

Wildlife Corridors Based on Spatial Modeling of Human Pressure: A Portuguese Case Study

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Abstract—In times of economical crisis, rewilding can be a less costly conservation management approach, able to generate economic value from wild lands and to rural communities. Simultaneously, improvement of connectivity between protected areas was identified as a global priority for conservation. Allowing the rewilding concept and connectivity concern, a model for identification of less disturbed corridors for wildlife was designed. Less disturbed corridors can be serious candidates become rewilding areas due to their already low human pressure for wildlife. Accordingly, it was asked of experts from different areas such as nature conservation, environmental and land planning to answer an inquiry to evaluate some variables representing human disturbance. The 51 expert answers obtained were used to create a single spatial gradient of human disturbance to wildlife. Between three Portuguese conservation areas, the least disturbance corridors to wildlife were designed and analyzed. Location of each corridor was compared with Iberian Wolf (*Canis lupus signatus*) distribution, a top predator known by its sensitivity to human presence and disturbance. When spatially compared, the obtained corridors fit the wolf confirmed presence distribution. This is a promising result for the model fitness to human pressure and to optimize a future network of rewilding corridors between protected areas.

Introduction

Wilderness and Rewilding

The concept of wilderness, legally defined by the US Wilderness Act (1964), is associated with the existence of areas with little or no human influence and that can be used for the promotion and maintenance of wildlife and natural processes, which benefit from minimal human intervention.

The rewilding concept, associated with the concept of wilderness, emerges as a conservation strategy that relies

primarily on the natural recovery processes that make ecosystems self-sustaining, involving only protective measures relating to the human activities and, wherever necessary, the reintroduction of key species (Brown et al., 2011). Rewilding can be one of the land management policies to be adopted in abandoned territories, as it promotes the natural regeneration of forests and other natural habitats favoring biodiversity increase and improving ecosystem services. It is a passive management conservation strategy with lower maintenance costs than other territorial management options presenting significant benefits, such as environmental regulation services provided by natural ecosystems, as well as greater economic value of wild lands to rural communities (REAR, 2012).

Rewilding in Europe and Portugal

Despite its many benefits, the bet on natural processes (rewilding) has been, until recently, dismissed as a European territorial management option (Navarro and Pereira, 2012). Initiatives like the adoption of the “European Parliament Resolution on Wilderness in Europe” in 2009, the establishment of the Wild Europe Initiative, the Rewilding Europe Project and PAN Parks Network are bringing the concept of rewilding to the European conservation policy discussion.

Rewilding management is starting to take its first steps in the field in Europe. In Western Iberia, helped by Rewilding Europe Project, Transumância e Natureza Association (ATN), a partner of the project, is managing Portuguese Faia Brava Private Reserve, one of two pilot areas in the Iberian Peninsula where the rewilding process is taking shape (REAR, 2012).

In fact, the Portuguese landscapes, characterized by this long history of humanization, now evidenced in the last decades a clear trend towards depopulation and the consequent abandonment of farming activities. Thus arises the opportunity to apply the concept of Rewilding, as a return to the wild.

The Importance of Corridors for Wildlife

The expansion of urban areas and the boost in infrastructures networks has been driving to a progressive fragmentation of the Portuguese landscape in the last decades. Under these conditions, in which there have been significant losses in important habitats, the existence of a conservation network connecting areas with high natural values through wildlife corridors, certainly contributes to a more effective protection of a large number of habitats and species (Gomes et al., 2011; Rudnick et al., 2012).

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Presently, emerging climate change effects are pushing the species out of the protected areas, as an adaptive response to changing environmental conditions. This migration can only be possible in a favorable environment to such species.

The static approaches that have been adopted in this field of conservation, where areas are selected and managed in order to protect the biodiversity of today (Lawler and Mathias, 2007), are becoming inadequate in the current context of a rapidly changing territory. Recent studies have shown that existing protected areas are not likely to lead to the protection of biodiversity in a continuous change future (Bengtsson et al., 2003). Moreover, many species, even whole communities, will be forced to move in response to climate change (Parmesan, 2006). Movements of populations will be one of the major challenges for many species (Lawler and Mathias, 2007) and such movements have already been detected, especially in altitude migrations (Parmesan, 2006).

In response to these environmental changes, many plants and animals will have to move inside and outside of the protected areas until they find a suitable habitat that guarantees their persistence. Such movements will only be possible if they have adequate conditions (Garcia and Araújo, 2010; Araújo et al., 2004).

Conservation planning is currently a challenging task (Kujala et al., 2013), as there is a growing consensus that conservation strategies must anticipate climate change impacts (Araújo and Rahbek, 2006; Thuiller et al., 2007.) In this constantly changing world it is necessary to identify solutions that minimally compromise the current needs of conservation and simultaneously create higher benefits in the future (Kujala et al., 2013). Such solutions include the implementation of mechanisms for integrated management of rural areas facilitating the movement of species between areas of conservation (Araújo et al., 2011). For this purpose, it is relevant to identify connectivity corridors between suitable areas (Williams et al., 2005; Opdam and Wascher, 2004).

The importance of Keystone Species for Corridors

The regulatory role of large predators based on keystone species theory is central to the rewilding concept (Brown et al., 2011). Keystone species are defined as having a structural role in their community although disproportionate to their abundance, usually large and wide-ranging predators. Protection of 'keystone species' may have an 'umbrella' protection effect upon other species, since many 'keystone species' are wide-ranging and sensitive to disturbance, requiring large and relatively unchanged habitats (Brown et al., 2011).

There is evidence that ecosystem function can recover following the return of keystone species. Some of the most known examples are related to wolves recolonisation where a cascade effect in survival rates and population density for some herbivores, plants, and even in diversity and abundance of riparian birds was generated (Hebblewhite et al., 2005; Beschta and Ripple, 2010).

Hilty et al. (2006) pointed out that a single species may also be used to justify the connection of protected areas in order to provide space for viable populations and potential increases in biodiversity. The wolf is a powerful and widely

recognised symbol of wilderness in the northern hemisphere (Brown et al., 2011).

The Iberian wolf is currently the largest terrestrial predator within the Portuguese fauna, and is also one of the most endangered species in our country. In Portugal it is nationally classified as Endangered (Cabral et al., 2005). Although the European wolf population is a large metapopulation with several distinct fragments (LCIE, 2007), the Iberian wolf population is distributed mainly in the north of the Iberian Peninsula (Pimenta et al., 2005).

Research Objectives

The work presented herein is part of a study of an alternative strategy for conservation developed for the concept of wilderness adapted to European reality, subject to a long history of anthropogenic occupation. This strategy is based on information about human influence, oriented to the identification of areas with less human disturbance for wildlife (Gomes et al., 2011), since wild species do not usually tolerate well human presence and are sensitive to environmental disturbances generated by human activities. Those less disturbed areas are potentially suited for protection of wildlife.

The project CVS—Corridors for wildlife: spatial modeling of human pressure and its usefulness to the conservation of Iberian Wolf, funded by the Portuguese national science foundation, intends to lead to the development of a methodology that aims to contribute to break the isolation between national protected areas, through the identification of corridors, as preferentially connecting paths allowing the migration of existing wild species.

To achieve this goal, an innovative approach was developed based on spatial modeling of anthropogenic influence in the territory that generates a gradient of the environmental disturbances derived from human presence and activities. This gradient constitutes the basis for identification of corridors between protected areas, following the areas with lower anthropogenic disturbance to the movement/progression of wildlife.

Subsequently, the idea is to validate this new strategy for identifying ecological corridors through the study of the location and movement of the Iberian wolf, an endangered species considered sensitive to human presence and activities.

Methods and Results

Gradient of Human Disturbance for Wildlife

The concept of wilderness is associated with remote and natural areas which are far from human influence and where natural processes are primarily responsible for the landscape dynamics (Wild EUROPE, 2013). Inherent to the wilderness concept itself, it is difficult to set rigid limits to delineate a territory with such characteristics. However, it is possible to identify a set of characteristics that contribute to wilderness quality, that are inversely related to the measure of environmental disturbance caused by human activities.

In this project, the methodological processes for spatial modeling of environmental disturbances derived from

human presence and activities are developed based on the research work “Wilderness Areas for Wildlife Conservation” (Gomes, 2005). It is considered that the spatial modeling of human influence relies on three major themes, regarded as representative of the major environmental disturbances: human presence, habitat pollution, and land use/land cover (Gomes et al., 2011). These themes, that can be represented in a continuous way on the territory, contribute to create a gradient that may be interpreted as the difficulty of movement/progression for general wildlife (Figure 1).

Data and Model

The Human Presence factor constitutes one of the major threats to wildlife, so the resident population distribution was one of the proxy variables considered in the methodology for obtaining the gradient of environmental disturbances. It used resident population data from the 2011 Census for Portugal’s mainland, to obtain human population density distribution.

The spatial distribution of industries which are under environmental license by Portuguese Law concerning integrated pollution prevention and control, were considered as point sources of pollution, especially in terms of noise generation and release of chemicals into the soil and air. The aim was to simulate the intensity and extent of environmental disturbances to wildlife caused by these sources. Data were obtained from the Portuguese Water Institute (INAG).

The linear infrastructures such as roads, railways and airports can produce significant environmental impacts. These infrastructures directly affect wildlife through trampling and cause environmental disturbances derived from noise and gas emissions. They also cause a barrier effect, disrupting directly the movement and use of territory by the species and disrupting the habitat continuity that results in the fragmentation of the landscape. Road and railway geographical features were obtained from the Directorate-General for Territory Development (DGT).

The Portuguese Land Cover Map - COS (2007), also from DGT, was used to assign an evaluation to the land use/land cover classes according to the level of human perturbation

generated within each type of class, regarding the direct disturbance to the movement and progression of wildlife species through the territory.

All cartographic variables that constitute the spatial data base were categorized in aggregated classes and converted into the raster format with a resolution of 100mX100m, which corresponds to a 1 hectare cell size. The main spatial analysis procedures for the calculation of environmental disturbances intensity and extent in Portugal’s mainland territory, are focused in neighborhood analysis, reclassification and map algebra processes (Gomes et al., 2013). Figure 2 shows the schematic overall methodological model for obtaining the gradient of environmental disturbances.

Expert Inquiry

Considering that the evaluation criteria that reflect environmental disturbances derived from human activities varies with the different sensitivities of species and that for most cases it is not scientifically quantified, a multi-criteria expert system was developed to obtain a gradient of environmental disturbances, based in the consultation of a pool of experts with different backgrounds. The experts were selected based on their knowledge and experience in areas such as terrestrial wildlife, nature conservation, environmental impact assessment and landscape planning, as well as knowledge in Portuguese land territory characteristics. The fact that these experts represent different interests and levels of knowledge about environmental impacts, ecology and wild species limitations, contributes to a greater range of responses leading to a gradient of human disturbances in the territory which tends to better reflect the reality for these species. It was intended that experts answer the various questions of the CVS (Corridors for wildlife Project) form (Gomes et al., 2013) to assess the disturbance to wildlife on a scale from 1 to 10. They were also asked to indicate what they considered to be the maximum distance of environmental disturbances influence caused by roads and industries, as well as the minimum width of wildlife corridors.

There were obtained 51 responses through the CVS form. All experts have higher education and over 25% are PhDs.

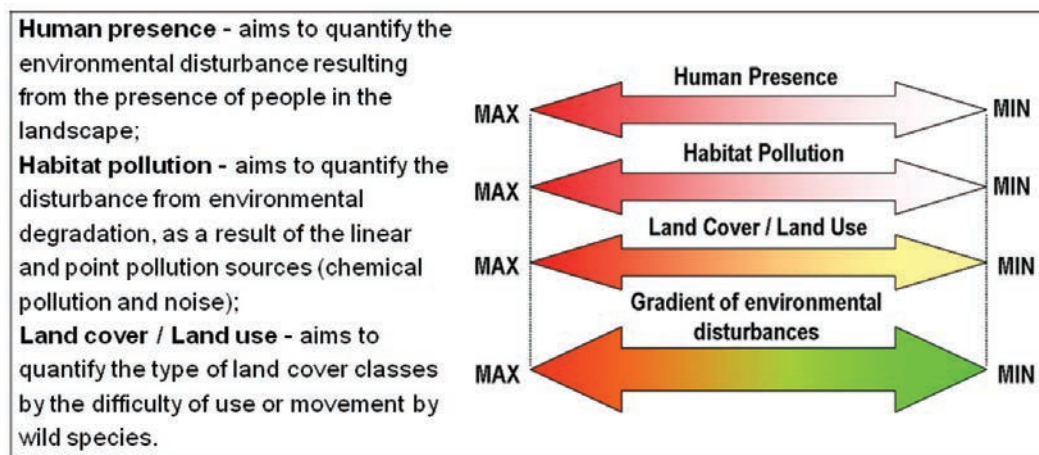


Figure 1—Factors that influence the gradient of environmental disturbances.

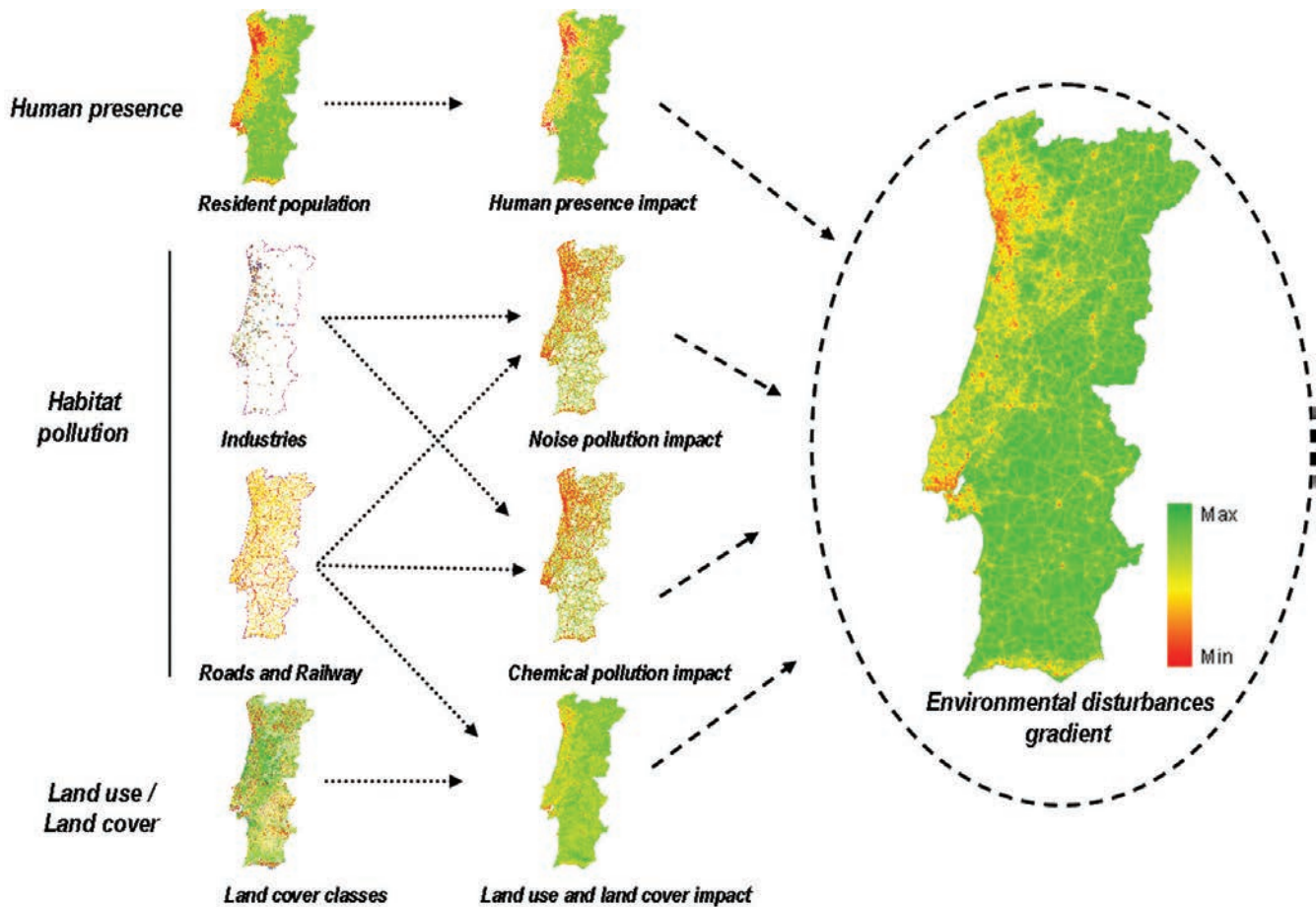


Figure 2—Methodological model: environmental disturbances gradient.

Experts were asked to answer the inquiry from a general wildlife perspective or from the viewpoint of a biological group (BG). There were 33% general answers and the other 67% were answers based on a specific BG.

Additional analysis was made to examine whether those experts should be divided into groups and if these groups had to do with the biological group on which they answered or with their academic background. In order to obtain one or more differentiated profiles of experts in the modeling of the environmental gradient, a correlation analysis was made, as well as principal component analysis (PCA) and hierarchical cluster analysis (HCA) on the distance matrix of the answers.

From the Kendall non-parametric correlation analysis between the expert answers, it was found that 95% showed a positive correlation and more than 31% of expert pairs were strongly correlated with each other (with a correlation value greater than 0.5), thus no contradictory trends among experts were observed. Analyzing the results of the PCAs and HCAs, there was no cluster trend either by biological group or by type of academic background, so the answers were grouped in a single profile for the spatial model.

As the values assigned in the expert responses did not show statistical normality in their values' distribution, it was calculated the median disturbance value from expert's answers for each question. The results are listed in Appendix 1. These

median values of disturbance were used for the reclassification of the variables, on a raster basis, in the spatial modeling. It was, then, possible to obtain a single gradient of environmental disturbances representative of all opinions of the 51 experts, which serves as the basis for identifying the least disturbance corridors between important areas for conservation.

Designing Corridors

The Portuguese National Network of Protected Areas (RNAP) and the Portuguese Natura2000 Network (resulting from the application of two European Directives) are the two essential nature conservation planning instruments in Portugal. However, these protected areas originate a fragmented set of overlapping areas that are not connected (Figure 3).

To produce the corridors using the CVS methodology it selected a pilot area involving three Portuguese classified areas for conservation - Gerês, Alvão and Montesinho. These three areas derive from the merger of the RNAP and the Natura2000 and are located in the North of Portugal (Figure 3).

A "suitability map" was produced as the inverse of the disturbance gradient previously obtained. We also avoid dam reservoirs with more than 100 ha since they are a physical barrier for a large number of species. Using CorridorDesigner toolbox v0.2 (Majka et al., 2007) that operates over ArcGis,

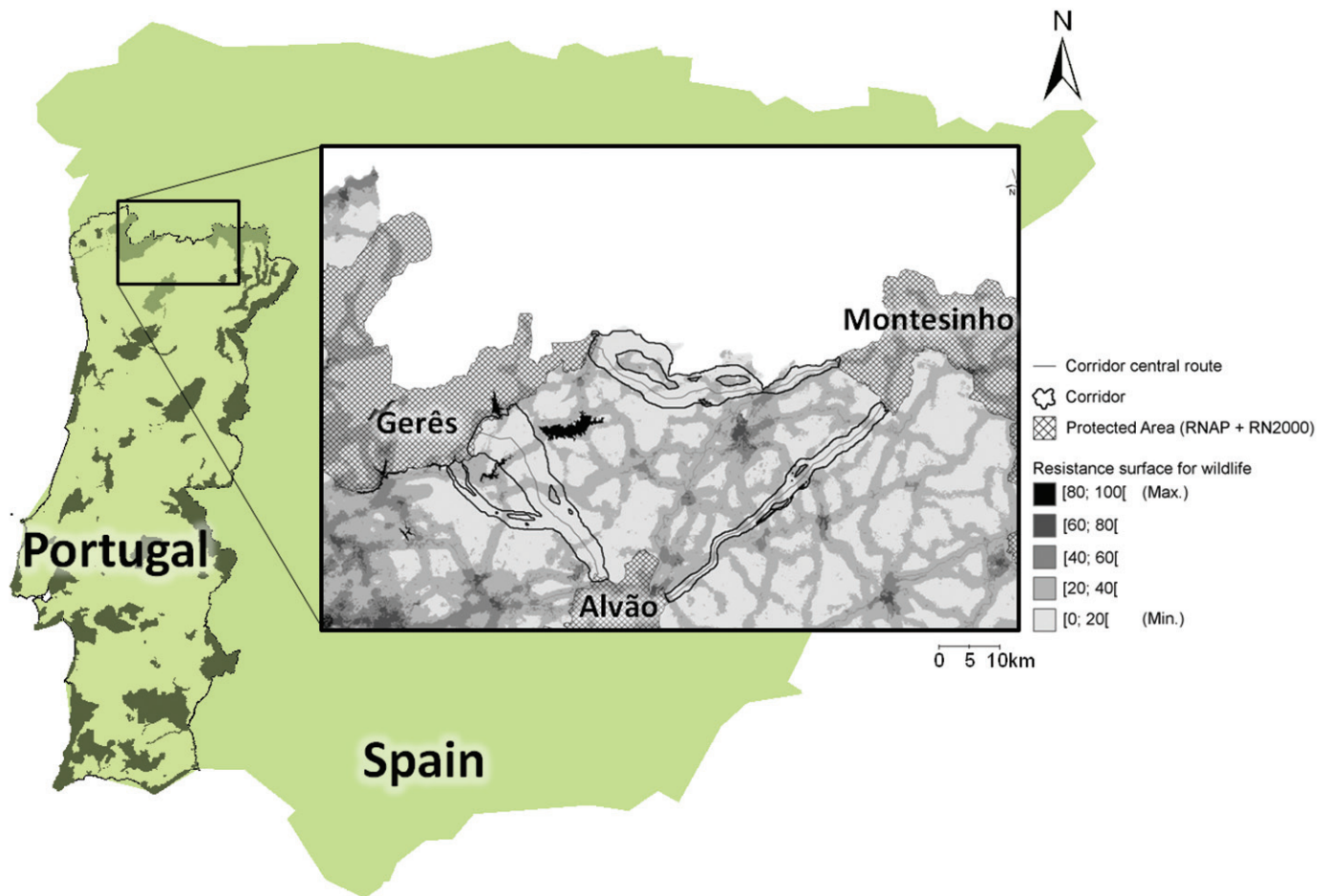


Figure 3—Proposed Wildlife Corridors (CVS) for the pilot area, between Gerês, Alvão and Montesinho.

the cost surface between each pair of areas was calculated based on the “suitability map” and a set of progressively less permeable to progression corridors was obtained. The quality of each corridor was analyzed using Evaluation Tools, an extension of CorridorDesigner Tool, used to find the best central route within each corridor and to calculate a set of statistics that allowed us to evaluate corridor width, bottleneck constriction issues and, based on the previous data, the disturbance levels, main cover classes and major barriers.

The less disturbed corridors were selected, meaning the more permeable to wildlife progression corridors, with a transversal amplitude equal or larger than the median proposed by the experts at least in 90% of the corridor length (Beier et al., 2007), 1000 m in this case. Figure 3 and Table 1 present the proposed Wildlife Corridors (CVS) for the pilot area, between Gerês, Alvão and Montesinho.

Uncertainty analysis of the model, the analysis of constraints at a regional/local scale in the identification of

Table 1 – Morphological characterization of Proposed Wildlife Corridors.

Gerês-Alvão	Gerês-Montesinho	Alvão-Montesinho
(C) – Central route length; (Lmin) – Minimum width; (Lmax) - Maximum width; (Lmed) - Average width, (%Lim) – Percentage above the width considered as minimum by the experts: 1 000 m;		
C = 36 000m Lmin = 1 900 m Lmax = 7 677 m Lmed = 4 820 m %Lim = 100	C = 48 000m Lmin = 365 m Lmax = 4 745 m Lmed = 2 569 m %Lim = 97	C = 52 000 m Lmin=975 m Lmax=2 531 m Lmed=1 547 m %Lim= 99

Wildlife Corridors as well as the discussion of mitigation measures for the critical points identified within CVS are some future developments.

Corridors Versus Wolf Distribution

When spatially compared with Iberian wolf distribution (Pimenta et al., 2005), the obtained corridors are very coincident with this species confirmed presence (Figure 4). This is a promising result considering that the wolf, as a keystone species, can be used as guide to the main corridor design between protected areas, and for future design refinements at a regional/local scale.

Future steps will involve more detailed wolf distribution information, identifying corridor areas with suitable habitats and habitats to avoid, and collecting information through monitoring the Iberian wolf within the proposed corridors, to identify pack locations, nesting sites or confirming pathways.

Conclusions

The legal mechanisms for conservation in Portugal derive from commitments under various international treaties, compliance with EU directives and specific national legislation. We are dealing with binding instruments, developed in accordance with the conservation strategy aimed at protecting species and habitats, associated to active territorial management in order to reduce or eliminate threats affecting species persistence.

From a conservation point of view, the choice between betting on natural processes (rewilding) or on active management will depend on the objectives and on the local context

(Navarro and Pereira, 2012). The active management tends to be the preferred option when the aim is to protect certain species or maintain priority habitats, while the passive management focuses on dynamic ecological processes that may be more sustainable at long term or more suitable for large areas of conservation. Moreover, rewilding can be seen as a less costly conservation management approach.

The improvement of connectivity between protected areas has been identified as a global priority for conservation (Brown et al., 2011) because it is gaining relevance due to climate change and loss of habitat generated by human pressures.

Abandoned lands between protected areas for conservation, as well as lands with less impact activities or regions with less human presence, are serious candidates to become areas of rewilding management. These lands may link areas with important natural values contributing to the creation of a network that can potentially favour the movements of species and landscape connectivity, preferentially designed through less disturbed areas.

This research work proposes a methodology that contributes to finding best corridors for a network of land with potential suitability for rewilding based on a gradient of human disturbance. The spatial match of the obtained corridors with the Iberian wolf confirmed presence distribution within the pilot study area is a promising result for the model fitness to human pressure since it is a species known by its sensitivity to human presence and disturbance. Top predators are pointed as good keystone species to improve local diversity and ecosystem services recovery, by their documented umbrella effect (Brown et al., 2011) so the creation of corridors adapted to wolf can potentially improve biodiversity resources indirectly.

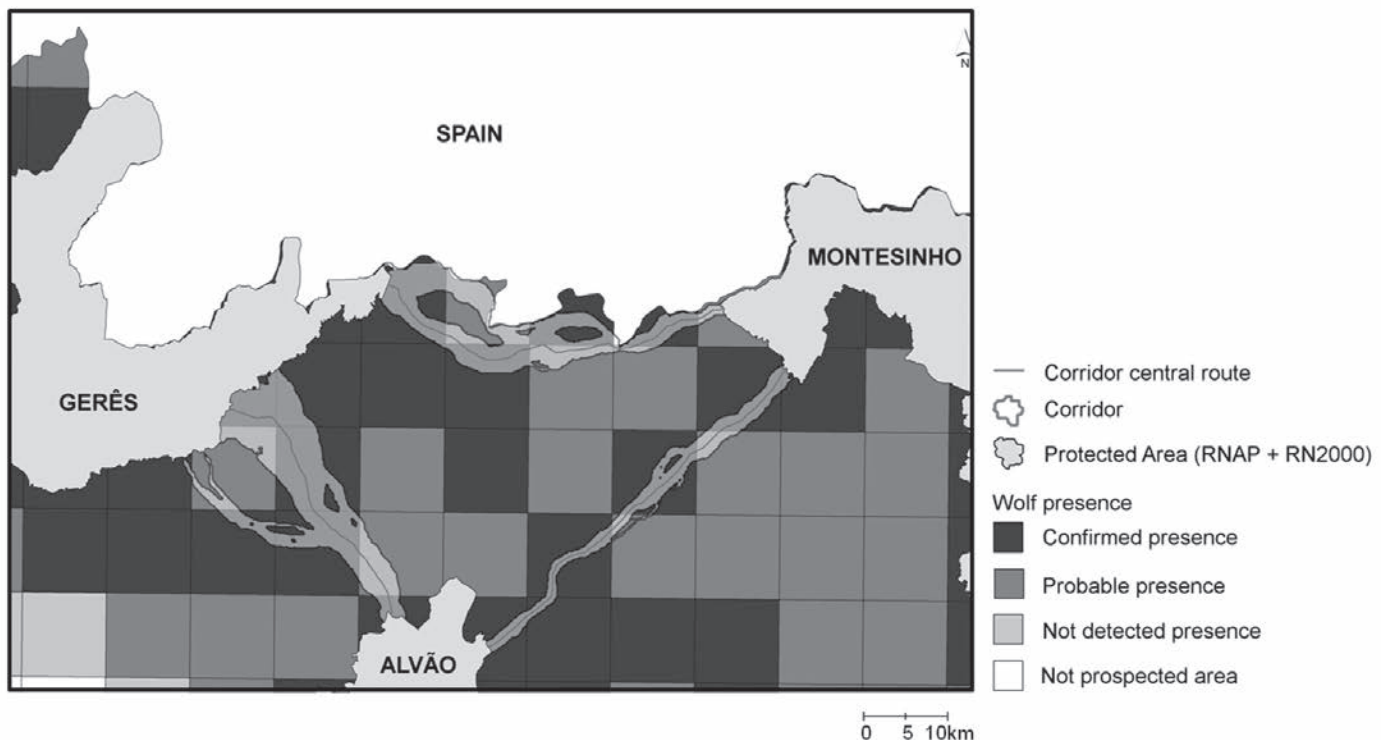


Figure 4—Iberian wolf distribution and proposed corridors.

More accurate results may be achieved when the analysis of constraints in the identification of the CVS corridors is concluded, as it will refine the corridors' design to wolf characteristics and limitations. The consideration of the mitigation measures for the critical points identified in the CVS corridors will contribute to a plausible implementation of this model in the field. The study of the temporal evolution of the environmental disturbance values is also another foreseen development aiming to improve the design quality of the obtained corridors. Further developments will deepen the analysis of the data on the wolf presence within the proposed corridors, involving not only direct observations but also scats confirmed with genetics, camera trapping photos and telemetry data, as well as wolf habitat modelling for predicting its occurrence.

Moreover the methodology will be applied to the remaining protected areas of the Portuguese mainland. The combination of the model results with the most relevant ecological habitat features distribution or particular target species suitability distribution at a regional/local scale level may convert it into a national level network of protected areas, which should be linked to the rest of the Iberian Peninsula.

The positive results already achieved in this work suggest that identifying wildlife corridors in areas with less human impact can be an additional perspective in the expeditious design of efficient corridors between protected areas, aiming to contribute to the biodiversity increase.

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Appendix—Median values from the experts' answers (CVS form)

<i>Pollution Impact (point and linear sources of pollution)</i>	<i>Noise Impact</i>	<i>Chemical Impact</i>	<i>Human Presence Impact (population density)</i>	
1: Landfill	4	5	1: Less than 0,2 persons per hectare	2
2: Waste Incineration	5	8	2: From 0,2 to 0,6 persons per hectare	3
3: Intensive livestock	5	6	3: From 0,6 to 2 persons per hectare	5
4: Slaughterhouses	4	5	4: From 2 to 6 persons per hectare	8
5: Food Processing	5	6	5: From 6 to 1000 persons per hectare	1
6: Ceramic/Glass	5	6		0
7: Cement	7	8	<i>Maximum distance of influence from environmental disturbance (meters)</i>	
8: Paper Pulp / Paper	6	8	Road and Railway Network	1 000
9: Textiles / Paints	6	8	Industry	1 250
10: Refinery / Hydrocarbon Production	7	9	<i>Minimum corridor width(meters)</i>	
11: Power Production	6	8	Minimum corridor width	1 000
12: Metals Production and Processing	7	8		
13: Chemicals / Fertilizers / Pharmaceuticals	6	8		
<i>Road and Railway network</i>				
1: Highway	7	6		
2: Main Roads	6	6		
3: National Roads	6	5		
4: Regional Roads	5	4		
5: Municipal Roads	3	3		
6: Single Railways	4	3		
7: Double Railways	5	3		

<i>Land use/land cover Impact (CVS nomenclature)</i>			
1: Urban	9	23: Dense mixed forest (excluding eucalyptus and invasive spp.)	1
2: Commercial units	8	24: Open mixed forest (excluding eucalyptus and invasive spp.)	1
3: Power production plants, capture and water treatment plants	7	25: Eucalyptus forest	3
4: Industries, ports, shipyards, airports	9	26: Mixed eucalyptus forest	3
5: Mineral extraction and dump sites	8	27: Mixed invasive spp forest	3
6: Green urban areas, historical areas, sport and leisure facilities	5	28: Moors, heathland and sclerophyllous vegetation	1
7: Greenhouses and nurseries	5	29: Cuts, new plantations	4
8: Complex cultivation patterns with scattered dwellings	3	30: Burnt areas	5
9: Annual crops associated with permanent crops (not irrigated)	2	31: Beaches, dunes and sands	2
10: Annual crops associated with permanent crops (irrigated)	4	32: Bare rocks and sparsely vegetated areas	2
11: Rice fields	4	33: Wetlands (excluding salines)	1
12: Vineyards, fruit and olive trees	3	34: Salines and aquaculture	4
13: Pastures and pastures associated with vineyards, fruit and olive trees	3	35: Water courses (natural and artificial)	1
14: Agriculture with significant areas of natural and semi-natural vegetation	2	36: Water bodies (natural and artificial)	3
15: Agro-forestry areas with annual crops (not irrigated)	2	37: Coastal lagoons and estuaries	2
16: Agro-forestry areas with annual crops (irrigated)	3	38: Highways	9
17: Agro-forestry areas with pastures	2	39: Main roads	8
18: Agro-forestry areas with vineyards, fruit and olive trees	2	40: National roads	6
19: Dense broad-leaved forest (excluding eucalyptus and invasive spp.)	1	41: Regional roads	5
20: Open broad-leaved forest (excluding eucalyptus and invasive spp.)	1	42: Municipal roads	4
21: Dense coniferous forest	2	43: Single railways	5
22: Open coniferous forest	2	44: Double railways	7