is 11.647%, for rarity 12.579% and for vulnerability 12.247%.

An inspection of the maps in Map 6 shows that the expansion of the network of protected areas of Andalucía with Natura 2000 covers areas with high values of all diversity attributes (0.6-1). Specifically the Natura 2000 network covers a much wider area of the Sierra Morena in the North of Andalucía and includes the Guadalmez River in the limit between Andalucía and Castilla de la Mancha. This inclusion of highly diverse areas in the Natura 2000 network is evidenced by a decrease of the frequency of pixels with values between 0.6 and 1 of disprotection of all diversity attributes (Figure 7). For example, under the EENNPP network there were 99 pixels with a disprotection between 0.6 and 1, with the Natura 2000 network 46 of these pixels are protected and 53 pixels remain unprotected.



Map 6. Maps of DD (Degree of disprotection) for each diversity attribute under the two networks: EENNPP (left) and Natura 2000 (right). The total sum of the diversity attribute in Andalucía (Total richness, rarity and vulnerability), total unprotected and DD for each diversity attribute is presented above each map.



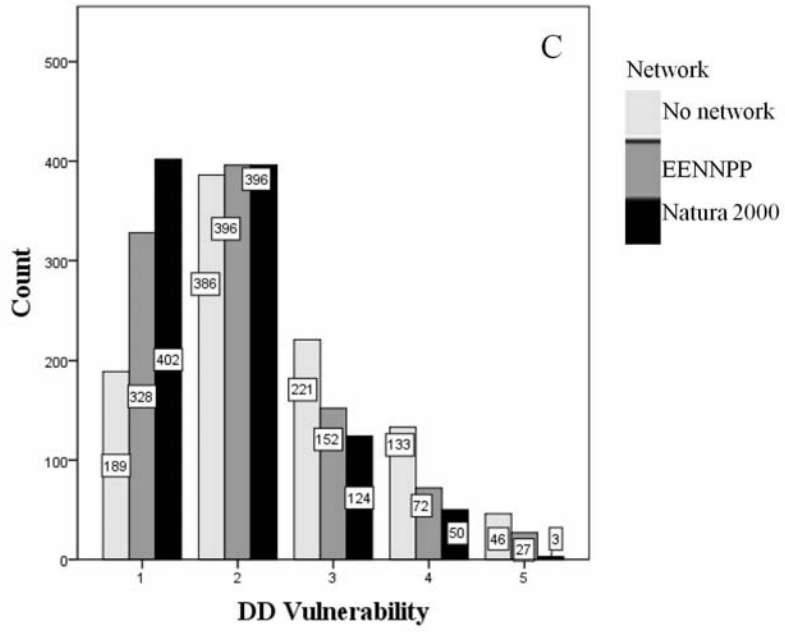


Figure 7. Frequency of DD values in 5 bins (0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1) for richness (A), rarity (B) and vulnerability (C) under No network (white), EENNPP (grey) and Natura 2000 (black).

5. Discussion

5.1. Environmental favourability models and evaluation results

5.1.1. Interpretation of the evaluation results for gap analysis

Different evaluation measures provide different information about the models; mainly about the discrimination capacity and the calibration of the models (Pearce, 2000). The choice and interpretation of evaluation measures should depend on the application that is going to be given to the models (Elith and Leathwick, 2009). Here the predictions of favourability were used, without transformation, for modelling diversity attributes and assessing the degree of disprotection of both species and diversity attributes at a landscape (for all Andalucía) and at a pixel level. The information on a landscape level says which species or which diversity attribute should be a priority for further conservation actions, and the pixel level indicates the locations that are priority if further expansion of the network is intended.

Both the calibration and the discrimination capacity of the models are very important for the gap analysis performed here. Well calibrated models produce reliable calculations of diversity attributes and comparable degrees of disprotection. Models with a good discrimination capacity are needed so that conservation priorities can be easily distinguished. Models that are not well calibrated but that have a good discrimination capacity are still good to identify areas of high conservation value for individual species.

AUC and kappa are supposed to be measures of the discrimination capacity of the models. Although AUC has been commonly used, high values of AUC could appear for species that have very restricted distributions in the range of environmental variation (Lobo et al., 2008). To assure that the models have a good discrimination capacity, both AUC and kappa (calculated with a threshold of 0.5 and based on favourability values) should be high. The kappa score calculated with favourability values is not affected by the prevalence of the species (Real et al., 2006a), as is the kappa score calculated with probability values (Allouche et al., 2006). Finding conservation priorities based on models with low kappa values will result in serious errors. An area could be regarded as a priority even when the species is not present or an area could be discarded as non priority even when the species is present. The degree of disprotection will be affected since presence and absence will be difficult to distinguish for these species.

The source of uncertainty of the models that presented low kappa values is very important when trying to find out the applicability and consequences of using the model. Two important sources of uncertainty can be distinguished: false positive or false negative errors. For example, the model for *F. tinnunculus* presents high false negative errors; the area of occurrence of this species is underestimated. Priorities set for this species will not be misleading in terms of the species not being present in the area, but its degree of disprotection may be overestimated. Differently, the low kappa scores of *E. caeruleus* and *F. subbuteo* are a result of both false negative and false positive errors that result from a high number of areas with intermediate favourability values. The models for these species are insufficient to accurately identify conservation priorities for the species at a pixel level or their degree of disprotection, and results in an underestimation of their individual rarity. These species will not be contributing to the pixel level rarity of raptors and prioritizing rarity will not be accounting for their conservation. For *A. monachus* and *N. percnopterus* the source of error is a high proportion of false positive errors, and the risk is the possibility of setting false priorities for conservation and the illusion that there are more options to locate protected areas than there really are (Loiselle et al., 2003). The species may appear more protected depending on the location of the false positive errors.

Ideally the calibration of the models should be evaluated by finding the relationship between the predicted probability of occurrence and the observed proportion of presences in an independent evaluation set. Methods for this type of evaluation are described in Pearce (2000). These plots and derived statistics were obtained using probability values and the same dataset used to calibrate the models (Examples of these plots are presented in Appendix 5). This was done to gain an idea of the calibration of the models, using the `Val.prob` function of the R library `Design`. Nonetheless, the evaluation of the calibration may be overestimated given that the same dataset used for calibration is being used for the evaluation. The slope and intercept of these plots show the spread (systematic departure of the regression line from a 45°) and bias (overestimate or underestimate of the probability of occurrence) of the models respectively. The species that presented either low AUC or low kappa values had also calibration problems. For example, the model for *E. caeruleus* is underestimating the probabilities under 0.5 (Appendix 5-a) and the model for *A. monachus* is underestimating the probability of occurrences over a value of 0.5 (Appendix 5-b). In addition to the species already mentioned, precaution must be taken with the model for *C. aeruginosus* which has a very high spread (slope) and bias (intercept), significant even when the same set for calibration is used for plotting the calibration curve (Appendix 5-c). Since the model for *C.*

aeruginosus had good discrimination capacity but was badly calibrated, the model is useful if the idea is to identify conservation priorities for the conservation of this species alone, but it introduces error in the calculation of diversity attributes, and its degree of disprotection is not comparable with the ones from other species. For the species' models that presented either calibration or discrimination problems a summary of their potential applicability is presented in Table 9.

5.1.2. Implications of the data resolution

An important issue when deciding the modelling approach was the modelling resolution. The species data is available at a coarse resolution (10x10km) and the environmental data at a much finer one (1x1km). Problems arise from either downscaling the species data or upscaling the environmental data. The risk of downscaling the species data is to assign the wrong geographical location to the presence of a species and for that reason sample the wrong environmental conditions (Guisan et al., 2007). However, the upscaling of environmental data entails the risk of matching the location of species with environmental conditions that do not relate to its presence but that occur nearby. The upscaling of environmental variables is here justified by the mobile nature of species like raptors. Raptors location is not only based on the conditions nearby of the nest (land cover, slope, south exposure, etc) but also on the environmental conditions that surround the nest, such as the ones determining the availability of appropriate feeding areas.

Table 9. Effects of discrimination and calibration problems, and of the source of errors false positives (F+) or false negatives (F-) in the definition of conservation priorities within a pixel level for each species, in the degree of disprotection of the species at a landscape level and on the calculation of diversity metrics (Richness, rarity, vulnerability). * low error because of a high number of intermediate values of favourability that do not over or underestimate richness significantly.

Species model	Model problem			Effect on conservation planning			
	Discri.	False +/-	Calib.	Ability to identify cons. Priorities (species-pixel level)	Degree of disprotection (species-landscape level)	Species rarity	Richness and vulnerability (pixel level)
<i>Aegypius monachus</i>	Bad	F+	Bad	False priorities/ False options	Underestimation	Under	Over where F+
<i>Circus aeruginosus</i>	Good	None	Bad	Neutral	Error	Low error	Error
<i>Elanus caeruleus</i>	Bad	F+/-	Bad	No discern	Error	Error	Low Error *
<i>Falco subbuteo</i>	Bad	F+/-	Bad	No discern	Error	Error	Error
<i>Falco tinnunculus</i>	Bad	F-	Bad	Correct priorities/Less options	Overestimation	Over	Under where F-
<i>Neophron percnopterus</i>	Bad	F+	Bad	False priorities/ False options	Underestimation	Under	Over where F+

5.2. Richness, rarity and vulnerability: Correlation of diversity attributes

Habitat heterogeneity is considered one of the most important factors determining species richness because it entails more ecological niches available (Tews et al., 2004). Climate, as it relates to productivity, is thought to influence the richness of species as well. Higher productivity means larger populations' sizes and the larger the populations are, the lower the risk of becoming extinct and the higher the number of species coexisting (Wright, 1983). Climate and habitat heterogeneity have been found to affect richness patterns of birds in Spain with different degrees of influence depending on the scale (Moreno-Rueda and Pizarro, 2007, Moreno-Rueda and Pizarro, 2009). At a national level Moreno-Rueda and Pizarro (2009) found that precipitation and habitat diversity correlated positively with birds richness, with precipitation being the variable that explained a greater portion of the richness variance. At a local scale in a study in the province of Granada (southern Andalucía) Moreno-Rueda and Pizarro (2007) found that the most important factor determining birds richness was habitat heterogeneity, and that specifically for raptors habitat diversity was positively and human population density was negatively correlated with richness. The scale of the present study is between the national and the regional levels previously mentioned. It is expected that the richness patterns observed are explained by both the habitat heterogeneity and the climate.

High diversity values of raptors were mainly located in mountainous areas of Andalucía and in the mouth of the Guadalquivir River. The mountainous areas of Andalucía cover a wide altitudinal range and for this reason contain a higher number of habitats than lowlands such as the Guadalquivir valley. Additionally, mountainous areas are less suitable for agricultural activities which reduce the homogenizing effect that is caused by human transformation. Mountainous areas provide nesting habitats for cliff and forest nesting species, which constitute 15 out of the 20 breeding raptors of Andalucía. The mouth of the Guadalquivir River provides a high number of habitats and is highly productive given its condition as buffer zone between the terrestrial and marine environments. The high diversity of habitats and the high productivity are plausible explanations of the richness patterns of breeding raptors in Andalucía.

At a global scale, Orme et al.(2005) found that large islands and islands archipelagos have high numbers of rare species. Evolutionary processes such as allopatric speciation would be responsible for this pattern. At a local scale, such as Andalucía,

species could be considered rare even when they are widely distributed globally or could be considered common even when they are extremely rare globally. The explanation behind the rarity of a species is the fact that the specific environmental conditions that it requires are met only by few places in Andalucía. Places that contain these specific environmental conditions will have a high diversity of rare species. Having said that richness patterns are likely to be a result of high habitat heterogeneity then, it is likely that within the set of environmental conditions present in rich areas, the specific conditions needed by rare species are included. This would explain why the pattern of rarity in this region coincides with the pattern in richness.

It is considered that species that occupy small geographical ranges and that occur at low densities tend to have a higher risk of extinction (Purvis et al., 2000). Given the fact that rarity here depends on how wide the distribution of the species is in Andalucía, irrespective of how wide is the distribution globally, it would be expected that rarity does not imply a higher risk of extinction of the species. Nevertheless, in the present study the vulnerability assessment used to weight the favourability values is the local one, provided by the Andalucía government. This means that the vulnerability assigned to each species, in reality reflects the risk of the specie's local populations to become extinct rather than the whole species' risk. Given this context, it may still apply that species with restricted distributions in Andalucía have a higher risk of extinction at the population level. In fact the most vulnerable species (critically endangered and endangered) have an average of species rarity of 0.005 while the remaining species have an average rarity of 0.002. This relation between species rarity and category of vulnerability are probably explaining the correlation between rarity and vulnerability of raptors at the pixel level.

There may be two explanations for richness and vulnerability correlating, one is that areas high in richness are subject to a higher number of threats and/or species in rich areas are more vulnerable to threat (Gaston and Blackburn, 1996). According to the previous paragraphs it can be expected that in the case of raptors in Andalucía the second alternative is true: species in rich areas are more vulnerable to threat. This is inferred from the fact that rich areas contain higher number of rare species of raptors, and rarity yields a higher risk of extinction making richness and vulnerability to be correlated in Andalucía.

The possibility that the correlation of the diversity attributes is a result of how the indices are formulated should be explored more deeply. A preliminary check has been performed creating simulated species to understand the behaviour of the

indices. It was possible to simulate scenarios where the indices were not correlated. Still a bigger number of simulated species and larger simulated areas need to be used to support these preliminary results.

No previous studies had done a gap analysis specifically for raptors and the importance of doing one is reiterated by the results of previous gap analysis of birds in Andalucía. Estrada (2008b), using the same methodology employed here, modelled diversity attributes of bird species in Andalucía. Although the richness pattern of birds was similar to the richness patterns of raptors, diversity patterns of birds present some differences worth mentioning. Raptor's richness, rarity and vulnerability values, as modelled here, are high in the entire Sierra Morena whilst for birds values are high only in the east and west extremes of this Sierra. The area with high diversity values in the mouth of Guadalquivir River is wider for birds than for raptors. Remarkably, the Guadalmez River, which has high values of raptor's richness, rarity and vulnerability, does not have high values of overall bird's richness, rarity or vulnerability. Priorities set based on bird's diversity may be overlooking areas that are extremely important for the protection of raptor's diversity which highlights the importance of a gap analysis that deals specifically with this group of birds.

5.3. Fuzzy degree of disprotection

Several studies doing gap analysis have used predefined thresholds to transform outputs of SDM's into binary present and absent data and to define the protection status of grid cells (Maiorano et al., 2006, Martinez et al., 2006, Araújo et al., 2007, López-López et al., 2007, Rondinini et al., 2005, Sanchezfernandez et al., 2008, Traba et al., 2007). Previous studies that have used favourability values to evaluate networks of protected areas have also defined thresholds to divide high diversity areas and to define the protection of grids (Estrada, 2008b, Estrada et al., 2008). It has been shown that the threshold chosen for setting the protection status of grid cells affects the estimated representation of species in networks of protected areas (Araújo, 2004) and that the use of two thresholds (probability and protection) in gap analysis may increase the uncertainty of the results (Alagador et al., 2011). To address the uncertainties involved with the threshold approach, the present study proposes a degree of disprotection at the species, diversity and pixel level that does not rely in predefined thresholds.

Recently, Alagador et al. (2011) proposed a similar approach to evaluate the representativeness of species in a network of protected areas, formulating an equation equivalent to a degree of protection at the species level but based on probabilities of occurrence. Alagador et al.(2011) tested the consistency of this method compared to the use of thresholds and showed that traditional thresholds yield inconsistent results. In the present research a degree of disprotection is proposed and it is based on favourability values. The disprotection provides information on how the species or the diversity attributes are underrepresented in the protected areas and helps identifying conservation priorities. Furthermore, the degree of disprotection obtained at pixel level aids in the identification of areas that should be prioritised for future conservation efforts. An advantage of the degree of disprotection here proposed is that it is comparable among species with different prevalence because it is based on favourability values. The comparability of the degrees of disprotection is highly important when conservation priorities are to be set based on its results.

The degree of disprotection should be carefully interpreted. It is not the unprotected percentage of the total area where the species is distributed. Indeed, the real distribution of a species may be completely falling inside protected areas and still the degree of disprotection will give a value different from zero. Anyway, the degree of disprotection is proportional to that percentage and as such provides the same information on how effective is the protection of the species.

Precaution should be taken when obtaining degrees of disprotection for species that have intermediate favourability values even on areas where it is present; the degree of disprotection may give a low value, and still a large amount of areas where the species are present may be disprotected.

5.4. Gaps at the species level

The analysis of the degrees of disprotection of species with different nesting habitats showed that the networks of protected areas of Andalucía are not effective for the protection of steppe raptors. Previous studies have shown that the networks of protected areas of Spain are not effective for the protection of steppe birds Traba et al. (2007) and had called for special attention to endangered steppe avifauna given the recent changes in the Iberian steppes (Laiolo and Tella, 2006). Agricultural intensification, scrub encroachment caused by the abandonment of traditionally cultivated areas, transformation for industrial activities and wind turbines are some of the threats that steppe habitats face in Spain (Laiolo and Tella, 2006). In fact,

steppes are included in annex I of the European Union habitat directive of the Natura 2000 network. Nevertheless, in Andalucía the Natura 2000 network does not show an improvement in protection of steppe species over forest or cliff nesting species. In fact the species having a high degree of disprotection under the EENNPP network, that are all steppe species, are the ones with the lowest gain with the implementation of the Natura 2000 network.

Important to consider is that given the evaluation results of the favourability models of *F. subbuteo* and *E. caeruleus* different approaches to identify conservation priorities for these species must be developed.

5.5. Gaps at the diversity level

Both networks of protected areas of Andalucía are effective in reducing the disprotection of the three diversity attributes of raptors: richness, rarity and vulnerability. The effectiveness is higher for rarity and vulnerability compared to richness. This is due to the networks covering areas high in richness, vulnerability and rarity, but not covering areas high in richness but low in rarity and vulnerability.

The higher protection of rarity and vulnerability is particularly true for the Natura 2000 network. It could be explained by the inclusion of key regions such as the Guadalmez River and the Guadiato-Bembezar. As mentioned in section 4.3 these regions have high values of all diversity attributes, but even higher values of vulnerability or rarity compared to richness (Map 4). In fact the presence of *H. fasciatus* is one of the reasons for declaring the Guadalmez River a protected area. This shows the importance that vulnerability plays in the selection of Natura 2000 sites and explains the preference observed for rarity and vulnerability over richness of raptors in Andalucía.

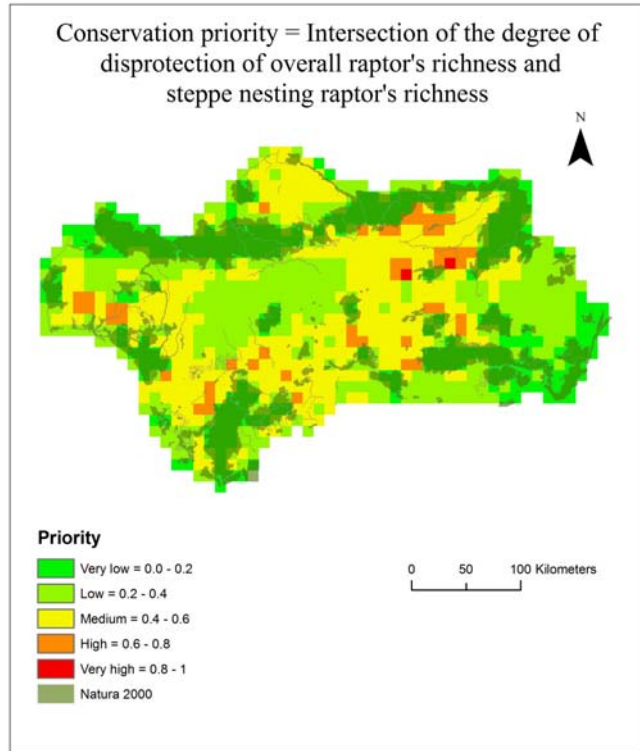
5.6. Implications for conservation

The following section is particularly aimed at conservation practitioners. The implications of the results obtained here are explained in the context of conservation practice.

- Rarity or vulnerability can be used as surrogate for the remaining diversity attributes of raptors in Andalucía. Considering that the diversity attributes are highly correlated and that rarity and vulnerability in most of the cases have lower values than richness, the conservation of areas with high rarity or high vulnerability would be covering areas of high value of the remaining diversity attributes.

- Although diversity attributes of raptors in Andalucía are effectively protected, the network presents an important gap: steppe species. The representativeness is one important criteria in systematic conservation planning (Margules and Pressey, 2000). As seen from the results of the degree of disprotection at the species level, one important risk of using diversity attributes, such as richness, to identify conservation priorities is the fact that species distributed in areas of low richness are disprotected. The incorporation of both criteria: diversity and species representativeness is very important when evaluating the effectiveness of a network of protected areas.
- Since the economical usefulness of steppe habitats makes difficult the establishment of protected areas covering this habitat type, other management strategies should be undertaken to take care of this gap in the network of protected areas of Andalucía.
- A gap in coverage of areas that are high in richness but not high in rarity or vulnerability was encountered. This gap should not be overlooked. These areas are probably containing species that are underrepresented in the network of protected areas as the mentioned steppe nesting raptors and are extremely important for covering both the gap in steppe raptors and in richness. The Map 7 shows those areas where high values of both overall richness and steppe raptors richness coincide.
- The maps of degree of disprotection at the pixel level for species (Map 5) and diversity attributes (Map 6) serve as guide to identify areas of conservation priority for future conservation actions either in the form of expansion of protected areas or of implementation of management strategies. The table showing the implications of the evaluation results of the favorability models (Table 9) should be used, in addition to the mentioned maps of disprotection, so that no misguided priorities are set.
- The results presented here are limited to the breeding part of the populations. Different priorities should be set for the raptors that winter in Andalucía and for the juvenile part of the populations. These two are still important components of the diversity of raptors in Andalucía and deserve conservation actions. Additionally, information about the

ranging behaviour and foraging habitats of the species should be included in the modelling process as they have been proved to be extremely important for locating conservation priorities (Guixé and Arroyo, 2011).



Map 7. Conservation priorities for steppe nesting raptors and for the overall raptors' richness.

6. Conclusion

Environmental favourability models were obtained for the raptors breeding in Andalucía and used to calculate diversity attributes (richness, rarity and vulnerability) within a fuzzy logic framework. Richness, rarity and vulnerability of raptors are correlated in Andalucía, and serve as surrogates of each other in conservation planning.

A fuzzy degree of disprotection was proposed as a measure of the effectiveness of protected areas to reduce the uncertainty arising from the use of arbitrary thresholds and targets in gap analyses. Using the degree of disprotection proposed here, it was found that the network of protected areas of Andalucía is effective for the protection of raptors' diversity attributes. Nevertheless, it is more effective in protecting rarity and vulnerability, leaving unprotected areas where the richness is high but where the rarity and the vulnerability are not.

Steppe nesting raptors in Andalucía are an important gap in the network of protected areas. Areas where both overall richness and steppe raptors' richness are high are proposed as conservation priorities to overcome the gaps encountered.

7. Recommendations

- Perform evaluation of the calibration in a cross-validation procedure by splitting the data n times and reporting the average results. Unfortunately when the models were run the splitting procedure was not set to store each prediction separately so the curves could not be done afterwards.
- Combined degrees of disprotection based on the rarity of the species: a rare species should appear more disprotected than a common species even if the same proportion of its favourability values is under protection.
- It is possible to test if habitat heterogeneity and climate are influencing the patterns of richness of raptors observed in Andalucía. This could be done by performing multiple regression analyses with richness as the dependant variable and number of land cover classes inside each cell and surrogates of productivity such as temperature and precipitation as explanatory variables.
- In order to assess the impact of using environmental variables at a coarse resolution and to obtain results more easily used in real conservation scenarios, a randomization of the species data could be done to downscale it to a 1x1km resolution. The standard deviation from a set of n models could be used as a measure of uncertainty of the outputs.
- Further development of measures of effectiveness, such as the deviation of the degree of disprotection from the one expected by a randomly located set of protected areas and the deviation from the lowest possible degree of disprotection.

8. References

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Appendix 1. Scientific and common names of species modelled. Their category of vulnerability in Andalucía, prevalence, number of environmental variables input in the modelling and the maximum number of variables that should be input in the modelling process to avoid over fitting given the prevalence according to (Harrell et al., 1996).

Species	English name	Spanish name	Breeding status/nesting habitat	Vuln. category	Prevalence	# var input	Max # of var
<i>Aquila adalberti</i>	Spanish Imperial Eagle	Águila Imperial Ibérica	Resident Forest	Critically endangered	0.064	14	6
<i>Aquila chrysaetos</i>	Golden Eagle	Águila Real	Resident Rock	Vulnerable	0.434	19	30
<i>Accipiter gentilis</i>	Northern Goshawk	Azor Común	Resident Forest	Not threatened	0.411	20	28
<i>Aegypius monachus</i>	Cinereous Vulture	Buitre Negro	Resident Forest	Endangered	0.041	7	4
<i>Accipiter nisus</i>	Eurasian Sparrowhawk	Gavilán Común	Resident Forest	Not threatened	0.362	20	26
<i>Buteo buteo</i>	Common Buzzard	Busardo Ratonero	Resident Forest	Not threatened	1.468	20	40
<i>Circus aeruginosus</i>	Marsh Harrier	Aguilucho Lagunero Occi.	Resident Steppe	Endangered	0.110	18	10
<i>Circus gallicus</i>	Short-toed Eagle	Culebrera Europea	Breeding Forest	Not threatened	0.690	18	47
<i>Circus pygargus</i>	Montagu's Harrier	Aguilucho Cenizo	Breeding Steppe	Vulnerable	1.079	21	40
<i>Elanus caeruleus</i>	Black-shouldered Kite	Elanio Común	Resident Steppe	Vulnerable	0.052	7	5
<i>Falco naumanni</i>	Lesser Kestrel	Cernícalo Primilla	Breeding Steppe	Near Threatened (NT)	0.432	21	29
<i>Falco peregrinus</i>	Peregrine Falcon	Halcón Peregrino	Resident Rock	Vulnerable	0.391	19	27
<i>Falco subbuteo</i>	Eurasian Hobby	Alcotán Europeo	Breeding Forest	Data deficient	0.098	18	9
<i>Falco tinnunculus</i>	Common Kestrel	Cernícalo Vulgar	Resident Steppe	Not threatened	10.337	23	9
<i>Gyps fulvus</i>	Eurasian Griffon	Buitre Leonado	Resident Rock	Not threatened	0.114	19	10
<i>Hieraetus fasciatus</i>	Bonelli's Eagle	Águila-azor Perdicera	Resident Rock	Vulnerable	1.061	19	38
<i>Hieraetus pennatus</i>	Booted eagle	Águilla calzada	Breeding Forest	Not threatened	0.457	18	47
<i>Mibvus migrans</i>	Black Kite	Milano Negro	Breeding Forest	Not threatened	0.102	18	31
<i>Mibvus milvus</i>	Red Kite	Milano Real	Resident Forest	Critically endangered	0.071	19	9
<i>Neophron perenopterus</i>	Egyptian Vulture	Alimoche Común	Breeding Rock	Critically endangered	0.625	16	7

Appendix 2. List of environmental variables prepared for the modelling. Categories: topography (1), water availability (2), energy availability (3), productivity (4), climatic stability (5), human activity (6) and land cover (7)

Category	Variable	Units	Reference
1	Altitude	(m)	4
	Slope (average from 30x30m)	(% rise)	Calculated
	Maximum slope from the 30x30 raster	(% rise)	Calculated
	South exposure	(Degrees- 0=North 180=South)	Calculated
	West Exposure	(Degrees 0=East, 180=West)	Calculated
	Annual Precipitation	(mm)	5
	Precipitation of Wettest Month	(mm)	5
2	Precipitation of Driest Month	(mm)	5
	Precipitation of Wettest Quarter	(mm)	5
	Precipitation of Driest Quarter	(mm)	5
	Precipitation of Warmest Quarter	(mm)	5
	Precipitation of Coldest Quarter'	(mm)	5
	Mean annual runoff	(mm)	1
	Mean annual number of snow days	Days	3
	Annual Mean Temperature	(°C * 10)	5
	Max Temperature of Warmest Month	(°C * 10)	5
	Min Temperature of Coldest Month	(°C * 10)	5
3	Mean Temperature of Wettest Quarter	(°C * 10)	5
	Mean Temperature of Driest Quarter	(°C * 10)	5
	Min Temperature of warmest quarter	(°C * 10)	5
	Mean Temperature of Coldest Quarter	(°C * 10)	5
	Mean annual solar radiation	(kWh/m2/day)	2
	Mean annual insolation	(h/year)	2
	Mean annual number of frost days (min temp < 0°C)	Days	2
	Actual evapotranspiration	mm/year	6

Category	Variable	Units	Reference
	Potential evapotranspiration	mm/year	6
5	Isothermality (P2/P7) (* 100)	(°C * 10)	5
	Mean Diurnal Range (Mean of monthly (max temp - min temp))	(°C * 10)	5
	Temperature Seasonality (standard deviation * 100)		5
	Temperature Annual Range (P5-P6)	(°C * 10)	5
	Precipitation Seasonality (Coefficient of Variation)		5
	Annual relative air humidity range (= <i>HuJan-HuJul</i>)	(%)	
	Continental index		3
	Mean annual number of days with precipitation >=0.1 mm	Days	2
6	Distance to cities	(m)	Calculated
	Distance to water	(m)	Calculated
	Distance to roads	(m)	Calculated
7	Coverage of agricultural land	(%)	7
	Coverage of artificial land	(%)	7
	Coverage of forest land	(%)	7
	Coverage of scrub/herbaceous	(%)	7
	Coverage of wetlands and water bodies	(%)	
	Ndvi winter	Scaled 1-255	8
	Ndvi summer	Scaled 1-255	8
	Ndvi spring	Scaled 1-255	8
	Ndvi autumn	Scaled 1-255	8

References

1	(IGME, 1979)	5	(Worldclim, 2010)
2	(Font, 1983)	6	(USGS)
3	(Font, 2000)	7	(European Environment Agency, 2010)
4	(NASA, 2004)	8	(Spot Vegetation, 2010)

Appendix 3. Corine land cover classes contained in the land cover classes used in the modelling.

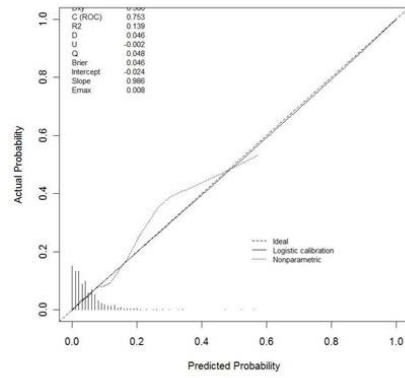
Land cover class	Corine land cover classes containing
Artificial surfaces	Urban fabric Industrial, commercial and transport units Mine, dump and construction sites Artificial, non-agricultural vegetated areas
Agricultural areas	Arable land Permanent crops Pastures Heterogeneous agricultural areas
Forest	Broad-leaved forest Coniferous forest Mixed forest
Scrub and/or herbaceous	Natural grasslands Moors and heath land Sclerophyllous vegetation Transitional woodland-shrub
Wetlands and water bodies	Inland marshes Peat bogs Salt marshes Salines Intertidal flats Water bodies Coastal lagoons Estuaries

Appendix 4. Tukey test for multiple comparisons of nesting habitats. * significant at the 0.01 level.

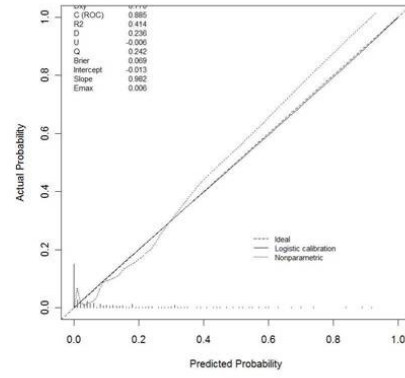
Tukey HSD		Sig.	
EENNPP	Forest	Cliff	0.5551
		Steppe	0.0001*
	Cliff	Forest	0.5551
		Steppe	0.0000*
	Steppe	Forest	0.0001*
		Cliff	0.0000*
Natura 2000	Forest	Cliff	0.6817
		Steppe	0.0001*
	Cliff	Forest	0.6817
		Steppe	0.0001*
	Steppe	Forest	0.0001*
		Cliff	0.0001*

Appendix 5. Examples of the calibration curves. In bins, the median of the predicted probabilities are plotted against the actual probability of occurrence.

a *E. caeruleus*



b *A. monachus*



c *C. aeruginosus*

