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Roe deer reintroduction in central Portugal: a tool for Iberian wolf conservation

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Abstract

Species reintroduction is an increasingly important tool for species recovery programs and habitat restoration initiatives worldwide. Roe deer *Capreolus capreolus* (Linnaeus, 1758) densities are very low in central west Portugal (the Freita, Arada, and Montemuro mountains). This area is inhabited by the endangered Iberian wolf *Canis lupus signatus* Cabrera, 1907, whose numbers have dramatically decreased since the 20th century. An important step in a roe deer reintroduction program is to establish suitable reintroduction sites. The aim of the study was to identify such sites in central Portugal. An Analytical Hierarchy Process (AHP) in combination with a GIS was applied to develop a habitat suitability model, which integrated empirical models and expert knowledge. The variables used in the model included land use, hydrographic network, asphalted roads, population/villages, and relief. Three reintroduction sites suitable for roe deer were identified as potential habitats for their future natural expansion. Those sites were considered as preliminary ones. Finally, future goals and actions are discussed in relation to the promotion of the ecological and social conditions that would favour the survival of roe deer and Iberian wolf in central Portugal.
Key words: *Canis lupus signatus*, *Capreolus capreolus*, habitat suitability, Portugal, reintroduction.

Resumen

La reintroducción de especies es una herramienta clave en programas de recuperación de especies y de restauración de hábitats. El corzo *Capreolus capreolus* (Linnaeus, 1758) se ha extinguido prácticamente de las sierras de Freita, Arada y Montemuro (centro de Portugal), ambas habitadas por el lobo ibérico *Canis lupus signatus* Cabrera, 1907. Tanto el número como la distribución de este carnívoro se han reducido drásticamente en Portugal durante el siglo XX. Uno de los aspectos clave en cualquier programa de reintroducción es establecer qué lugares son los más adecuados para introducir la especie. Los objetivos de este trabajo fueron identificar los lugares idóneos para reintroducir el corzo en el centro de Portugal (sierras de Freita, Arada y Montemuro). Para ello, desarrollamos un modelo de adecuación del hábitat aplicando un Proceso Analítico Jerárquico (AHP, en inglés) y técnicas de SIG. Las variables utilizadas en el modelo fueron: uso del suelo, red hidrográfica, carreteras asfaltadas y otras variables antropogénicas y topográficas. A partir de ese análisis, identificamos tres lugares de reintroducción idóneos que garantizan tanto el establecimiento como la dispersión del corzo. Finalmente, en este trabajo discutimos qué acciones pueden favorecer la supervivencia tanto del corzo como del lobo ibérico en el centro de Portugal.
Palabras clave: *Capreolus capreolus*, *Canis lupus signatus*, modelo de adecuación del hábitat, Portugal, reintroducción.

Introduction

Species reintroduction is an increasingly important tool in species recovery programmes and habitat restoration initiatives worldwide (Armstrong & Seddon 2008). Reintroductions can improve the long-term survival of a species by establishing additional viable populations or reinforcing existing ones. Many species of large carnivores have been persecuted for centuries and this is one of the reasons why they are now facing serious threats and suffering substantial decreases in their populations and geographic ranges worldwide (Ripple *et al.*

2014). This has led to concern regarding their local extinction and the resulting implications for ecosystems. A subspecies of the gray wolf (*Canis lupus* Linnaeus, 1758) called the Iberian wolf inhabits Portugal. According to the UICN, the Iberian wolf in Portugal is considered Endangered (EN), having suffered a significant decrease in its distribution and abundance in recent decades, partly due to direct persecution (Bessa-Gomes & Petrucci-Fonseca 2003). In central Portugal, south of the Douro river, there is a very isolated and fragmented population of Iberian wolf that is more vulnerable to environmental and demographic stocasticity and local extinction. This population faces several problems that include scarce food resources (lack of wild prey and/or regression extensive livestock), the decrease in refuge areas, and habitat fragmentation and mortality caused by humans (*e.g.*, poaching, poisoning, road kill; see Cabral *et al.* 2005). Vos (2000) showed that in the areas north-west and south of the Douro river, wolves can exclusively feed on domestic prey, which has only been reported once (Cuesta *et al.* 1991). In the area south of the Douro river, an almost monospecific diet was found, with the domestic goat (*Capra hircus* Linnaeus, 1758) as the main prey. Several studies have demonstrated the importance of increasing the abundance of wild prey, in order to reduce the impact of wolf on livestock, thereby reducing conflicts with humans (Cuesta *et al.* 1991, Vos 2000, Barja 2009, Meriggi *et al.* 2011). Therefore, in due course, the reintroduction of roe deer in central Portugal would provide a source of wild prey for the Iberian wolf, decreasing wolf livestock predation, thus reducing conflicts with humans (Treves & Karanth 2003, Treves *et al.* 2004). Finding effective methods to decrease the damage to livestock is pivotal to improving tolerance among the local human population to the Iberian wolf and, consequently, its conservation. In 1997, roe deer were reintroduced into the present study area, at São Macário Mount, in São Pedro do Sul, Viseu (Vingada *et al.* 1997). This reintroduction process did not aim to conserve the species *per se*, but was also based on the premise of creating a stable population to promote the conservation of the Iberian wolf. In the process, ten animals were released in a forest area, four of them with telemetry collars. However, due to dispersal mechanisms, namely echo and shadow, it was impossible to implement the original plan and after a certain period of time the location of the animals was lost and their fate became uncertain.

Reintroducing a species to an ecosystem may have impacts that need to be evaluated *a priori* based on a rigorous scientific component (Hodder & Bullock 1997). The first steps in a reintroduction program should include the assessment of the potential short-term consequences of management plans and long-term viability (Seddon *et al.* 2007). This could be achieved by generating habitat suitability models, which can be created using a theoretical approach based on knowledge of the ecological requirements of the species (Dettki *et al.* 2003, Yamada *et al.* 2003, Rüger *et al.* 2005). Habitat suitability models summarize the conceptual knowledge of the habitat associated with the species through the description of important environmental variables based on several sources of information (Storch 2002). The combination of population modelling and Geographical Information Systems (GIS) has been widely used in several studies that assessed landscape suitability for different species (Thatcher *et al.* 2006, Doswald *et al.* 2007, Olsson & Rogers 2009).

This study is the first phase (the viability phase) of a project to reintroduce roe deer populations in central Portugal and attempts to determine the habitat suitability of the area for the species. Therefore, the main aims of the study were: (i) to review and incorporate human and roe deer needs into a weighted, multi-criteria, habitat-suitability model; and (ii) to identify suitable habitats for roe deer reintroduction. It was expected that well-developed tree cover areas with a high density of shrubs would be more suitable for roe deer, whereas areas close to roads and urban areas would be less suitable (Torres *et al.* 2011b, 2012).

Material and methods

Study area

The study was conducted in central Portugal in two sites of the Natura 2000 Network (Fig. 1). This area is a mountainous region with steep slopes and medium altitudes ranging from 800 to 1381 m.a.s.l. The climate is mainly Mediterranean, with a strong oceanic influence and high levels of rainfall. The vegetation is diverse and is mainly formed by different types of shrubs, such as common broom *Cytisus scoparius* and *Cytisus grandiflorus*, common gorse *Ulex europaeus*, dwarf gorse *Ulex minor* and *Ulex micranthus*, *Genista triacanthos*, *Erica australis*, tree heath *Erica arborea*, bell heather *Erica cinerea*

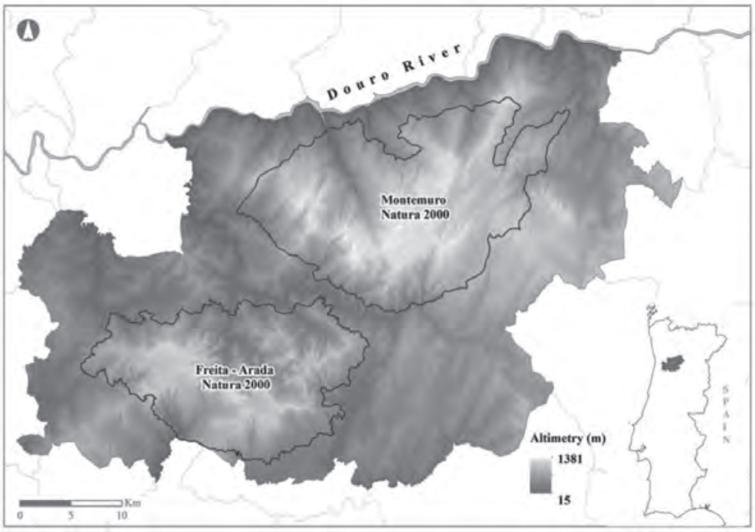

Figure 1. Location of the study area in continental Portugal.

and *Erica umbellata*, and gorse *Pterospartum tridentatum*. Tree species in the area are English oak *Quercus robur,* Pyrenean oak *Quercus pyrenaica*, sweet chestnut *Castanea sativa*, and Maritime pine *Pinus pinaster* in pure stands or mixed with the eucalyptus *Eucalyptus globulus.* Scattered pastures and agricultural fields are still found in the study area, which is crossed by several rivers and streams. The riparian vegetation is mainly ash *Fraxinus angustifolia* and birch *Betula alba*. The wild boar *Sus scrofa* Linnaeus, 1758, is the only wild ungulate in the study area. Subsistance agriculture and pastoralism are still practiced in which native cattle and small ruminants predominate along with the extensive use of uncultivated land. The human population is dispersed through the valleys in villages with population densities of approximately 314 inhabitants/km^2 (INE 2011).

Data collection

Field work was conducted between October 2011 and March 2012 using pellet group counting, a survey method that is frequently used to assess large ungulate habitat use (Telesco *et al.* 2007). Twenty triangular transects (1 km per side) were systematically placed to provide equal coverage of the different habitats in the surveyed area (Fig. 2). This sampling design confirmed roe deer presence/absence in the study area. In total, 240 sampling plots (50 m x 2 m) were established and each of these transect sections was considered a sampling unit. In order to maximize spatial coverage and to mitigate sampling dependence, plots were spaced along the line every 200 m. Firstly, at each segment, roe deer presence was assessed by recording the number of pellets, and then the habitat variables that could potentially affect species distribution

Figure 2. Triangular transects defined in the study area for field data collection.

were recorded over a 10-m radius circle. Geographic information system software (*ArcGIS 10.0*) was used to derive several ecological descriptors known to be important for roe deer presence, which ranged from local scales (patch scales; 1.26-km buffer) to land scales (landscape scales; 12.6-km buffer) (*e.g.* macro-habitat, landscape structure variables, as well as human disturbance and topographic factors). The smallest buffer (1.26 km), termed the home range, was calculated based on home range values in Portugal reported by Carvalho *et al.* (2008) and in similar Mediterranean habitats (Rosell *et al.* 1996, Lamberti *et al.* 2006). The largest buffer (12.6 km) represents a wider spatial scale and indicates how the surrounding landscape potentially affected roe deer occurrence.

Environmental variable selection

The environmental variables used were selected according to the ecological requirements of roe deer, as described in previous studies (San José *et al.* 1997, Virgós & Tellería 1998, Torres *et al.* 2011b, 2012). The variables were grouped according to three factors: i) habitat composition; ii) topography; and iii) human disturbance (Table 1). Habitat composition was represented by three general land-use predictor variables divided into forest (including broadleaved and coniferous woodland, wetlands, and scrubland), agricultural fields (including herbaceous and woody crops, arable horticulture, and heterogeneous crops), and urban areas. Information was obtained from CORINE Land Use/Land Cover database (CLC06) with a spatial resolution (pixel width) of 250 meters. Roe deer food resources are mainly affected by habitat and, to a lesser extent, by season (Tixier & Duncan 1996), which suggests that availability is a key determinant of diet (Duncan *et al.* 1998). Therefore, food availability was inferred from the presence of habitats that are well-suited to providing food for the species (Faria 1999, Torres *et al.* 2011b). Topographic factors were represented by slope and relief. In a dry Mediterranean environment, the availability of free water is a physiological and behavioural constraint for roe deer (Wallach *et al.* 2007). Thus, distance to water sources is a factor that should also be taken into account when analysing roe deer habitat use. Consequently, measurements were made of the distance from the centre of the segment to the closest water body. Human disturbance was represented by road density, the asphalted road network, and urban areas (houses, buildings, and industrial areas). These factors can influence roe deer distribution as they may be considered analogous to predation risk. To analyse the different levels of disturbance relative to each segment, the distance to settlements and the distance from the centre of the segment to paved roads were measured.

Multi-criteria analysis: the Analytical Hierarchy Process method

The weight of each criterion was obtained using the Analytical Hierarchy Process (AHP) (Saaty 2005). The criteria and weightings were employed in the GIS based on Multicriteria Decision Making (MCDM), which associate the environmental factors under analysis in a single assessment parameter (Chen *et al.* 2010). This methodological approach has been widely used in habitat suitability studies (Mardle *et al.* 2004, Li *et al.* 2009, Xiaofeng

Table 1. Comparison matrix with the relative weight assigned to the factors under analysis. (FA-Forest areas; AA-Agricultural areas; RD-Road density; DAR-Distance to asphalted road network; DHN-Distance to Hydrographic network; DUA-Distance to urban areas; S-Slopes; RA-Relief Aspects).

Variables	FA	AA	RD	DAR	DHN	DUA	S	RA
FA	**1**	-	-	-	-	-	-	-
AA	1/7	**1**	-	-	-	-	-	-
RD	1/5	5	**1**	-	-	-	-	-
DAR	1/7	5	1/5	**1**	-	-	-	-
DHN	1/7	5	1/7	1/7	**1**	-	-	-
DUA	1/5	5	1	5	7	**1**	-	-
S	1/7	3	1/5	1/3	1/3	1/5	**1**	-
RA	1/9	1/5	1/9	1/9	5	1/9	1/9	**1**

et al. 2011). Despite some subjectivity inherent to this method, it has proven to be a valuable option in the absence of presence data and contributes to reducing the subjectivity associated with heuristic methods. This method integrates data from different sources and correlates their respective weights. The AHP method is based on three fundamental steps: i) defining the objectives and variables to be considered in the analysis; ii) developing a pairwise comparison matrix of factors using a given scale; and iii) defining the final weights. A weighted linear combination was used since it is the most common procedure for multi-criteria evaluation. Factors (*e.g.* variables) are combined together by applying a weight to each one followed by the sum of the weights applied to each factor. The evaluation also included our field experience and knowledge of the study area, which was fundamental to developing the final model. The final output is a habitat suitability map generated according to the following equation:

$$S = \sum (wi\ xi)$$

where S is suitability, wi is the weight of factor i, and xi is the criterion score of factor i.

In the present case, the result was a Habitat Suitability Index (HSI), which quantitatively characterizes the capacity of an area to fulfil the ecological requirements of roe deer.

The criteria weights were assigned according to Saaty's pairwise comparisons (Saaty & Vargas 2012) to reduce subjectivity. Firstly, a qualitative numerical scale was used to score each pairwise comparison between the chosen criteria. The relative preference between two variables under analysis was obtained by using a 9-point rating scale ranging from 1 (equal importance) to 9 (extreme importance) and reciprocal values (Table 2). All continuous variables were standardized (linear scaling and scale inversions) prior to map algebra operations to avoid the effect of different measurements scales and to simplify direct comparisons. The following equation was used:

$$xi = \frac{(Ri - Rmin)}{(Rmax - R\ min)}$$

where R_i is the raw score of factor i.

The comparison matrix was then completed in both directions (Table 1). Using the given values, the specific weights for each criterion were calculated to be used in the weighted linear combination (Table 3).

Data analysis

The final model representing habitat suitability in the study area was divided into three suitability classes by applying the Natural Breaks method, which is one of the most common procedures to classify quantitative data. The low number of classes provides more accurate and robust information (Hirzel *et al.* 2006). Class ranges are defined by comparing them to the distribution of the entire dataset thus making it possible to identify break points. Finally, the data available are divided to maximize the differences between the number of classes desired. Habitat evaluation and the selection of habitat patches with high suitability were performed by comparing highly suitable habitat patches and the species annual home range. Since

Table 2. Saaty's pairwise comparisons. The values vary between 1 and 9 (factor on the vertical axis is more important than the factor on the horizontal axis) or 1/3 and 1/9 (factor on the vertical axis is less important than the factor on horizontal axis).

Degree of importance	Definition
1	Equal importance
3	Weak importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	Reciprocal values

Table 3. Final factor weights to be applied. (FA-Forest areas; AA-Agricultural areas; RD-Road density; DAR-Distance to asphalted road network; DHN-Distance to Hydrographic network; DUA-Distance to urban areas; S-Slopes; RA-Relief Aspects).

FA	AA	RD	DAR	DHN	DUA	S	RA
0.38	0.03	0.17	0.10	0.05	0.17	0.06	0.03

no information was available on roe deer home ranges in the study area, home range values from Mediterranean habitats from other areas of the Iberian Peninsula were used (Rosell *et al.* 1996; Carvalho *et al.* 2008).

Results

The fieldwork showed that no sampling plot contained any evidence of the presence of roe deer. The network of transects covered the entire study area and was representative of its range. A final map representing the different degrees of suitability of potential reintroduction areas (Fig. 3) was obtained by intersecting the three ecological variables considered relevant to the species: habitat/shelter, food availability, and disturbance. Three main classes of suitability were considered by grouping the scale values in the final map. Thus, white areas represent highly suitable areas, grey represents moderate suitability areas, and black represents low suitability. By dividing the suitability model into three quantitative parameters, approximately 18% of the study area was classified as highly suitable for roe deer. The remaining 82% were divided into moderate (38%) and low suitability (44%). Taking into account the ecological requirements of roe deer, three nuclei of reintroduction were selected by using the Habitat Suitability Index (HIS).

Discussion

Habitat suitability map: reintroduction nuclei

Based on knowledge of roe deer requirements, a habitat suitability model of the species was developed. Three reintroduction nuclei were selected by using the Habitat Suitability Index (HSI) and by fieldwork to confirm all the relevant variables in the model. The results showed that the study area contains suitable areas for roe deer occurrence and expansion. The Freita mountains contain areas that are suitable for roe deer reintroduction (*RCore 1*): the area exhibits continuity between habitats, which promotes the natural expansion of the species. This area has dense vegetation with large patches of highly suitable habitat, mainly consisting of well-developed tree cover (*Castanea sativa, Quercus* sp., *Betula* sp., *Pinus* sp., *Pseudotesuga menziezii*) and a dense shrub layer (*Pterospartum tridentatum*, *Erica* sp., *Ulex* sp. and *Cytisus* sp.). Tree cover with sparse shrubs can provide rest areas for roe deer, while dense shrubs can offer protection

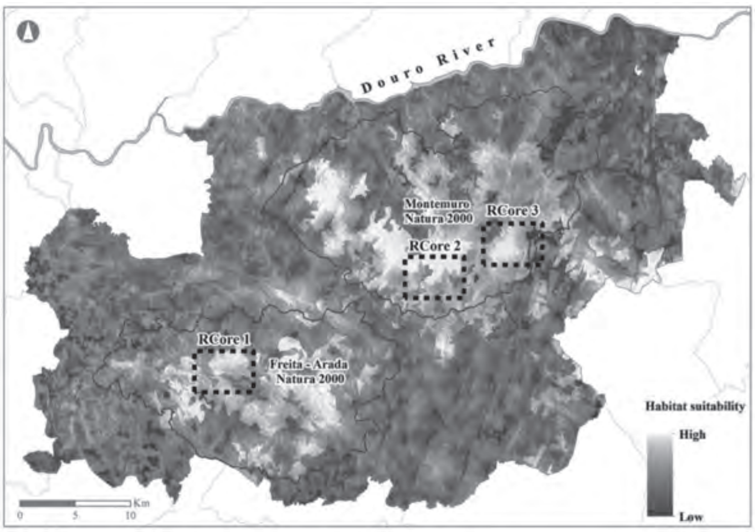

Figure 3. Habitat suitability model output with the potential reintroduction cores. Colours graded from black (unsuitable areas) to white (suitable areas).

(Torres *et al.* 2011b). This type of vegetation not only provides shelter and cover from predators, but also provides highly nutritious food (Duncan *et al.* 1998). According to Torres *et al.* (2011b), roe deer distribution in Portugal is positively associated with areas of high shrub density, especially *Erica* sp. and thorny shrubs. The positive preference of roe deer for patches rich in shrubs is probably linked to the quality of the site, since they have more opportunities to select better food from the great number of plant species (Torres *et al.* 2011b). The results also suggest two other reintroduction nuclei in the Montemuro mountains: *RCore 2* and *RCore 3*. *RCore 2* is located along a river valley with an extensive oak forest and broadleaf and deciduous trees that offer the species cover, food, shelter, and safety. The valley contains pastures which contrast and function as an ecotone and are extremely important for roe deer. The shrub layer is rich and varied, contributing to the species food requirements. Finally, *RCore 3* is an area of woody vegetation mainly consisting of oaks, chestnut trees, and some broadleaf trees. It is characterized by transitional habitats (ecotones), which are very important for this species, alternating with fields mainly composed of grasses, oak trees, and bushes. In addition, the digestive adaptability of roe deer would favour their successful colonization of these heterogeneous landscapes (Serrano *et al.* 2012).

Human disturbance is relatively low in all reintroduction nuclei. This is of importance because, like many other wild ungulates, roe deer usually fear human presence, particularly in Portugal (Torres *et al.* 2011b, 2014). The low suitability areas were mainly urban areas with a relatively well-developed asphalted road network, or sloping areas without a shrub layer or tree vegetation. As mentioned, this can limit roe deer expansion and distribution, and thus these areas were not selected by the model nor were they close to any potential reintroduction nuclei. The areas contiguous to reintroduction nuclei with moderate suitability may play an important role in habitat connectivity and act as wildlife corridors from which roe deer can eventually expand.

Methodology

A strong, multi-criteria method was applied based on the complementary use of a GIS. This approach can report many of the inconsistent criteria leading site suitability and can offer an accurate evaluation of the overall viability of the reintroduction process. The choice of the method is often subject to the model's objective, the species, and the data available (Manel *et al.* 1999) and several techniques include expert opinion in habitat suitability models (Carver 1991, Pereira & Duckstein 1993, Pearce *et al.* 2001, Store & Kangas 2001). The model could not be validated with presence data because these were unavailable. Although we are aware of the importance of model validation, we choose not to replace absent data with data from another area because of the difficulty of finding other regions with a similar environment. Furthermore, such projections always entail uncertainties, such as asymmetrical transferability due to environmental causes, which are specific to differences between geographical regions (Fielding & Haworth 1995), or biotic causes, which are intrinsic to each species being modelled (Randin *et al.* 2006). Nevertheless, by using AHP as an heuristic method, the final suitability map output shows that the environmental variables for the analysis were sensibly and correctly selected. According to Ananda & Herath (2003), the success of this method is strongly determined by the way the decision problem is structured and by the weighting method, and therefore by the way the pairwise comparisons are conducted.

Similar to other methods, there are always some uncertainties associated with this modelling approach (South *et al.* 2000). However, the main benefits of this method are related to the possibility of integrating empirical models and expert knowledge and of considering the habitat factors on different scales (Store & Jokimäki 2003). Store & Kangas (2001) showed that while GISs include tools for managing and producing georeferenced information at the different scales needed (*e.g.* in habitat suitability assessment), multicriteria methods offer tools for modelling expert knowledge. This study attempts to prove that expert knowledge (even when no other data is available) (Doswald *et al.* 2007, Cianfrani *et al.* 2013) can be used in order to generate a habitat suitability model; however, the model needs to be validated after the species reintroduction. The model can be validated by using indirect records of species presence or by using data obtained from the animals using GPS.

Future actions and goals

Future steps in this project include releasing animals at the selected reintroduction sites. Some animals will be fitted with GPS collars and the information obtained by this method will be related to other ecological issues related to the project. Although studies with telemetry (GPS) in roe deer are common in the rest of Europe, in Portugal this technique has not been used for this species (but see Carvalho *et al.* 2008). The information obtained will not only be used to improve potential habitat models and predict population expansion, but will also be of use to develop an adaptive management plan crucial to such reintroduction initiatives (Sarrazin & Barbault 1996). It is also intended to increase the availability of suitable habitat for roe deer through a set of management measures (*e.g.*, controlling poaching; defining boundaries at reintroduction areas regarding hunting activities; and conserving the mosaic vegetation type which provides suitable habitat for the species). The factors that can negatively affect the viability of roe deer populations should be mitigated. These factors should be analysed and measured on a case-by–case basis. It is also important to increase public awareness through local campaigns on the problem of Iberian wolf conservation and the importance of the roe deer reintroduction program.

Conclusions

The availability of suitable habitat is a prerequisite to ensure the success of any reintroduction project and to ensure the persistence of the reintroduced population. Thus, studies on habitat suitability for a species must be conducted as part of a reintroduction process. This study defined several suitable areas for the reintroduction of the roe deer. The results illustrate an approach that contributes to the planning of roe deer reintroduction in central Portugal with the aim of evaluating species habitat suitability and assessing the implications of the results in relation to developing tools for biodiversity conservation.

Conservation actions will be implemented to increase the probability of achieving the proposed objectives. Above all, this project is attempting to make an important contribution to the conservation of roe deer and, consequently, the Iberian wolf in Portugal.

Like any reintroduction project, it also has a strong social dimension. The next steps in the project should focus on education and environmental awareness, thereby sensitizing local populations to the issue of the reintroduction of roe deer and conservation of the Iberian wolf.

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