Wildl. Biol. Pract., 2011 December 7(2): ..-..
doi:10.2461/wbp.2011.7.16

ORIGINAL PAPER

Habitat Assessment to Select Areas for Reintroduction of the Endangered Iberian Lynx

J.M. Gil-Sánchez[1,*], R. Arenas-Rojas[2], M. García-Tardío[1], J. Rodríguez-Siles[1], M.A. Simón-Mata[3].

[1] Equipo Life Lince Ibérico, EGMASA-Consejería de Medio Ambiente Junta de Andalucía, O. P. Jaén, Avenida de Andalucía 106, 1ª planta, 23006 Jaén, Spain.

[2] Equipo Life Lince Ibérico, EGMASA-Consejería de Medio Ambiente Junta de Andalucía, O. P. Córdoba, C/Pepe Espaliú 2, 14004 Córdoba, Spain.

[3] Consejería de Medioambiente, D. P. Jaén, C/ Fuente del Serbo 3, 23071 Jaén, Spain.

* Corresponding author: Phone: +34 670947804; Fax: +34 953006413. E-mail: jmgilsanchez@yahoo.es

E-mails: R. Arenas-Rojas: rarenas@egmasa.es
M. García-Tardío: maribelgatar@gmail.com
J. Rodríguez-Siles: rioyeguas@hotmail.com
M.A. Simón-Mata: miguelangel.simon@juntadeandalucia.es

Keywords
Andalusia;
Iberian lynx;
Lynx pardinus;
Habitat assessment;
Oryctolagus cuniculus;
Reintroduction.

Abstract
We conducted habitat assessment for the purpose of selecting areas for the first reintroduction efforts of the critically endangered Iberian lynx (*Lynx pardinus*). Two scale-based approaches were developed. First, we followed a hierarchical process to select the best areas at the large scale landscape based on five key factors in reintroduction success: 1) suitable habitat structure, based on known habitat selection by resident radio-tagged Iberian lynxes applied to a Geographic Information System (GIS) and a regional map, 2) optimal food resources, based on surveys of the staple prey, the European rabbit (*Oryctolagus cuniculus*), 3) area size, 4) existing legal protection and 5) possibilities of contributing to a meta-population system, linking with existing populations through dispersing individuals. The second phase of our evaluation examined the pre-selected areas with more detail to fine-out the reintroduction site selection. We compared fourteen variables related to four key-factors for the lynx: human-induced mortality (poaching and road-kills), micro-habitat structure, carrying capacity and possibilities of natural expansion. Guadalmellato and Guarrizas out of five potential areas selected by the large-scale assessment were considered adequate after the detailed assessment. Both areas showed optimal values of most of the variables studied, and offered a good potential scenario for the establishment of a large meta-population, which could include the current population plus a large suitable patch located nearby, but outside Andalusia. The three remaining areas should not be discounted once the priority goal of obtaining a long-term self-sustaining population is reached.

Introduction

Reintroduction is an important tool for both the recovery of threatened species [1-7] and for ecosystem restoration due to the key-role of some locally extirpated species [7,8]. This is the case of top-order predators such as felids, canids or bears, which comprise a functional group relatively rare in wild landscapes because they are at the top of the food chain and furthermore because they are conflict species with human activities such as livestock and hunting [7,9,10]. Consequently, numerous populations of large carnivores have been eradicated from large areas of the planet [11,12].

The Iberian lynx (*Lynx pardinus*), with less than 200 individuals comprised in two small populations located in Doñana and the eastern Sierra Morena [13,14], is the only wild cat species listed on the "Critically Endangered" IUCN red list category [15]. The former distribution of this species was limited to the Iberian Peninsula, where it was considered common in some areas of the southwest at the beginning of the 20th century [16]. Human-related mortality has been identified as one of the main causes of such a dramatic decline, with indiscriminate trapping practise playing an important role [17,18]. The situation became even worse due to broad-scale depletion of its staple prey, the European rabbit (*Oryctolagus cuniculus*), when the myxomatosis and hemorrhagic diseases reached the Iberian Peninsula since the middle of the 20th century [18,19]. The Iberian lynx has was legally protected in Spain in 1973, and currently important conservation programs, including captive breeding, have been launched on the last two populations [14,20,21]. However, conserving only these isolated and small populations is obviously insufficient for long-term restoration. Natural recolonisation by the species from the current populations into the former range is highly limited by fragmented habitats [13,19]. Therefore, reintroduction programs to form new population nuclei within the expected dispersal distance of the existing populations that could facilitate larger meta-populations, is one of the most important steps towards species recovery in the coming years [22].

We present the assessment used to select the areas where the first reintroduction efforts of this endangered species have been carried out [20]. Our goal was to provide an ideal setting of landscape and habitat analysis to evaluate potential sites for lynx reintroduction. The Iberian lynx occurrence is mainly limited by the availability of wild rabbits, its single most important prey species. However rabbit abundance fluctuates due to diseases and competition with wild and domestic animals and is therefore difficult to model in a geographic information system (GIS). The hierarchical site selection approach presented could be used to determine reintroduction areas for future releases of this and other endangered carnivores.

Methods

The study area was Andalusia, a region comprising 87,597 km^2 located in southern Spain, where the last two populations of the Iberian lynx currently occur [13]. There are three well-defined bio-geographical areas: **1)** the Sierra

Morena (24,734 km², 200-1,600 m altitudinal range) occupies the northern border with a landscape dominated by Mediterranean scrublands plus holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) forests; **2)** the Sierras Béticas (43,037 km², 0 – 3,492 m altitudinal range) occupy the southern Mediterranean coast, with highly variable landscapes of oak forest in the western part, mixed areas of cereal and olive crops with patches of Mediterranean scrublands and pine forests in the centre and north-east, and semi-deserts at the south-eastern limit; **3)** the Guadalquivir River Valley (19,826 km², 0 - 600 m altitudinal range) is the area located between the Sierra Morena and the Sierras Béticas, comprising a transformed area dominated by crops of mainly of cereals and olive trees. At the beginning of the 20th century, the Iberian lynx was present in most of the Sierra Morena, some patches of the Sierras Béticas and within the small patch of Doñana at the mouth of the Guadalquivir River Valley [19].

Predictive habitat distribution models [23] based on habitat requirements have been used to build predictive ranges of some felid species [24-26]. Following other studies of wild cats reintroductions [27,28], we attempted to use large-scale suitability maps based on habitat selection models as a first step to narrow down potentially suitable areas. Detailed habitat models for the Iberian lynx were constructed for the Doñana population [29] and the Sierra Morena population [30], with their respective predictive maps. However, both models had important limitations that prohibited their incorporation in our site selection habitat assessment. The implemented models were quite different from one another [29,30], and their accuracy is questionable, since only 44,2% of the predictive map of Sierra Morena [23] coincided with the current population's distribution [21] as calculated using the Cole [31] index (Fig. 1). Additionally, both models were based on detailed environmental covariates which are difficult to obtain at the regional level.

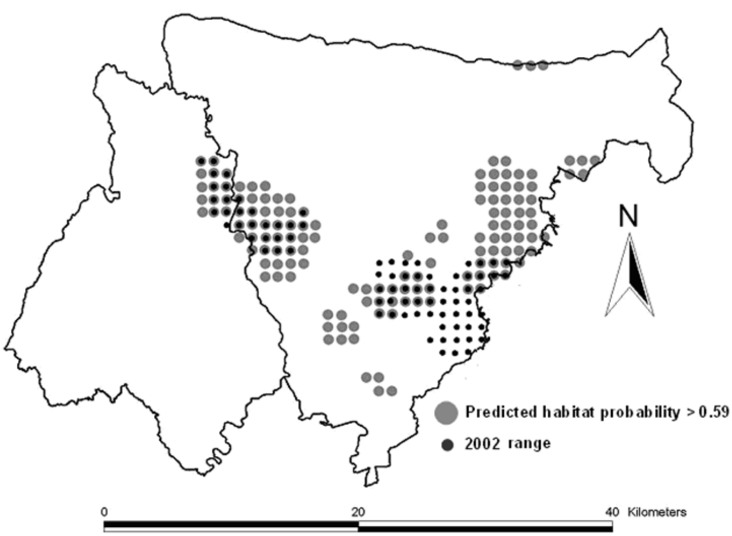

Fig. 1: UTM 1x1 km overlapped grid cells between the predicted (redrawn from [30]) and current ranges of the Iberian lynx in the Andújar and Cardeña-Montoro Natural Parks, Sierra Morena mountains [21].

Consequently, we developed our approach assuming that habitats suitable for the species are those present within the currently lynx occupied distribution range, as in habitat suitability model models for the tiger (*Panthera tigris*, [32]) and the endangered Florida panther (*Puma concolor coryi*, [33]). We used the most precise available GIS database on the habitat types of Andalusia (1 m accuracy), which was updated in 2003 and contains 112 habitat units within 409,164 polygons [34]. The potentially suitable habitat units for lynx (Table 1) were defined based on attributes of the currently occupied habitat units within the species' current range (year 2006) of the Sierra Morena population [21]. The Sierra Morena population was assumed to be more representative of habitats formerly occupied by lynx than the smaller Doñana population since almost all former populations occupied inland mountains areas quite different of the coastal plains of Doñana [18,35]. Since the tree species within scrubland habitats (Table 1) had no biological significance for the Iberian lynx [36], the different types of scrublands were pooled into just two units: dense shrubs and cleared shrubs, since shrub cover has a major influence on habitat selection of the species [36]. The rest of the habitat units were pooled together since there was a low availability of each (less than 6%; Table 1).

Table 1: Availability of habitat units within the current range (2006) of the Iberian lynx in the Sierra Morena.

HABITAT DESCRIPTION	ha	%
Dense shrub without trees	774.8	4.6
Dense shrub with dense oak forest	160.5	0.9
Dense shrub with cleared oak forest	2210.5	13.3
Dense shrub with dense pine forest	61.7	0.3
Dense shrub with cleared pine forest	2401.8	14.4
Dense shrub with oaks and pines	244.5	1.4
TOTAL DENSE SCRUBLAND	**5853.8**	**35.2**
Cleared shrub without trees	25.2	0.1
Cleared shrub with dense oak forest	3477.3	20.9
Cleared shrub with cleared oak forest	2926.6	17.6
Cleared shrub with dense pine forest	448.6	2.7
Cleared shrub with cleared pine forest	164.81	0.9
Cleared shrub with oaks and pines	1551.8	9.3
TOTAL CLEARED SCRUBLAND	**8594.3**	**51.7**
Dense pine forest without scrubland	785.2	4.7
Dense oak forest without scrubland	5.6	0.0
Grassland with trees ("dehesa")	835.1	5.0
Olive crops	409.3	2.4
Other crops	82.8	0.5
Pastureland	40.1	0.2
TOTAL OTHER HABITATS	**2158.3**	**12.9**

We carried out a habitat selection analysis by using radio-tracking data [33]. Between 2006 and 2008 in the Sierra Morena we obtained 997 locations of 14 resident radio-tagged lynxes in the eastern Sierra Morena with non-overlapping home-ranges: 5 equipped with VHF radio-collars (Wagener collar, Brenaerham, Germany) and 9 equipped with GPS-GSM collars (Televilt Tellus Collar, Lindesberg, Sweden). The estimated accuracy of locations [37] was calculated at 122.4 m for the conventional collars (SD = 91.4, n = 20 field trials) and less than 50 m for the GPS collars. Therefore locations within 50 – 122.4 m respectively of to habitat borders were rejected to classify each location in the correct habitat type. Locations were assumed to be independent since one location was obtained every two days for at least one year. The habitat selection was estimated using the Savage index (W_i = use / availability) and analysed with Mann-Whitney U tests. The availability of the habitat units was calculated for each of the fourteen annual home-ranges, estimated with a 95% minimum convex polygon. A range of 86 – 417 locations was used per home range, which reached an asymptote after 64.5 ±5.1 fixes (for more details on radio-tracking protocol see [38]). Not all habitat types were represented in each home range, thus the described combination of land cover types reduced effects of inflated Type I error rates on our results [39]. Once the selection of the GIS habitat units was made, we constructed a suitability map at the regional level representing the positively selected habitat units and the neutrally selected units. The program Arcview© was used for all described mapping processes.

It is well known that the Iberian lynx depends on just one prey species, the rabbit [36,40-44]. Therefore, we conduced field surveys to detect the best rabbit patches within and adjacent to the species former range. Rabbit surveys were conducted between 2001 and 2003 in UTM 5x5 km grid cells within the range of the Iberian lynx described by Rodríguez and Delibes [19]. A total of 383 cells were sampled, all except 54 were located within Sierra Morena and Doñana (Fig. 2). Each cell was sampled once by one person walking during four hours looking for rabbit latrines, since this is a good method to objectively study rabbit abundance ([45], present study see below). Sampling was stratified following the main types of habitat (scrublands, oak forests, pine plantations and crops) and each transect was recorded with a GPS. The minimum rabbit density necessary was determined by examining rabbit densities in areas of known stable lynx presence within the largest most representative current lynx population of Sierra Morena. A total of 22 UTM 2.5x2.5 Km grid cells were annually sampled between 2003 and 2009 by walking within each grid cell during two hours, following the same described method. Stable lynx presence and reproduction were confirmed (see [21]) in grids with at least 10 rabbit latrines per Km^{-1}. Therefore, at the level of large-scales habitat assessment, the UTM 5x5 Km grid cells with > 10 rabbit latrines per Km^{-1} were categorized as optimal for supporting stable lynx presence.

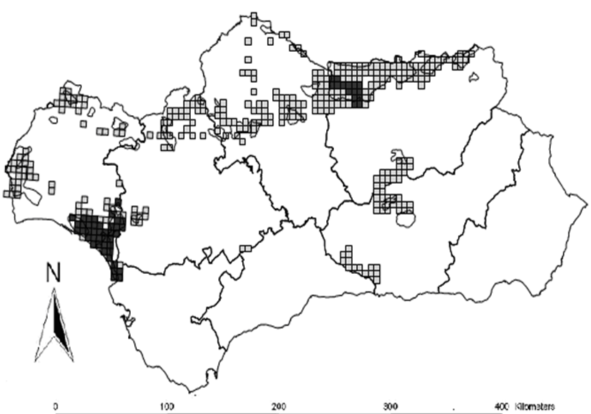

Fig. 2: Rabbit survey of UTM 5x5 km grid cells (current range of the Iberian lynx shown in black). Limits of the Andalusia provinces (thick lines) and 1980-1988 lynx range as estimated by Rodríguez and Delibes [19] are provided.

During the selection process, suitable habitat patches were selected only if they were larger than 10,000 ha. This is the minimum proposed size for reintroduction of the species to ensure a carrying capacity of ca 16 female territories, similar to the Doñana population [35]. A new filter was set up by selecting only those patches included in protected areas of the European Natura 2000 network. Due to the small size of the current Iberian lynx population and the suitable patches identify in this study, we decided to select the reintroduction areas for the creation of the largest possible meta-population rather than focusing on any single population [27,46,47]. We selected only suitable habitat patches that were sufficiently connected to one of the existing populations so as to potentially contribute to a meta-population dynamic by being: 1) located within the dispersal radius (DR) of 42 Km, which is the maximum dispersal distance cited for Iberian lynx [48], from the nearest extant source population and 2) containing suitable dispersal habitats (see [36]) available between the patch and the nearest present population (Doñana and Sierra Morena). No major barriers are present in Andalusia, being the most important two highways, however many bridges over rivers and streams likely minimize the isolation effects of these barriers. The hierarchical process of pre-selection is shown in Figure 3.

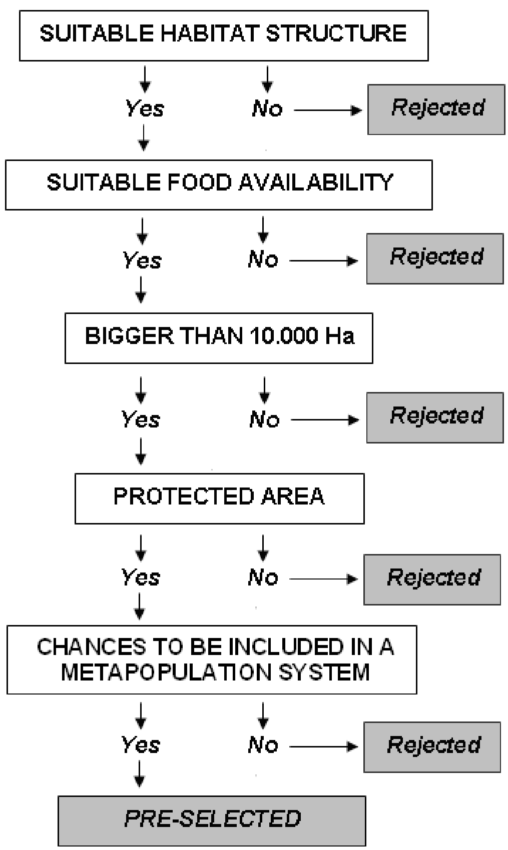

Fig. 3: Hierarchical process of pre-selection of the best areas for lynx re-introduction.

Once we had prioritized the suitable habitat patches at the large scale, we conduced a detailed fine-scale evaluation of the best areas. The first objective was to identify the pre-selected areas that contained conditions similar to those associated within the extant Iberian lynx populations. Secondly, we estimated the carrying capacity and potential for expansion for each of the pre-selected areas. Based on a literature review of the Iberian lynx biology, we assigned five groups of variables were assumed as key attributes that contribute to the long-term survival and reproductive success of the species in a local context:

a) Mortality risk. Direct persecution has been the main source of mortality within the former range of the Iberian lynx, in particular due to leg-hold traps and neck snares [49-52]. Indeed, trapping was a main causes contributor to many local extinctions of the species [17,53] and is a threat that continues across the species' former range [53-55]. More recently, vehicle collisions have heavily affected some populations, such as in the Doñana area [56].

b) Habitat structure. This species depends entirely upon Mediterranean scrublands [29,30,57-60].

c) Food availability. The European rabbit is the staple prey of the Iberian lynx, representing more than 80% of ingested biomass [40-44,61]. Palomares *et al*. [61] determined that a threshold density of 100 rabbits per km^2 is required for stable occurrence and reproduction of Iberian lynxes. Modelling for reintroduction of Canadian lynx (*Lynx canadensis*), a similar lagomorh specialist, concluded that reintroduction success depends upon high densities of snowshoe hares (*Lepus americanus*).

d) Possibilities of natural expansion. It describes the potential of a reintroduced population to colonise other suitable unoccupied patches. This was assumed as a key attribute since apparently the suitable habitats could be highly fragmented into small patches [19].

We quantified a total of fourteen variables to describe the five key attributes in each pre-selected area (Table 2).

Table 2: Detailed assessment of the pre-selected reintroduction areas (means ± SE). The variables statistically different from optimal reference values (ORVs) from within the two remaining Iberian lynx populations are shown in bold. Doñana ORVs taken from Palomares [36]. Sample sizes within brackets.

VARIABLE	Key factor	Guadalmellato	Guarrizas	ORVs S. Morena	ORVs Doñana
1- Nº illegal trapping sanctions x (year^{-1} and 100 km^{-1})	Mortality risk	**0.18 ±0,04 (30)**	0.096 ±0.10 (6)	0.03 ±0.03 (5)	-
2- Nº illegal trapping events found during specific surveys per sampling effort	Mortality risk	0 ±0.00 (53)	0 ±0.00 (24)	0.019 ±0.01 (834)	-
3- Nº road-killed carnivores x (10 km^{-1} and sampling)	Mortality risk	0.14 ±0.11 (75)	2.37 ±2.92 (16)	-	-
4- Length of high road killing risk (km)	Mortality risk	1.6	13.0	55,6	-
5- Percentage of tree cover	Habitat structure	**30.1 ±3.9 (210)**	**26.4 ±5,5 (176)**	5.9 ±3.6 (30)	14.2 ±4.4
6- Percentage of tall shrub cover	Habitat structure	**34.9 ±4.8 (210)**	**17.2 ±7.0 (176)**	8.8 ±6.2 (30)	20.4 ±3.5
7- Percentage of short shrub cover	Habitat structure	33.8 ±5.4 (210)	**9.2 ±4.0 (176)**	18.8 ±1.0 (30)	34.4 ±9,4
8- Tree height (m)	Habitat structure	5.6 ±0.3 (210)	4.8 ±1.1 (176)	5.1 ±0.9 (30)	6.8 ±0.8
9- Tall shrub height (cm)	Habitat structure	208.2 ±19.4 (210)	87.5 ±20.4 (176)	134.0 ±21.3 (30)	250.0 ±140.0
10- Short shrub height (cm)	Habitat structure	62.8 ±5.2 (210)	44.6 ±19.0 (176)	57.3 ±14.4 (30)	100.0 ±60.0
11- Rabbit *ha^{-1} (June)	Food availability	3.1 ±0.80* (20)	3.6 ±0.8 (15)	1.6 ±0.4 (19)	-
12- Nº UTM 2.5x2. 5 squares with more than 1 rabbit *ha^{-1} (June)	Food availability	18	20	16 – 27 (range 2002-2006)	-
13- Nº population nucleus of high density of rabbits within the DR	Chances for expansion	2	1	-	-
14- Total size of population nucleus of high rabbit density within the DR (km^2)	Chances for expansion	167	460	-	-

Each variable was estimated as follows:

The number of illegal trapping sanctions imposed by environmental authorities: carnivore trapping is forbidden in Andalusia (except for cage-traps), however hunters illegally use traps to control red fox (*Vulpes vulpes*) managing small game species, particularly red-legged partridge (*Alectoris rufa*; [54,55]). We used the archives of the regional governmental authorities from 1997 to 2006, which contain all the sanctioning procedures filed when an illegal trapping event was found by the countryside rangers. Illegal traps were usually neck snares and leg-hold traps.

The number of illegal trapping events found during specific surveys: records from government archives were complemented by specific surveys to avoid potential effort-related biases. The surveys, conduced during January- August 2006 when most predator control occurs, consisted of a trained personnel on foot searching for traps and snares during two hours per survey; hence one survey was assumed as the sampling unit.

The number of road-killed carnivores: the roads within each of the pre-selected areas were sampled once a week between May 2007 and April 2008 for road-killed carnivores. A total of 85 surveys covering 1384.4 km. were was carried out by two observers driving a car at 30 - 40 km per hour.

Length of road with high killing risk: all the paved roads were surveyed for sections with the highest mortality risk for lynx by matching areas of scrubland habitats with local high rabbit densities that were traversed by roads.

Cover percentage and height of tree, tall shrub and short shrub: all variables related to habitat structure were taken and measured following a previous study on Iberian lynx habitat selection [36]. In the pre-selected areas we conduced a habitat- stratified transect within all the UTM 2.5 x 2.5 Km grid cells, a spatial sampling scale assumed to be representative of the evaluated areas; a sampling point of 25 m of diameter was taken each 500 m. Dominant tree species were: *Quercus ilex, Q. suber, Olea europaea, Pinus pinea* and *P. pinaster*; tall shrub: *Q. coccifera, Pistacea lentiscus, Arbutus unedo* and *Phillyrea angustifolia* and short shrubs: *Cistus ladanifer, C. albidus* and *Lavandula stoechas.*.

Rabbit abundance: each UTM 2.5 x 2.5 Km grid cell was sampled using a stratified design by one observer on foot tallying all rabbit latrines encountered during two hours, using a GPS to record the data. The surveys were carried out in June 2007, which represents the season of maximum rabbit density [61,62]. Counts of latrines per km^{-1} were used to calculate rabbits per ha^{-1} using a model expressly built with data from twelve sampling transects where we estimated both rabbit density following Palomares *et al*. [61] and latrine abundance (Fig. 4). The transects were sampled within the lynx population range of the Sierra Morena during June 2007. The number and population nucleus size of high rabbit density areas within the dispersal radius was determined by using data from our own surveys for areas of Andalusia and data from Guzmán *et al*. [13] for the northern slopes of the Sierra Morena Mountains located outside of Andalusia.

Each variable of the key attributes was compared with reference values assumed to be optimal for the species. These optimal reference values (ORV) were obtained in the same previously described ways as for the current lynx population of the Sierra Morena, which has been intensively monitored since 2001 [20], and includes both

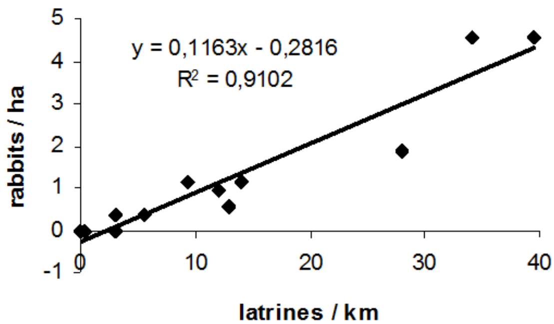

Fig. 4: Relationship between rabbit density and rabbit latrine abundance.

illegal trapping control and rabbit surveys. The vegetative habitat structure was sampled at 30 randomly distributed sampling points within a well-defined areas containing the highest lynx density within Sierra Morena (14 lynx territories in 50 Km^2). Available data of vegetative habitat structure obtained for the Doñana lynx population [36] was also used to determine ORVs. Both lynx populations showed different habitat structures from the six selected variables (Table 2), therefore in order to evaluate the reintroduction areas, each habitat variable was compared with the closest ORV from either Sierra Morena or Doñana population. For example, if scrub cover of a pre-selected area was closer to the ORV of the current population in Sierra Morena then the Sierra Morena ORV was chosen to evaluate this potential reintroduction area. Each variable was included in one of three categories: optimal, suitable pending management and non-suitable.

The carrying capacity of each pre-selected area was estimated according to the extension of each patch. For this calculation, we evaluated only the UTM 2.5 x 2.5 squares with more than 100 rabbits x km^{-1} (SQ100), the threshold density at which lynx have been found to establish territories and to reproduce [61]. The total suitable area was estimated from the number of SQ100. The number of female territories, a good demographic measurement for the Iberian lynx [21,30,61,63,64], was used as the carrying capacity unit. Therefore, the total suitable area was divided by the mean size of female territories (4.1 km^2, 95% CI = 2.6 – 5.8, n = 14, [30]). This calculation was repeated with both extremes of the confidence interval of female territory size, in order to estimate the confidence interval of the carrying capacity. It is a conservative estimation since the potential overlapping between female home ranges is not taken into account.

Results

Best areas at the large scale

Overall the composition of available vegetative habitat types throughout the lynx population of eastern Sierra Morena (Table 1) was similar ($G = 1.3$, $p = 0.5$, $d.f. = 2$) to habitat availability within the areas occupied by radio-collared lynxes (Fig. 5). In the Sierra Morena, the Iberian lynx neutrally selected two types of Mediterranean shrubs habitats, and negatively selected the other habitat types (Fig. 5). The regional suitability map was built by representing dense and cleared Mediterranean scrublands, which included most of the 1980-1988 lynx range (Fig. 6). The region of Andalusia offered two main ranges of suitable habitat at the vegetation level, one within the Sierra Morena Mountains and another within the Sierras Béticas Mountains, although the patches for the second appeared more widely dispersed (Fig. 6). The total extension of the potential habitat from a structure point of view was 13,909 km^2. However, just five patches with a total size of 525 km^2 (3.77%) actually offered a suitable abundance of rabbits (Table 3; Fig. 6). After applying the criteria of patch size, protected status, and distance from source populations, only two patches remained: Guadalmellato and Guarrizas, both included in the European Natura 2000 network. Based on the close proximity (35 and 32 km respectively) to an existing population and suitable connective habitats in between (Fig. 6), these two patches could form a meta-population together the current Andújar-Cardeña population in the eastern Sierra Morena Mountains (50 territorial females in 2011, unpublished pers. information). According to our carrying capacity estimates this meta-population could potentially harbour a metapopulation of 99 female lynxes. Sierra Harana did fulfil the first two selection criteria but at 80 km from the eastern Sierra Morena population it was located outside of the documented dispersal range of the species and was further isolated by substantial barriers. Hornachuelos was rejected since its suitable area was less than 10,000 ha large and furthermore it was lying out of the range of the maximal dispersal distance from the sources populations. Guadalmez was rejected since most of the suitable habitat was completely unprotected.

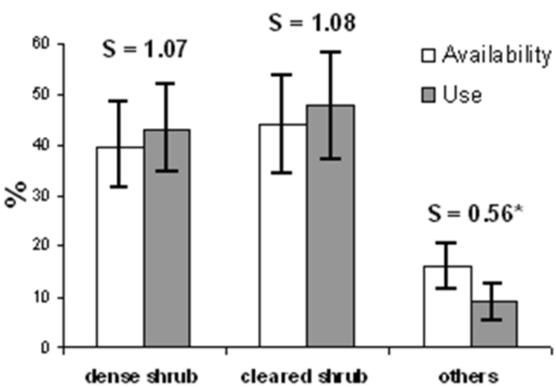

Fig. 5: Habitat selection of the Iberian lynx in the Sierra Morena (mean values and SE bars). W_i: Savage's index (use / availability).

Table 3: Rabbit surveys within the former range of the Iberian lynx.

Ref. in Fig. 6	Patch	5x5 km grid cells surveyed	Suitable grid cells (> 10 rabbit latrines x km^{-1})	Area with suitable rabbit abundance, km^2
3	Guadalmellato	20	5	125
4	Guarrizas	11	6	150
5	Hornachuelos	19	3	75
6	Guadalmez	5	2	50
7	Sierra Harana	17	5	125

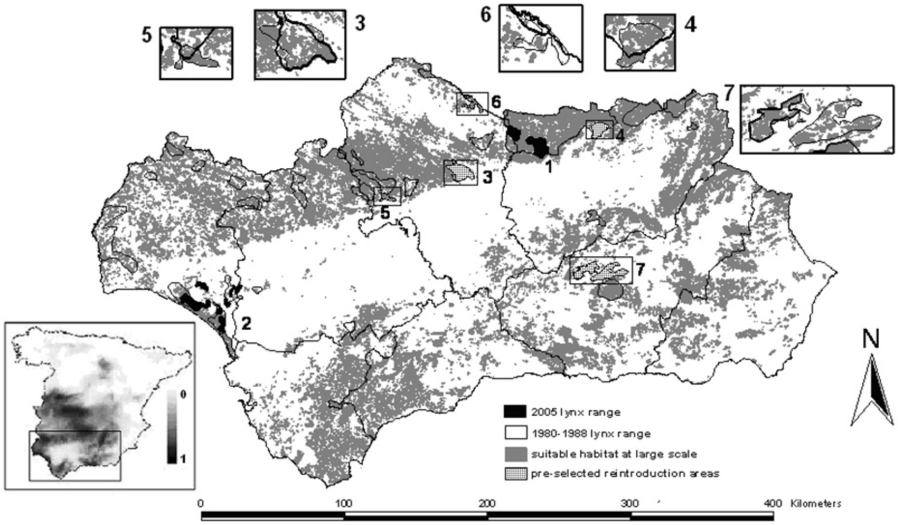

Fig. 6: Suitable habitat structure in Andalusia and environmental favourability in Spain (small square, re-drawn from [65]) for the Iberian lynx. Numbers indicate the current populations (1 Andújar-Cardeña, 2 Doñana), and the pre-selected patches with optimal rabbit populations (3 Guadalmellato, 4 Guarrizas, 5 Hornachuelos, 6 Guadalmez, 7 Sierra Harana). The limits of Andalusia provinces are provided.

Detailed evaluation of the best areas

Most habitat parameters within the pre-selected areas could be assumed as optimal, since few statistical differences were detected from the ORVs (Table 2). The main exception was the standardized number of illegal trapping sanctions by environmental authorities observed in the Guadalmellato area, which presented higher values than the ORV (U=7.5, Z = -3.2, p = 0.0013); therefore it was evaluated as suitable pending management improvements. Some variables related to habitat structure (percentages of tree, tall shrub and short shrub cover) also showed significantly higher values than the ORVs in Guadalmellato and Guarrizas (Table 2). A comparison between Guadalmellato and Guarrizas showed high similarities in most variables, although Guadalmellato offered higher values of shrub cover, whereas Guarrizas had a higher potential for the natural expansion due to the vicinity of a large patch of suitable habitat with high rabbit density on the northern slopes of the Sierra Morena (Table 2). The mean rabbit abundance was similar in both areas (U = 126.5, Z = -0.78, p = 0.43) and the estimated carrying capacity was also quite similar: 26 ±11,5 territories (95% CI = 14.5 – 37.5) for Guadalmellato and 23 for Guarrizas (95% CI = 13.0 – 33.0). Finally, the road-killed carnivore incidence was higher in Guarrizas (U = 371.0, Z = -2.38, p = 0.016).

Discussion

There were many similarities between our habitat suitability map and a recent environmental favourability map for the Iberian lynx built with a model that selected 15 out of 27 predictor variables related to location, topography, climate, lithology and human activity to predict potential lynx habitat throughout Spain [65].

Although our results were more restrictive, both maps showed the two main ranges of suitable habitat at large scale in the region of Andalusia (Sierra Morena Mountains and Sierras Béticas Mountains; fig. 6). However both approaches failed in order to emphasize the patches with optimal food resources. Some of the selected habitat units for our large-scale map could be of little biological significance, since the scrubland habitat is realistically comprised of a miscellaneous mixture of several different kinds of botanical communities [66]. The habitat variables selected were far too general for accurate predictive maps, since large areas of potentially suitable habitat from a structural point of view, were selected but were literally void of rabbits. The scrubland structure has been assumed important for the Iberian lynx due to the relationship between rabbits and shrubs [36]; however, there are no detailed studies on the relationships between rabbit abundance and the high Mediterranean scrubland diversity. Unfortunately, there are probably no current means of obtaining adequate models to predict rabbit distribution and abundance at the required scale for lynx reintroduction programs. Such models are difficult due to the low precision of current GIS data bases and the strong local interactions of rabbits with habitat heterogeneity (scrub, pastureland and good soils to digging burrows, [45]), predators (humans included, [55,67]) and diseases [68]. In fact, only precise locally focused studies have been proven as useful to identify the key variables for the prey species [36,45,69,70], and it remain unknown if these local results can be extrapolated to a broader spatial scale.

The role of the cleared scrubland in the Sierra Morena was an unexpected result given the predictive model of Fernández *et al*. [30], since it was a non-studied variable by these authors despite its high availability and use by lynx within this population. This disagreement was one of the main reasons for the mismatching observed between predictive and current maps (Fig. 1), which highlights some of the limitations resulting from local approaches, even when these are conducted in a detailed manner. The percentages of tall shrub and shot shrub cover were higher in Guadalmellato and Guarrizas than in the current Andújar-Cardeña population, which could indicate healthy vegetation structure and a positive factor for lynxes by providing valuable cover habitats [36].

Although illegal trapping in the Guadalmellato area presented higher values than the ORV, the situation can be improved by management actions to remove or reduce the causes. In fact, since 2007 the environmental authorities have increased both patrol efforts and legal agreements with local hunting societies for cooperation in game management, resulting in a decrease in illegal trapping of carnivore mammals. The 12 Iberian lynxes realised within in Guadalmellato Since 2009, have shown optimal survival rates similar to Andújar-Cardeña population (personalcommunication), indicating that efforts to reduce illegal trapping have been productive.

Population viability analyses (PVAs) are recommended by the IUCN [71] to assess reintroduction programs prior to the release phase, as this tool has been used for reintroduction projects of some carnivore species [72,73]. Population viability analyses conducted for both the Iberian and Eurasian lynx, indicate that population sizes of 10-15 territorial females and scenarios with low mortality of territorial residents reach viable populations within a timeline of 50 -100 years [27,63]. The carrying capacities of the Guadalmellato and Guarrizas areas are superior to those areas, and the mortality sources had a lower prevalence than the Andujar-Cardena population. Therefore, although the local PVAs are not yet available for these sites, the scenarios appear to be favourable towards the 50-100 year goal. However, self-sustaining populations of carnivore mammals require more than 500 individuals [1]. Indeed, the total current population of the species, with ca 200 free-living individuals [20], is effectively not a viable population. Fortunately, the two best areas identified in our study can be combined to provide the opportunity to develop a meta-population together with the current population of Andújar-Cardeña. No other such meta-population of comparable size or connectivity potential could feasibly be re-established within the species' former range, as can be deduced from the rabbit abundance distributions given by Guzmán et al. [13] for Spain and Sarmento *et al*. [74] for Portugal. However, if this meta-population dynamic is reached, it could grow to support even more individuals than the threshold of 500, regardless of whether the large path of high rabbit abundance located just beyond the northern of Andalusia is included (see variable 14 for Guarrizas in Table 2). If we extrapolate our carrying capacity estimation to include Guadalmellato, Guarrizas and the current Andújar-Cardeña population, the resulting meta-population could reach ca 120 potential female territories. Specifically, the larger meta-population that could be achieved could be the best possible scenario in the near future for the Iberian lynx.

It is important to study the probabilities of natural connection between population nuclei [27,58]; at least five lynx originating from within the Jándula and Yeguas valleys of the Andújar-Cardeña population have dispersed to reach Guarrizas, Guadalmez and Campo de Calatrava areas since 2007 (unpublished pers. information). Aditionally, genetic management by assisted translocations could help mitigate the effects of endogamy [46]. Taking into account the distances between most of the other suitable areas identified in Andalusia, additional reintroduction efforts may be important for increasing the meta-population size in the Sierra Morena Mountains, once the Guadalmellato and Guarrizas areas are recovered. The Guadalmellato area is a key stepping stone between the eastern and central Sierra Morena (Fig. 6). Finally, the isolated suitable area of Sierra Harana may be also important to establish a small population similar to that in Doñana, since the presence of small but isolated populations may be a useful strategy to avoid the effects of stochastic disease outbreaks that could affect the bigger populations [7].

Acknowledgements

The study was supported by the projects LIFE NAT //E//8609 "Recuperación del Lince Ibérico en Andalucía", and LIFE 02 NAT/E/209 "Conservación y Reintroducción del Lince Ibérico en Andalucía". We are especially grateful to the people of the LIFE program teams: Rafael Cadenas, Jose García, Manuel Moral, José Bueno, Bernardo Torralba, Santiago Lillo, Jose Manuel Martín, Gerardo Valenzuela, Joaquín Pérez, Miguel Diaz and Eva Rojas (EGMASA-CMA Junta de Andalucía). Roberto García, Jorge Alcaina, Rafael Solano, Ana Pello, Magdalena Vara and Inmaculada Tenorio (EGMASA-CMA Junta de Andalucía) helped with logistic support. We also wish to express our gratitude to directors of the natural parks of Sierra de Andújar and Sierras de Cardeña y Montoro, Ascensión García, Jose M. Quero and Jose M. Molina. John Lawerence and Emil McCain revised the language and Fridolin Zimmermann largely improved early drafts of paper.

References

Five "key references", selected by the authors, are marked below (*Three recommended* (●) *and two highly recommended* (●●) *papers*).

1. Griffith, B., Scout, J.M., Carpenter, J.W. & Reed, C. 1989. Translocation as a species conservation tool: status and strategy. Science 245: 477-480.

   doi: 10.1126/science.245.4917.477

2. Brocke, R.H., Gustafson, K.A. & Fox, L.B. 1991. Restoration of large predators: Potentials and problems. In: Decker, D.L., Krasny, M.E., Goff, G.R., Smith, C.R. & Gross, D.W. (Eds.), Challenges in the conservation of biological resources, a practitioner' guide. Boulder, CO, Westview Press, pp. 303-315.

3. Wolf, C.M., Griffith, B., Reed, C. & Temple, S.A. 1996. Avian and mammalian translocations: update and reanalysis of 1987 survey data. Conserv. Biol. 10, 1142-1154.

   doi: 10.1046/j.1523-1739.1996.10041142.x

4. Seddon, P.J. 1999. Persistence without intervention: Assessing success in wildlife reintroductions. Trends Ecol. Evol. 14, 503-503.

   doi: 10.1016/S0169-5347(99)01720-6

5. Breitenmoser, U., Breitenmoser-Würsten, C., Carbyn, L.N. & Funk, S.M. 2001. Assessment of carnivore reintroductions. In: Gittleman, J.L., Funk, S.M., Macdonald, D. & Wayne, R.K. (Eds.), Carnivore Conservation. Cambridge: Cambridge University Press, pp. 241-281.

6. Seddon, P.J., Armtrong, D.P. & Maloney, R.F. 2007. Developing the science of reintroduction biology. Conserv. Biol. 21: 303-312.

   doi: 10.1111/j.1523-1739.2006.00627.x

7. Hayward, M.W. & Somers, M.J. 2009. Reintroduction of Top-Order Predators: Using Science to Restore One of the Drivers of Biodiversiy. In: Hayward, M.W. &. Somers, M.J (Eds.), Reintroduction of Top-Order Predators. Oxford: Blackwell Publishing LTD. pp. 1-9.

8. Hilderbrand, G.V., Hanley, T.A., Robbins, C.T. & Schwatrz, C.C. 1999. Role of brown bears (*Ursus arctos*) in the flow of marine nitrogen into a terrestrial ecosystems. Oecologia 121: 546-550.

   doi: 10.1007/s004420050961

9. Breitenmoser, U. 1998. Large predators in the Alps: the fall and rise of man's competitors. Biol. Conserv. 83: 279-289.

   doi: 10.1016/S0006-3207(97)00084-0

10. Treves, A. & Karanth, K.U. 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. Conserv. Biol. 17: 1491-1499.

    doi: 10.1111/j.1523-1739.2003.00059.x

11. Weber, W. & Rabinowitz, A. 1996. A global perspective on large carnivore conservation. Conserv. Biol. 10: 1046-1054.

    doi: 10.1046/j.1523-1739.1996.10041046.x

12. Wilson, D.E., & Mittermeier, R.A. 2009. Handbook of the Mammals of the World. Vol. 1. Carnivores. Lynx Editions, Barcelona.

13. Guzmán, J.N., García, F.J., Garrote, G., Pérez, R. & Iglesias, C. 2004. El lince ibérico (*Lynx*

pardinus) en España y Portugal. Censo - diagnóstico de sus poblaciones. [The Iberian lynx (*Lynx pardinus*) in Spain and Portugal. Populations' census - diagnostic]. Dirección General para la Biodiversidad. Madrid.

14. Simón Mata M. 2006. Status of the Iberian lynx populations in Andújar-Cardeña and Doñana. Progress made in conservation projects in situ since the I seminar in Andújar. Issues, challenges and future of current conservation efforts. In: Junta de Andalucía (Ed.), II International Seminar on the Conservation of the Iberian Lynx. Córdoba: Junta de Andalucía, pp. 75-84.

15. Nowell K. 2002. Revision of the Felidae Red List of threatened species. Cat News 37: 4-6.

16. Cabrera, A. 1914. Fauna Ibérica. Mamíferos. Madrid: MNCN.

17. Rodríguez, A. & Delibes, M. 2004. Patterns and causes of non-natural mortality in the Iberian lynx during a 40-year period of range contraction. Biol. Conserv. 118: 151-151.

    doi: 10.1016/j.biocon.2003.07.018

18. Gil-Sánchez, J. M. & McCain, E. (in press). Former range and decline of the Iberian lynx (*Lynx pardinus*). J. Mammal.

19. Rodríguez, A. & Delibes, M. 1992. Current range and status of the Iberian lynx (*Felis pardina* Temmick 1824) in Spain. Biol. Conserv. 61: 189-196.

    doi: 10.1016/0006-3207(92)91115-9

20. Simón Mata, M., Cadenas, R., Gil-Sánchez, J. M., López-Parra, M., García, J., Fernández, L., Ruiz, G. & López, G. 2009. Conservation of free-ranging Iberian lynx (*Lynx pardinus*) populations in Andalucía In: Vargas, A., Breintenmoser, C. & Breintenmoser, U (Eds), Iberian Lynx *Ex situ* Conservation: An Interdisciplinary Approach. Madrid: Fundación Biodiversidad, pp. 42-55.

21. Gil-Sánchez, J.M., Simón, M.A., Cadenas, R., Bueno, J., Moral, M. & Rodríguez-Siles, J. 2010. Current status of the Iberian lynx (*Lynx pardinus*) in eastern Sierra Morena, southern Spain. Wildlife Biology in Practice 6: 14-33.

22. Breitenmoser, U., Breitenmoser-Würsten, C., García Santiago, J. & Zimmermann, F. 2006. The IUNC/SSC red list assessment, reintroduction guidelines and the Iberian lynx. Applying the red list criteria to define a recovery strategy for the Iberian lynx. In: Junta de Andalucía (Ed.), II Seminario Internacional sobre la Conservación del Lince Ibérico. Córdoba 15 16 17 dic 2004. Jaén: Junta de Andalucía, pp. 45-50.

23. Guisan, A. & Zimmermann, N.E. 2000. Predictive habitat distribution models in ecology. Ecol. Model. 135: 147-186.

    doi: 10.1016/S0304-3800(00)00354-9

24. Woolf, A., Nielsen, C.K., Weber, T. & Gibbs-Kieninger, T.J. 2002. Statewide modeling of bobcat, *Lynx rufus*, habitat in Illinois, USA. Biol. Conserv. 104: 191-198.

    doi: 10.1016/S0006-3207(01)00164-1

25. Gavashelishvili, A. & Lukarevskiy, V. 2008. Modelling the habitat requirements of leopard *Panthera pardus* in west and central Asia. J. Appl. Ecol. 45: 579-588.

    doi: 10.1111/j.1365-2664.2007.01432.x

26. Klar, N., Fernandez, N., Kramer-Schadt S., Herrmann, M., Trinzenf, M., Büttnerf, I. & Niemitzb, C. 2008. Habitat selection models for European wildcat conservation. Biol. Conserv. 141: 308-319.

    doi: 10.1016/j.biocon.2007.10.004

27. Kramer-Schadt, S., Revilla, E. & Wiegand, T. 2005. Lynx reintroductions in fragmented landscapes of Germany: Projects with a future or misunderstood wildlife conservation? Biol. Conserv. 125: 169-182.

doi: 10.1016/j.biocon.2005.02.015

28. Thatcher, C.A., Van Manen F.T. & Clark J.D. 2006. Identifying suitable sites for Florida Panther reintroduction. J. Wildlife Manage. 70: 752-763.

doi: 10.2193/0022-541X(2006)70[752:ISSFFP]2.0.CO;2

29. Fernández, N., Delibes, M., Palomares, F. & Mladenoff D. J. 2003. Identifying breeding habitat for the Iberian lynx: inferences from a fine-scale spatial analysis. Ecol. Appl. 13: 1310-1340.

doi: 10.1890/02-5081

30. Fernández, N., Delibes, M. & Palomares, F. 2006. Landscape evaluation in conservation: molecular sampling and habitat modeling for the Iberian lynx. Ecol. Appl. 16: 1037-1049.

doi: 10.1890/1051-0761(2006)016[1037:LEICMS]2.0.CO;2

31. Cole, C. 1949. The measurements of interspecific association. Ecology 30: 411-424.

doi: 10.2307/1932444

32. ●● Ranganathan, J., Chan, K.M.A., Karanth, K.U. & Smith, J.L.D. 2008. Where can tigers persist in the future? A landscape-scale, density-based population model for the Indian subcontinent. Biol. Conserv. 141: 67-77.

doi: 10.1016/j.biocon.2007.09.003

33. ●● Kautz, R., Kawula, R., Hoctor, T., Comiskey, J., Jansen, D., Jennings, D., Kasbohm, J., Mazzotti, F., McBride, R., Richardson, L. & Root, K. 2006. How much is enough? Landscape-scale conservation for the Florida panther. Biol. Conserv. 130: 118-133.

doi: 10.1016/j.biocon.2005.12.007

34. Moreira Madueño, J.M. 2007. Mapas de usos y Guía técnica coberturas vegetales del suelo de Andalucía. [Land use map and téchnical guide of Andalucía's vegetation cover]. Escala 1/25.000. Junta de Andalucía, Sevilla.

35. Rodríguez, A., Delibes, M. & Palomares, F. 2002. Lince ibérico. Bases para su reintroducción en las sierras de Cádiz. Consejería de Obras Públicas y Transportes, Junta de Andalucía.

36. Palomares F. 2001. Vegetation structure and prey abundance requirements of the Iberian lynx: implications for the design of reserves and corridors. J. Appl. Ecol. 38: 9-18.

doi: 10.1046/j.1365-2664.2001.00565.x

37. Millspaugh, J.J. & Marzluff, J.M. 2001. Radio Tracking and Animal Populations. Academic Press, San Diego.

38. ● Gil-Sánchez, J.M., Moral, M., Bueno, J., Rodríguez-Siles, J., Lillo, S., Pérez, J., Martín, J.M.,Valenzuela, G., Garrote, G., Torralba B. & Simón-Mata, M.A. 2011.The use of camera trapping for estimating Iberian lynx (*Lynx pardinus*) home ranges. Eur. J. Wildlife Res.

doi: 10.1007/s10344-011-0533-y

39. Bingham, R.L.& Brennan, L.A. 2004. Comparison of type I error rates for statistical analyses of resource selection. J. Wildlife Manage. 68: 206-212.

doi: 10.2193/0022-541X(2004)068[0206:COTIER]2.0.CO;2

40. Delibes, M., Palacios, F., Garzón, J. & Castroviejo, J. 1975. Notes sur l'alimentation et la biologie du Lynx pardelle, *Lynx pardina*, (Temminck, 1824), en Espagne. [Notes about Iberian

lynx's (*Lynx pardina*) diet and biology in Spain] Mammalia 39: 387-393.

doi: 10.1515/mamm.1975.39.3.387

41. Delibes, M. 1980. Feeding ecology of the Spanish lynx in the Coto Doñana. Acta Theriol. 25: 309-324.

42. Aymerich, M. 1982. Etude comparative des régimes alimentaires du Lynx pardelle (*Lynx pardina* Temmick, 1824) et du Chat sauvage (*Felis silvestris* Schieber, 1777) au centre de la péninsule Ibérique. [Comparative study of the Iberian Lynx's (*Lynx pardina* Temmick, 1824) and of the Wild cat's (*Felis silvestris* Schieber, 1777) diet in the central Iberian Peninsula]. Mammalia 46: 515-521.

doi: 10.1515/mamm.1982.46.4.515

43. Beltrán, J.F. & Delibes, M. 1991. Ecología trófica del lince ibérico en Doñana durante un periodo seco. [Trophic ecology of the Iberian lynx in Doñana during the dry season]. Doñana Acta Vertebrata 18: 113-122.

44. Gil-Sánchez, J.M., Ballesteros, E. & Bueno, J. 2006. Feeding ecology of the Iberian lynx *Lynx pardinus* in eastern Sierra Morena (Southern Spain). Acta Theriol. 51: 85-90.

doi: 10.1007/BF03192659

45. Virgós, E., Cabezas-Díaz, S., Malo, A., Lozano, J. & López-Huertas, D. 2003. Factors shaping European rabbit abundance in continuous and fragmented populations of central Spain. Acta Theriol. 48: 113-122.

46. Davies-Mostert, H.T., Mills, M.G.L. & Macdonald, D.W. 2009. A Critical Assessment of South Africa's Managed Metapopulation Recovery strategy for African Wild Dogs. In: Hayward, M.W. &. Somers, M.J (Eds.), Reintroduction of Top-Order Predators. Oxford: Blackwell Publishing LTD. pp. 10-42.

47. Clark, J.D. 2009. Aspects and Implications of Bears Reintroduction. In: Hayward, M.W. &. Somers, M.J (Eds.), Reintroduction of Top-Order Predators. Oxford: Blackwell Publishing LTD. 126-145.

48. Ferreras, P., Delibes, M., Palomares, F., Fedriani, J.M., Calzada, J. & Revilla, E. 2004. Proximate and ultimate causes of dispersal in the Iberian lynx *Lynx pardinus*. Behav. Ecol. 15: 31-40.

doi: 10.1093/beheco/arg097

49. García-Perea, R. & Gisbert, J. 1986. Causas de mortalidad del lince ibérico en los Montes de Toledo y Sierra Morena. [Mortality causes for Iberian lynx in the Toledo and Sierra Morena Mountains]. In: Naturaleza y Sociedad. Jornadas sobre la Conservación de la Naturaleza en España; 1986 November 27-29; Principato de Asturias, Oviedo, p 183-185.

50. Rodríguez, A. & Delibes, M. 1990. El lince ibérico (*Lynx pardina*) en España. Distribución y problemas de conservación. ICONA, Madrid.

51. González Oreja, J.A. 1998. Non-natural mortality of the Iberian lynx in the fragmented population of Sierra de Gata (W Spain). Miscellània Zoològica 21: 31-35.

52. García-Perea, R. 2000. Survival of injured Iberian lynx (*Lynx pardinus*) and non-natural mortality in central-southern Spain. Biol. Conserv. 93: 265-269.

doi: 10.1016/S0006-3207(99)00142-1

53. ● Cabezas-Díaz, S., Lozano, L. &Virgós, E. 2009. The declines of the wild rabbit (*Oryctolagus cuniculus*) and the Iberian lynx (*Lynx pardinus*) in Spain: redirecting conservation efforts. In:

Aronoff, J.B (Ed.). Handbook of Nature Conservation. Nova Science Publishers, Inc. pp. 283-310.

54. Virgós, E. & Travaini, A. 2005. Relationship between small-game hunting and carnivore diversity in central Spain. Biodiver. Conserv. 14: 3475-3486.

doi: 10.1007/s10531-004-0823-8

55. Delibes-Mateos M., Ferreras P. & Villafuerte, R. 2009. Rabbit (*Oryctolagus cuniculus*) abundance and protected areas in central-southern Spain: why they do not match? Eur. J. Wildlife Res. 55: 65-69.

doi: 10.1007/s10344-008-0216-5

56. Ferreras, P., Aldama, J.J., Beltrán, J.F. & Delibes, M. 1992. Rates and causes of mortality in a fragmented population of Iberian lynx *Felis pardina* T. 1824. Biol. Conserv. 61: 197-202.

doi: 10.1016/0006-3207(92)91116-A

57. Gil, J.M., Molino, F. & Valenzuela, G. 1997. Efecto de la litología y de las repoblaciones forestales sobre la distribución y la abundancia del Lince Ibérico (*Lynx pardina*) en la Sierra de Andújar. Aegypius 14: 21-28.

58. Ferreras, P. 2001. Landscape structure and asymmetrical inter-pach connectivity in a metapopulation of the endangered Iberian lynx. Biol. Conserv. 100: 125-136.

doi: 10.1016/S0006-3207(00)00213-5

59. Palomares, F. & Fernández, N. 2000. The selection of breeding dens by the endangered Iberian lynx (*Lynx pardinus*): implications for its conservation. Biol. Conserv. 94: 51-61.

doi: 10.1016/S0006-3207(99)00164-0

60. Palomares, F., Delibes, M., Ferreras, P., Frediani, J.M., Calzada, J. & Revilla, E. 2000. Iberian lynx in a fragmented landscape: predispersal, dispersal and postdispersal habitats. Conserv. Biol. 14: 809-818.

doi: 10.1046/j.1523-1739.2000.98539.x

61. Palomares, F., Delibes, M., Revilla, E., Calzada, J.& Frediani, J.M. 2001. Spatial ecology of Iberian lynx and abundance of European rabbits in south-western Spain. Wildlife Monogr. 148: 1-36.

62. Moreno, S., Beltrán, J.F., Cotilla, I., Kuffner, B., Laffite, R., Jordán, G, Ayala, J., Quintero, C., Jiménez, A., Castro, F., Cabezas, S. & Villafuerte, R. 2007. Long-term decline of the European wild rabbit (*Oryctolagus cuniculus*) in south-western Spain. Wildlife Res. 34: 652-658.

doi: 10.1071/WR06142

63. Gaona, P., Ferreras, M. & Delibes, M. 1998. Dynamics and viability of a metapopulation of the endangered Iberian lynx (*Lynx pardinus*). Ecol. Monogr. 68: 349-370.

64. Ferreras, P., Gaona, P., Palomares, F. & Delibes, M. 2001.Restore habitat or reduce mortality? Implications from a population viability analysis of the Iberian lynx. Anim. Conserv. 4: 265-274.

doi: 10.1017/S1367943001001317

65. Real, R., Marcia Barbosa, A., Rodríguez, A., García, F.J., Vargas, M., Palomo, L.J. & Delibes M. 2009. Conservation biogeography of ecologically interacting species: the case of the Iberian lynx and the European rabbit. Divers. Distrib. 15: 390-400.

doi: 10.1111/j.1472-4642.2008.00546.x

66. Rivas Martínez, S., Asensi, A., Díez-Garretas, B., Molero Mesa, J. & Valle, F. 1997. Biogeographical synthesis of Andalusia (southern Spain). J. Biogeogr. 24: 915-928.

67. Virgós, E., Cabezas-Díaz & S., Lozano, J. 2007. Is the wild rabbit (*Oryctolagus cuniculus*) a threatened species in Spain? Sociological constraints in the conservation of species. Biodivers. Conserv. 16: 3489-3504.

doi: 10.1007/s10531-006-9054-5

68. Calvete, C. 2006. Modeling the effect of population dynamics on the impact of rabbit hemorrhagic disease. Conservs. Biol. 20: 1232-1241.

doi: 10.1111/j.1523-1739.2006.00371.x

69. Carvalho, J.C. & Gomes, P. 2003. Habitat suitability model for European wild rabbit (*Oryctolagus cuniculus*) with implications for restocking. Game Wildl, Sci. 20: 287-301.

70. Beja, P., Pais, M. & Palma, L. 2007. Rabbit *Oryctolagus cuniculus* habitats in Mediterranean scrubland: the role of scrub structure and composition. Wildl. Biol. 13: 28-37.

doi: 10.2981/0909-6396(2007)13[28:ROCHIM]2.0.CO;2

71. IUCN 1998. IUCN Guidelines for Re-introductions. IUCN, Gland, Switzerland.

72. Schadt, S., Revilla, E., Wiegand, T., Knauer F., Kaczensky, P., Breitenmoser, U., Bufka, L., Cerveny, J., Koubek, P., Huber, T., Stanisa, C. & Trepl, L. 2002. Assessing the suitability of central European landscapes for the reintroduction of Eurasian lynx. J. Appl. Ecol. 39: 189-203.

doi: 10.1046/j.1365-2664.2002.00700.x

73. ● Steury, T. D. & Murray, D.L., 2004. Modeling the reintroduction of lynx to the southern portion of its range. Biol. Conserv. 117: 127-141.

doi: 10.1016/S0006-3207(03)00287-8

74. Sarmento, P., Cruz, J., Moterrosso, P., Tarroso, P., Negroes, N. & Ferreira, C. 2004. The Iberian lynx in Portugal. Status survey and conservation action plan. Instituto da Conservção da Naturaleza (ICN).