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Using MaxEnt algorithm to assess habitat suitability of a potential Iberian lynx population in central Iberian Peninsula

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Abstract: Iberian lynx distribution is currently restricted to the south of the Iberian Peninsula. Nevertheless, there is evidence of the presence of several small groups in the peninsular centre that have been forgotten by management and conservation actions. In this research, we gathered evidences of Iberian lynx presence along 21 transects located in the southwest of the Madrid province. In these transects lynx DNA was identified in 47 scats, which scientifically proves the presence of the species in that location. Using these locations (presence-only data) we built a maximum entropy model (MaxEnt) to estimate the suitability of the study area for the species. Our results show the existence of an almost continuous area that is approximately 744 km^2 that is suitable for the Iberian lynx. Seventy-eight percent of this area is within the Natura 2000 network and, therefore, it falls under regulations to preserve and restore habitat types, flora and fauna. This study shows the suitability of this territory has for the Iberian lynx.

Abbreviations: AUC–Area Under the Curve; GAM–Generalised Additive Models; GLM–Generalised Linear Models; IUCN–International Union for Conservation of Nature; LOESS– Locally Estimated Scatterplot Smoothing; NTD5000–National Topographic Database 1:50,000; PCA–Principal Component Analysis; SAC–Special Area of Conservation; SCI–Site of Community Interest; SDIM–Spatial Data Infrastructure of the Madrid community; SPAB–Special Protected Area for Birds.

Introduction

The Iberian lynx (*Lynx pardinus* Temminck, 1827) has been regarded as the most threatened predator in Europe (Mallinson 1978) and the most endangered species of the *Felidae* family (Nowell and Jackson 1996). In 2002 it was catalogued as 'Critically endangered' in the 'Red list of threatened species' by the International Union for Conservation of Nature (IUCN, San Miguel 2006). Nevertheless, as a result of conservation and recovery actions, its threat category was officially reduced in 2015 to 'Endangered' (Rodríguez and Calzada 2015).

Until the middle of the nineteenth century, the Iberian lynx had not been subject to high human pressure, as it could be found in practically the entire Iberian Peninsula (Graells 1897, Valverde 1963, Rodríguez-Varela et al. 2015). However, lynx populations began their decline after 1950 (Valverde 1963), due to the synergic effect of predator control laws and the steep decline of wild rabbit (*Oryctolagus cuniculus* L.) populations (Cabezas-Díaz et al. 2009). Consequently, the Iberian lynx populations underwent a severe decline throughout the entire Iberian Peninsula at the end of the twentieth century (Delibes 1990, Virgós 1994, Virgós and Travaini 2005), bringing the species to the verge of extinction and relegating it to spaces with very restricted features that currently make up its known habitat. By that time the species had lost 98% of its distribution area (Rodríguez and Delibes 1992), with two large populations remaining, known as Doñana-Aljarafe and Andújar-Cardeña (Simón et al. 2011), but also some small groups in the centre of the Iberian Peninsula (Torres et al. 1998, Guzmán et al. 2005, Fundación CDV-Hábitat 2006, San Miguel 2006, Alda et al. 2008).

After six decades of decline, Iberian lynx populations have experienced continuous growth as a result, mainly, of the execution of *ex-situ* conservation actions (Simón et al. 2011, Rodríguez and Calzada 2015). Therefore, the estimated number of free ranging lynxes in the Iberian Peninsula is currently 589 (Simón 2017).

Knowledge of the geographic distribution of species, both past (Rodríguez-Varela et al. 2015) and present (Calzada et al. 2007, Clavero and Delibes 2013), and its species-habitat relationships (Morrison et al. 2012) are extremely important tools for establishing the theoretical framework that allows us to set conservation goals and priorities (Barea-Azcón et al. 2007, Tobler et al. 2008, Clavero and Delibes 2013), as well as for defining the conservation status of populations (Gugolz et al. 2008). The absence of such information could lead to incorrect management and/or decision making as well as the development of biased conservation programs.

There is a considerable amount of well-documented information that includes the western region of the Madrid province within the distribution range of the Iberian lynx (Rodríguez and Delibes 1992, Aldama 1996). In spite of this, and probably due to the small size of the population, the species has been considered extinct from this territory since the early twenty-first century (Guzmán et al. 2002, 2004, Gil-Sánchez and McCain 2011, Garrote and de Ayala 2015). Nevertheless, reports of Iberian lynx presence in this territory have not ceased in recent years (Virgós and Casanovas 1993, Boscaje S.L. 2000).

Mammal carnivores are usually scarce, elusive and nocturnal (Barea-Azcón *et* al. 2007); therefore, classic sampling methods such as direct observation or capture-recapture techniques often fail to record such organisms (Tobler et al. 2008). Consequently, alternative non-invasive sampling methods such as sightings and other evidence, principally footprints and scats (Din and Nawaz 2010, Frey et al. 2013), have been emphasised in recent years (Long et al. 2012). This kind of information has been widely criticised because of the likelihood of error when assigning the samples to one species or another (Boshoff and Kerley 2010, Molinari-Jobin et al. 2012, Garrote and de Ayala 2015).

For this reason, other non-invasive techniques (Long et al. 2012), such as camera trapping or hair traps to obtain DNA, among others, have become crucial tools for studying elusive species, such as mammal carnivores (Kohn and Wayne 1997, Gompper et al. 2006, Garrote et al. 2011). Of all these techniques, the genetic analysis of scats, regarded as critical samples due to their poor conservation (Cruz et al. 2018), is one of the most reliable for obtaining scientifically documented information about the presence, distribution and abundance of elusive species (Palomares et al. 2002, Creel et al. 2003, Rodgers and Janečka 2013, Cruz et al. 2018).

The ecological and ethological features of mammal carnivores impose serious limitations on their study (Torre et al. 2003, Chávez et al. 2013) due to the scarce number of individuals and the fact that their behaviour is extremely discreet and elusive (Blanco et al. 1997, San Miguel 2006). The Iberian lynx has a social and spatial organisation that makes its study significantly more difficult, since it is territorial and solitary (San Miguel 2006, Calzada et al. 2007, Martín et al. 2007). Moreover, young individuals go through a five-month dispersive period in which their movements are random (Ferreras et al. 2004, San Miguel 2006), with a habitat plasticity that is higher than when they are choosing where to settle down (Gastón et al. 2016). As a consequence, lynxes are extremely difficult to find and track using conventional techniques.

Iberian lynx presence within this territory has been verified through specific genetic identification analyses especially designed for the treatment of critical samples (Cruz et al. 2018). We carried out an ecological characterisation of the territory based on climatic, physiographic and anthropic variables. We then used maximum entropy modelling to estimate the suitability of this territory with the aim of determining if it offers features that are suitable for species survival.

Material and methods

Study area

The western region of the Madrid province (Fig. 1) has a Mediterranean climate, as most of the Iberian Peninsula does. The marked seasonality of temperatures, the summer droughts and a lack of regular precipitation are thus the main

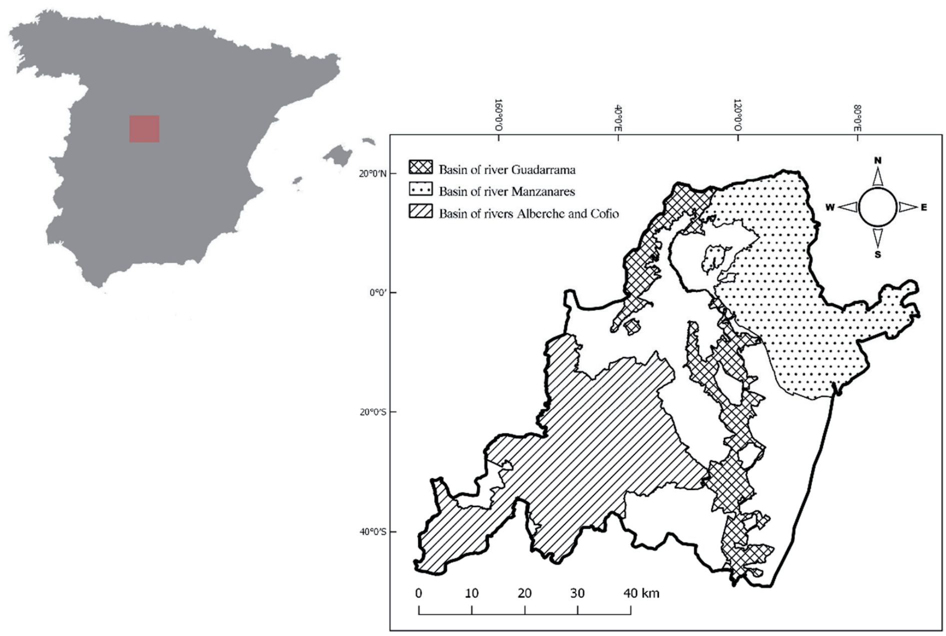

Figure 1. Location of the study area within the Iberian Peninsula. The three protected areas by Natura 2000 within the study area are shown here. Protection status of this areas are: Site of Community Interest (SCI), Special Area of Conservation (SAC) and Special Protected Area for Birds (SPAB).

Table 1. Code, description and source of climatic, physiographic and anthropic variables considered.

Code	Variable	Source
Human pressure		
Rdens	Road density (m/km^2)	Compiled by author
Topography		
RivDist	Distance to nearest river (m)	Compiled by author
Alt	Altitude (masl)	Compiled by author
Vegetation structure		
Bare	Bare soil coverage (%)	MDA Federal (2004)
Herb	Herbaceous coverage (%)	MDA Federal (2004)
Tree	Tree coverage (%)	Sexton et al. 2013
Climate		
Iso	Isothermality (Δ diurnal temperature / Δ annual temperature) (*100)	Hijmans et al. (2006)
MaxTwm	Maximum temperature of warmest month	Hijmans et al. (2006)
MDRange	Mean diurnal range (Mean of monthly (max temp - min temp))	Hijmans et al. (2006)
MinTcm	Min temperature of coldest month	Hijmans et al. (2006)
Pdriem	Precipitation of driest month	Hijmans et al. (2006)
Pann	Annual precipitation	Hijmans et al. (2006)
Psea	Precipitation seasonality (coefficient of variation)	Hijmans et al. (2006)
PWetM	Precipitation of wettest month	Hijmans et al. (2006)
TannRange	Temperature annual range	Hijmans et al. (2006)
Tmean	Annual mean temperature	Hijmans et al. (2006)
Tsea	Temperature seasonality (standard deviation*100)	Hijmans et al. (2006)

climatic features (Zabía and del Olmo 2007). The forest vegetation is predominantly evergreen (*Quercus ilex, Pinus* sp. etc.) with a stratum of xerophilous shrubs (*Cistus ladanifer, Lavandula pedunculata, Rosmarinus officinalis, Thymus vulgaris,* etc., García and Pérez 2016).

With the exception of some relatively large cities, this territory is controlled by well-integrated human activities that depend on the characteristics of the natural environment, such as traditional mixed rural systems based on forestry and pastoralism (Schmitz et al. 2007). In spite of the considerable number of population centres in the region, the urbanised area is low and the degree of naturalness is high (Arnaiz-Schmitz et al. 2018).

In addition, the fauna in the Madrid province is highly diverse, with some species requiring specific protection measures, such as those that can be found in Ministry of Environment and Ordination of the Territory (2017). Of note are predators such as the wildcat (*Felis silvestris*), the European otter (*Lutra lutra*) and the Iberian lynx (*Lynx pardinus*).

Field study

Prior to the field study, we reviewed the existing documentation on the presence of Iberian lynx in this territory, including two technical records (Aldama 1996, Boscaje 2000), as well as the '*Atlas and Red Book of Terrestrial Mammals of Spain*' (Palomo et al. 2007) and the '*Regional Catalogue of Endangered Species of Wild Flora and Fauna, and Unique Trees of Madrid province*'. With the information gathered from these documents, we designed 21 transects, each seven km long. Along these transcects, a minimum of two researchers searched and collected scats that were morphologically similar to Iberian lynx scat, as described in Rodríguez (2003) and Iglesias and España (2010). The transects were combed twice per year, at the beginning of summer (June-July) and in autumn (October-November), for three consecutive years, from 2015 to 2017. They were searched on foot along pathways, firebreaks, boundaries between scrubland and pasture or following other less regular landscape structures where evidence (scats) was more likely to be found (Martín et al. 2007). These structures could be at the base of large rocks, over rabbit holes, near rivers, etc.

The scats were analysed following the methodology described in Cruz et al. (2018). This methodology minimizes, as much as possible, the subjectivity inherent in visual identification in the field, providing us with scientifically confirmed locations of the presence of the species.

Ecological characterisation

In order to determine the availability of a suitable habitat for the Iberian lynx, we must focus on the macrohabitat scale, understood as the average minimum area that individuals of a certain species use for their biological functions (Morris 1987). To perform a study at this scale, we selected 17 climatic, physiographic and anthropogenic variables (Table 1).

Variables were selected for their potential influence on the distribution of the species and their availability to the entire study area. Because of the latter, data related to the presence, abundance or density of potential prey and/or competitors were not taken into consideration.

Climatic variables were extracted from the WorldClim database at a 30-second spatial resolution (Hijmans et al. 2006). Beltrán and Delibes (1994) demonstrate that temperature and precipitation have a significant influence over the daily activity patterns of the Iberian lynx. They showed that these climatic factors can display a differential effect depending on whether it is day or night. For example, the maximum high temperature at night will increase Iberian lynx activity, while during the day it has the opposite effect. Authors suggest that this influence could be an indirect effect of prey availability variations and, therefore, be related to Iberian lynx fitness and habitat suitability. We selected 11 variables (Table 1) to gather all possible climate features in order to reflect daily, seasonal and annual climate patterns that could influence habitat suitability.

The Iberian lynx is considered a habitat specialist that is bound to heterogeneous Mediterranean scrubland and forest (Valverde 1963, Rodríguez and Delibes 1992, Palomares 2001). It can be described as not entirely a forestry species but one adapted to mosaic landscapes (San Miguel 2006). Scrubland has been shown to be highly important for the species in previous research, where shrub coverage in areas were lynxes live was higher than 50% (Rodríguez and Delibes 1990, Palomares 2001). Recently Gastón et al. (2019) demonstrated that considering tree coverage when modelling habitat selection improves the performance of the model, showing the preference of the species for scattered woodlands (5-25% tree cover). Taking this previous knowledge into account, we selected three vegetation cover variables for the analysis (Table 1). As suggested by Gastón et al. (2019), we considered that these variables provide a better proxy for potential prey availability and shelter, and as a consequence, for Iberian lynx habitat suitability, than more general land cover classes.

Human pressure is one of the main reasons that led mammal carnivores to their global decline (Cardillo et al. 2004), with road mortality having special relevance for the Iberian lynx (Garrote et al. 2018). Road density is a reliable proxy of human pressure (Llaneza et al. 2018). We obtained both layers of highways and minor paved roads from the National Topographic Database 1:500.000 (NTD500). Then we built a road density raster layer by dividing road longitude (m) within each grid cell (1 km^2) into which the territory was divided.

Known Iberian lynx populations are located at between 400 and 1,300 meters above sea level, with the exception of the Doñana-Aljarafe population, which is close to sea level (Rodríguez and Delibes 1990). Low- and mid-mountain landscapes are associated with a higher diversity and abundance of potential prey, but also with lithological and edaphic features related to shelter and low human pressure (San Miguel 2006). We used a 20 m interval level curve layer, extracted from the Spatial Data Infrastructure of the Madrid province (SDIM), to build a digital elevation model.

In the Iberian Peninsula, some predators such as the badger (*Meles meles* L.), red fox (*Vulpes vulpes* L.), wildcat and stone marten (*Martes foina* Erxleben, 1777) used riparian woodlands in which they find shelter and food (Virgós 2001). High habitat heterogeneity together with the microclimate present in this kind of environment provide Iberian predators with a wide range of trophic resources (small mammal communities, birds and fleshy fruits) and shelter (scrubland cover and hollow trees), which are fundamental aspects for their survival (LaRue et al. 1995). We built a distance matrix between each grid cell centroid and the nearest river and converted it into a raster layer. The river layer was extracted from NTD500.

All variables were converted from raster to a 1 km × 1 km grid. When more than one pixel overlapped with the same cell of the grid, we calculated the average value of the variable inside the cell. All operations related to the spatial treatment of data were realised in QGIS (QGIS Development Team, 2017).

Usually, environmental variables show high correlations (Appendix 1) that can significantly affect the results obtained and, as a consequence, the conclusions extracted (Graham 2003). To avoid problems derived from multicollinearity, we performed a Principal Component Analysis (PCA) based on the correlation matrix in the statistical software R (R Core Team, 2017), using the package FactoMiner (Le et al. 2008). Component solutions were not rotated to extract factors in order of their importance (Hair et al. 1998). We retained only those components with an eigenvalue (λ) higher than or equal to one.

To test habitat suitability within the territory, we used a maximum entropy model (MaxEnt software version 3.4.1) because it is the most appropriate method for making inferences based on incomplete information (Phillips et al. 2006), as is the case of presence-only data. Such models present advantages with regard to others, such as the GLM or GAM models: i) only presence data are required, together with environmental information for the whole study area, ii) overfitting is avoided, iii) its generative, rather than discriminative, approach can be an advantage when the amount of data for training is limited (Phillips et al. 2006). To run the model, we used the genetically confirmed locations of Iberian lynx within the study area as presences and PCA extracted components with $\lambda \geq 1$ as independent variables.

To run the MaxEnt algorithm, we used 75% of the data for model training and the remaining 25% for test fitting. This was estimated through the area under the curve (AUC), which allows us to discern whether the predictive capacity of the model is significantly different or not from that expected in a random model (AUC = 0.5) (Phillips et al. 2006). Background samples were randomly placed in order to gather the entire environmental variability of the study area and avoid model parameter overestimation (Warton and Shepherd 2010, Northrup et al. 2013). The regularisation multiplier was adjusted at two for overfitting avoidance (Radosavljevic and Anderson 2014).

MaxEnt provides an estimation of presence probability for a species in each pixel of the map (Phillips and Dudik 2008) by comparing probability densities of the background samples and presence records (Elith et al. 2011). Nevertheless, as is explained in Mateo et al. (2011), presence probability is an exorbitant interpretation of what a measure of environmental similarity really is. Thus, these authors state that this type of results should be understood, at most, as a value of suitability of a territory for the development of a certain species, according to the environmental variables considered. To make results interpretation easier, suitability values were classified into four categories, as is recommended in Chefaoui et al. (2005): very low quality (0-0.25), low quality (0.26-0.50), high quality (0.51-0.75) and very high quality (0.76-1). Density distributions of these categories were plotted in a histogram. In addition, the effect that each component extracted from the PCA had on the habitat suitability was represented in a scatterplot.

Results

During the field study, we collected 84 scats of which 47 had positive results in the genetic analysis (Fig. 2). It should be noted that the scats were gathered outdoors and were thus exposed to erosive agents that can degrade and break down genetic material, making the appearance of false negatives relatively frequent, even when our technique has a high specificity and sensitivity.

Results from the PCA (Table 2) show that component I explains 58.50% of the total variance of the data, being positively correlated with temperature-related variables and precipitation seasonality and negatively so with those related with precipitation, altitude and isothermality. Component II absorbs 10.68% of variance and is positively correlated with temperature diurnal and annual ranges, while component III is positively correlated with bare soil cover and negatively with tree cover. Finally, component IV shows a positive correlation with herbaceous coverage. Altogether, the four retained components ($\lambda \geq 1$) explain 84% of total variance.

The adjusted model shows a significantly higher predictive capacity (training AUC = 0.859, test AUC = 0.884) than one whose probability distribution tends towards maximum entropy (AUC = 0.5). Obtained suitability results (average = 0.3154, standard deviation = 0.2739, Fig. 3) demonstrate the existence of a polarised territory for the Iberian lynx. The most repeated suitability values were those that denote a low quality habitat for the species. Nevertheless, density probability values in the second place are those that denote a very high quality habitat, followed by those of high quality. This shows that the territory studied, despite having a considerable surface of unsuitable habitat for the species, also presents a high number of pixels whose suitability is high or very high. When representing this results spatially (Fig. 4), we confirm the pattern observed in Figure 3.

Scatterplots from Figure 5 allow us to describe main features of an Iberian lynx suitable area. On the one hand, suitability increases with values closer to zero of component I and II. This shows the suitability of areas with moderate temperatures, perceptible diurnal range and marked seasonality but low precipitation rates. On the other hand, component III shows a trend of suitability increase in areas with low tree cover , while it decreases as much as bare soil increases. Component IV does not show any clear trend, although there is a considerable decrease of habitat suitability when it takes high values.

The study area has an approximate surface of 3,077 km^2, of which 12.9% (398 km^2) presents a high suitability and 11.2% (346 km^2) a very high one. Altogether, they amount to 744 km^2 whose environmental characteristics are suitable for the Iberian lynx, with 90% of this area falling within the Natura 2000 network of protected areas (86 km^2 within the SCI/SAC of the Guadarrama river basin, 545 within the SCI/SCZ/SPAB of the Alberche and Cofio river basin) and 40 km^2 within the SCI/SAC of the Manzanares river basin.

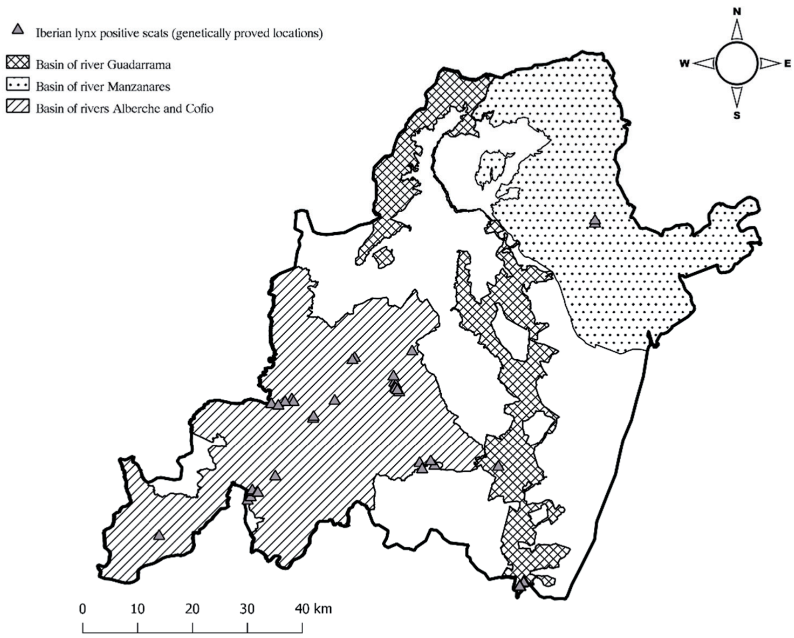

Figure 2. Map of proved Iberian lynx locations through genetic analyses of specific identification (positive scats) within the study area.

Table 2. Results of principal component analysis. The table shows correlations between retained components and the original variables, eigenvalues, percentage of explained variance and cumulative percentage of explained variance.

	I	II	III	IV
Rdens	–0.0421	–0.1315	–0.2847	0.2521
RivDist	–0.0785	–0.159	0.2296	0.1788
Alt	–0.9775	–0.0117	0.0599	0.0299
Bare	0.3462	–0.2036	0.7875	–0.3153
Herb	0.1838	–0.4216	0.0149	0.8051
Iso	–0.7846	0.4529	0.2682	0.1448
MaxTwm	0.989	0.0977	0.0254	–0.0331
MDRange	0.0042	0.8929	0.3232	0.2807
MinTcm	0.9803	–0.0904	–0.0464	–0.1
Pdriem	–0.9768	–0.0313	0.1324	–0.026
Pann	–0.9151	–0.2061	0.1733	–0.1486
Psea	0.9194	–0.0035	0.0113	–0.0943
PWetM	–0.9096	–0.158	0.1287	–0.1234
TannRange	0.8179	0.5057	0.1833	0.1251
Tmean	0.9936	–0.0109	–0.0395	–0.0555
Tree	–0.4534	0.446	–0.6314	–0.2445
Tsea	0.973	–0.1009	0.0166	–0.0892
Eigenvalue	9.9443	1.8155	1.4353	1.0883
Explained variance (%)	58.4961	10.6795	8.443	6.4018
Cumulative explained variance	58.4961	69.1757	77.6186	84.0205

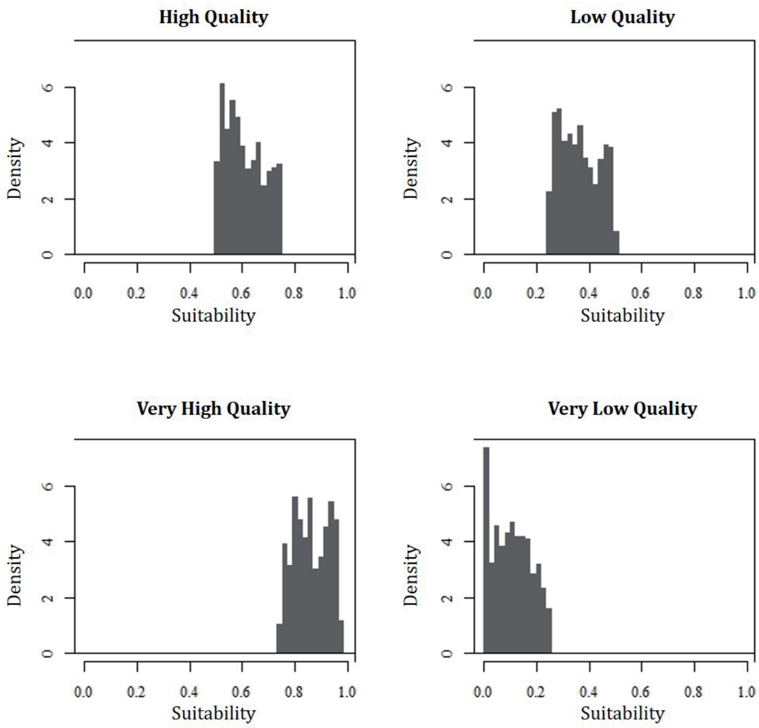

Figure 3. Histograms of density distributions of pixels according to habitat quality.

Discussion

In this study we demonstrate that species recorded citations can provide relevant information for the identification of areas of priority interest for sampling efforts with the aim of locating an elusive species, which is extremely difficult to see and track.

There is some debate about the ecological interpretation that should be given to results obtained through this method (Mateo et al. 2011). Nevertheless, here we considered that what the model really estimates is the fundamental or Grinnellian niche (James et al. 1984) of the target species. For Hutchinson (1957) this is the 'n-dimensional hypervolume', 'every point in which corresponds to a state of the environment which would permit a species to exist indefinitely'. Therefore, the model provides us with an over-estimation of the potential habitat since we have not taken into consideration inter-specific relationships with competitors, the dispersal capacity or the population dynamics, which would shape the realised or Eltonian niche (Guisan and Thuiller 2005). Hence, the results obtained should be interpreted with caution and considering their limitations.

The adjusted model showed the relevance that climatic features have for the Iberian lynx. Suitability is higher in areas with low precipitation and moderate temperatures, but also with marked thermal differences between day and night. These results agree with those obtained by Beltrán and Delibes (1994). According to these authors, this trend would be a consequence of prey availability and not an effect of a narrow climatic tolerance. For example, under high precipitation and/or low temperatures, prey activity would be reduced, forcing lynxes to spend more time and energy in forage, which would compromise their survival.

Our results show the species preference mixed vegetation structures where there is no predominance of any specific habitat, although there is shown a trend to inhabit areas with scattered trees. As stated above, the Iberian lynx is known for dwelling in mosaic landscapes, where woodland and scrub-

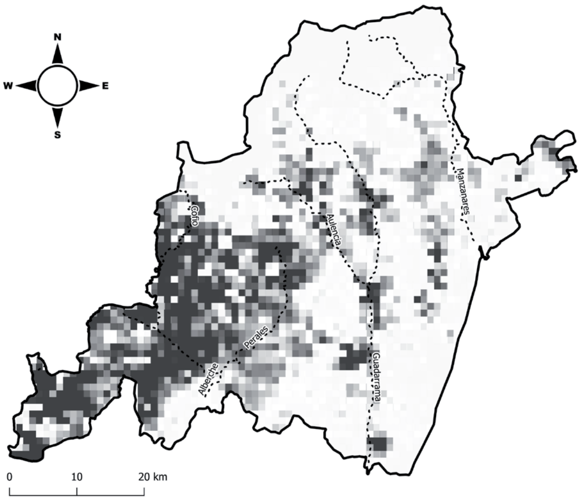

Figure 4. Habitat suitability results obtained after maximum entropy model (MaxEnt) adjustment. Light grey pixels represent those with suitability values comprised between 0.5-0.75 (high quality), while dark grey pixels are those with suitability values higher than or equal to 0.76 (very high quality). Dashed lines represent the main rivers within the study area.

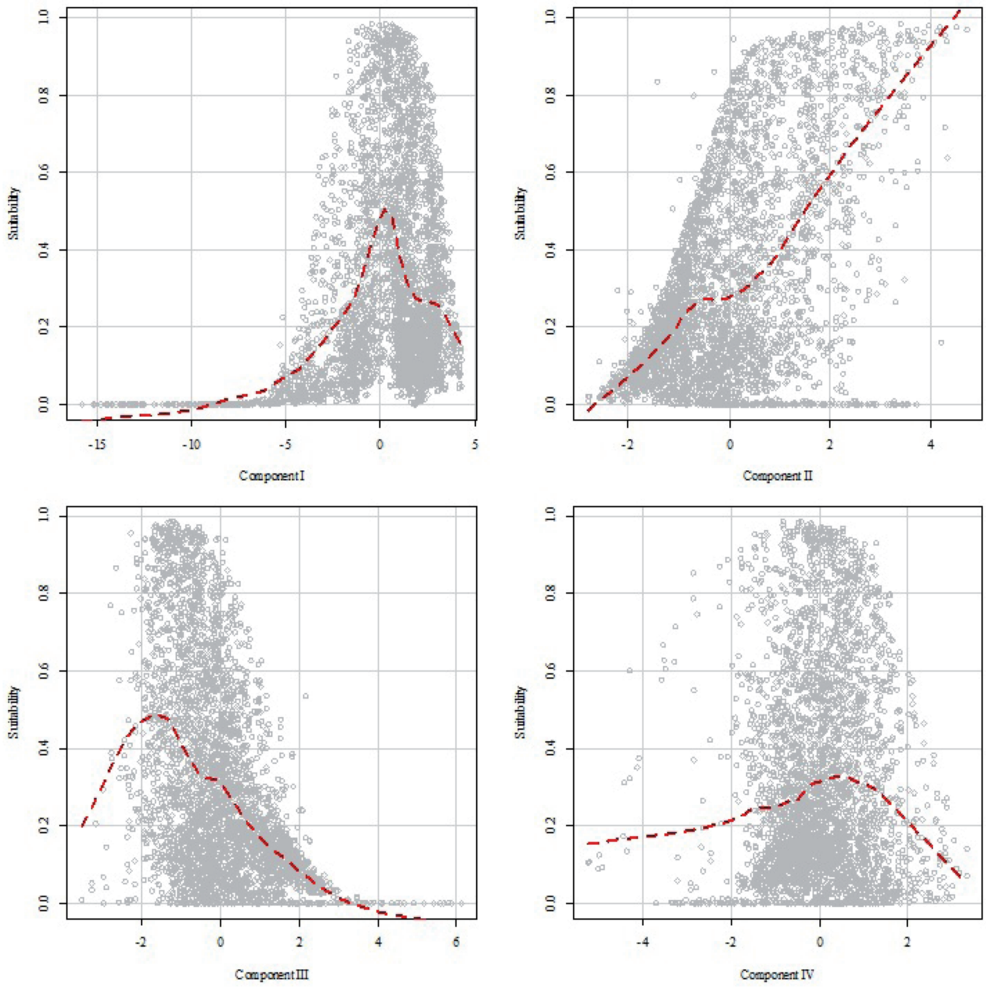

Figure 5. Influence of the four extracted components over MaxEnt habitat suitability results. Hollow circles represent each 1 km × 1 km cell in which the territory was divided, while the dashed line was calculated using locally estimated scatterplot smoothing (LOESS).

land patches are mixed with open pasture spaces (Rodríguez and Delibes 1990, Palomares 2001, San Miguel 2006, Gastón et al. 2019). This landscape structure provides both shelter and food. It allows lynxes to hide, breed and rest in scrubland or woodland patches, while stalking prey that usually graze in open areas (Rodríguez and Delibes 1992). Furthermore, it is well known that mammals follow a hierarchical habitat selection process (Rettie and Messier 2000, Beasly et al. 2007, Llaneza et al. 2018), which means that at each hierarchy level the variables will have different effects over species distribution. A major influence of climate in our study might be related with the scale used. In addition, the influence of road density and the distance from rivers are likely masked by variables that have an impact at a higher scale. To untangle the real effect of these variables, specific fine-scale research is needed.

The suitability map shows the existence of a wide surface, located at the southwest of the study area, which gathers suitable environmental conditions for the Iberian lynx. As was said in the introduction section, this territory presents high naturalness values and dispersed urban areas (Arnaiz-Schmitz et al. 2018), shaping a suitable, almost continuous area for the Iberian lynx. Thus, the existence of a potential Iberian lynx population within this territory that has survived in isolation from other known groups becomes a plausible hypothesis. This hypothesis, together with a probable low density and environmental stochasticity, would make the population density-dependent with Allee effect. Therefore, the habitat suitability map provides useful information that can focus future research on determining the degree of threat for the population. We urgently recommend the assessment of the minimum viable population (Courchamp et al. 1999) in order to make sound decisions for ensuring species persistence in the study area. Furthermore, results obtained by Fordham et al. (2013) demonstrate the relevance of this territory as a refuge under different climatic change scenarios. Nevertheless, these authors suggest that in order to achieve species survival, population reinforcement programmes should move towards a wider reintroduction scenario.

For extant Iberian lynx populations the mitochondrial DNA (mtDNA) control region diversity is very low (Johnson et al. 2004). From a conservation perspective, populations with low genetic variability might be at risk of having a reduced capacity to adapt to changing environments and this could reduce the long-term fitness of the population (Frankham and Kingslover 2004). Even when the low genetic diversity of the Iberian lynx over the last 50,000 years is accepted (Rodríguez et al. 2011), a reduction in the adaptive capacity of the species is of concern in a climate change scenario. As demonstrated by Alda et al. (2008), the existence of other isolated populations in central Spain could led to the identification of new low-frequency haplotypes that would be a relevant genetic resource for the known inbred populations.

The environmental conditions of the study area, together with the possible contribution of genetic diversity from an isolated potential population, make it a likely keystone for the conservation of the species. Consequently, decision-makers should consider this population for future research and possible reintroductions.

Conclusions

The territory studied shows that, for the variables considered here, its environmental conditions are suitable for potential Iberian lynx settlement. The territory shows a suitable, almost uninterrupted, wide area within the Natura 2000 protected network. Despite this, the potential population could be under the influence of the known Allee effect, making the assessment of the minimum viable population a priority for future research.

Fordham et al. (2013) show the relevance of the central Spanish territory for the long-term survival of the Iberian lynx. This territory will serve as a climate refuge for the species, even in the worst predicted scenario of climate change. Furthermore the existence of a new population could mean the discovery of new genetic haplotypes. This is especially relevant in a climate change scenario, in which the long-term fitness of the species could be compromised because of its low genetic diversity and, therefore, low adaptive capacity. This potential population would make it possible to launch initiatives to raise the genetic diversity of the species.

After these considerations, decision-makers should consider the major advance this population could mean for Iberian lynx conservation.

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Appendix 1. Correlation matrix among 17 original variables initially considered. The file may be downloaded from www.akademiai.com.