Gil-Sanchez, J. M., Simon, M. A., Cadenas, R., Bueno, J., Moral, M., and Rodriquez-Siles, J. (2010). Current status of the Iberian Lynx (*Lynx pardinus*) in Eastern Sierra Morena, Southern Spain. Wildl. Biol. Pract. 3(6): 14-33.

Keywords: 8ES/camera trapping/distribution/Iberian lynx/Lynx pardinus/monitoring/population size/Sierra Morena

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Wildl. Biol. Pract., ...(..): ..-..
DOI:10.2461/wbp.....

ORIGINAL PAPER

Current Status Of the Iberian Lynx (*Lynx pardinus*) in Eastern Sierra Morena, Southern Spain

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Keywords
Camera trapping; *Lynx pardinus*; Sierra Morena; Distribution; Population size; Monitoring.

Abstract
The distribution range of the largest Iberian lynx (*Lynx pardinus*) population of Eastern Sierra Morena was assessed between 1999 and 2006. The past distribution was evaluated using field interviews, the present range was determined by sign searching (scats) in 5x5 km and 1x1 km UTM quadrats, and the annual population size was estimated by camera-trapping. Our results indicate that lynx distribution has been limited to granite areas, and since the middle of the 20th century lynx occupation was detected in only 17 5x5 km UTM quadrats. An important decline in lynx numbers has been registered since the early 1990s, resulting in only 11 UTM 5x5 km occupied quadrats between 2001 and 2002, with two subpopulations separated by a 5 km distance occupying 3 and 8 quadrats each. Considering 1x1 km UTM quadrats, the distribution range increased from 125 km^2 in 2002 to 203 km^2 in 2006. Also, between 2002 and 2006 the number of female territories increased from 19 to 31. The population size was assessed since 2004, increasing from 84 detected individuals (32 adults) to 135 individuals in 2006 (43 adults). The positive dynamics observed during the study was partially related to the development of a major conservation program. The lynx distribution was correlated with rabbit distribution and abundance, therefore conservation measures must be based on rabbit management in order to recover habitat carrying capacity since the most important Iberian lynx population is still too small.

Introduction

The Iberian lynx (*Lynx pardinus*) is endemic to the Iberian Peninsula and it was declared as "Critically Endangered" [1]. Being the only felid species in this category, the Iberian lynx is the most endangered felid in the world [2]. Recent field surveys carried out throughout the potential distribution range in Spain [3] and Portugal [4], have found breeding populations only in Andalusia, within Andújar-Cardeña Natural Parks and Doñana National Park [3].

The previous status survey of the Iberian lynx in Spain described "Andújar", within eastern Sierra Morena, as the most important population [5], which occupied about 3,000 km^2 with about 370 lynxes estimated in 1988 (average = 12.33 lynxes/100 km^2).

A few years later, the same authors stated that this population maintained a stable spatial distribution since 1988 [6]. However, a field study based on scat sampling, carried out during autumn and winter of 1994/95 [7] showed that the Iberian lynxes were inhabiting only a very limited space, located in the granite outcrop area in the south-western quarter of the distribution range previously proposed by Rodríguez & Delibes [5].

Using Geographical Information System (GIS) predictive models based on DNA scat sampling [8] estimated 28-62 potential breeding territories with only 16% of the area occupied presenting potential habitat for lynx. According to this model the lynx population inhabited both granite and non granite areas [8] (Fig. 1). However, this model was based on partial field samplings, which covered only a small area during late winter and spring of 2001 [8] producing a discrepancy between lynx distribution data in this area, thus constituting an important handicap for the conservation of the species.

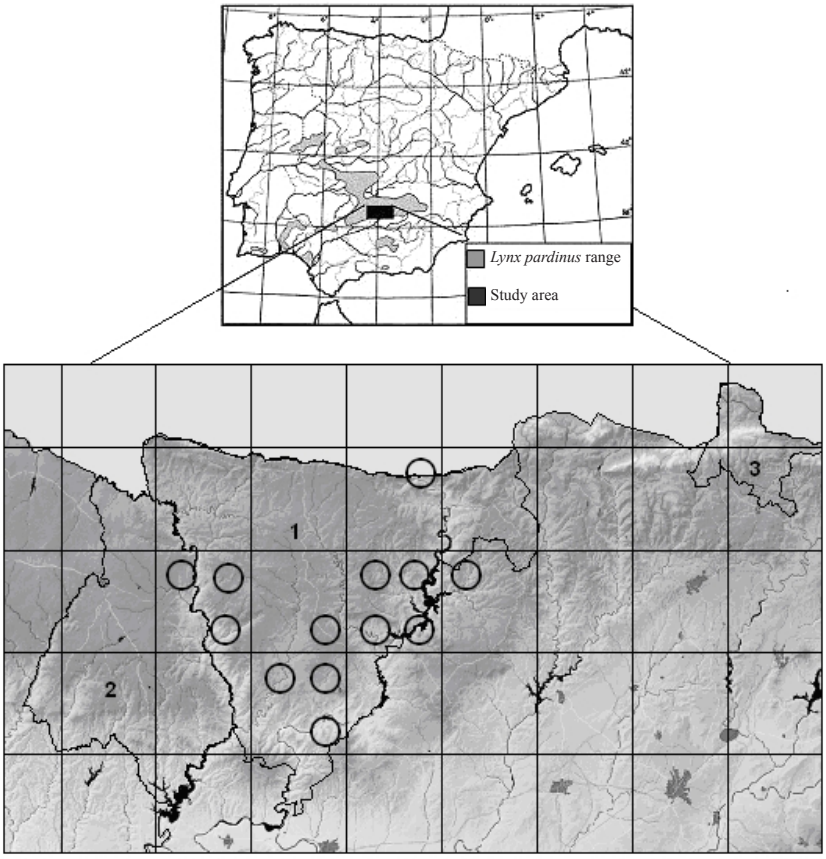

Fig. 1. Study area showing the overall distribution range of Iberian lynx proposed by Rodríguez & Delibes [5] and the Andújar-Cardeña range estimated by Fernández et al [8], which has been re-drawn using 5x5 Km UTM quadrats. Protected areas: 1, Sierra de Andújar Natural Park; 2, Sierras de Cardeña y Montoro Natural Park; 3, Despeñaperros Natural Park. 10x10 km UTM quadrats, Andalusia northern boundaries and main rivers and reservoirs are shown below.

In this paper, we describe both past and present status and distribution of Iberian lynxes of Eastern Sierra Morena, with the objective of designing adequate strategies for management and conservation. The results herein presented constitute the outcome of the first long-term monitoring program based on sighting data, sign sampling (scats) and camera trapping developed for all the "Andújar" area of Andalusia, where the largest Iberian lynx population persists.

Study area

The study area, with about 2,500 km^2 is located within eastern Sierra Morena (southeast Spain) (Fig. 1). The climate is Mediterranean dry, with rainy mild winters and hot dry summers. It is a mountainous area, with an altitudinal range of 200-1,500 m, occupied by well-preserved Mediterranean woodlands and scrubland. Forests are dominated by *Quercus* (*Q. ilex, Q. faginea* and *Q. suber*), and scrublands are dominated by species such as *Q. coccifera*, *Pistacia lentiscus*, *Arbutus unedo*, *Phyllirea angustifolia*, and *Myrtus communis*. Formations dominated by *Cistus ladanifer* cover a significant part of the area and pine plantations (*Pinus pinea* and *P. pinaster*) are also common. There are two well-defined geological areas, one dominated by granite outcrops (the southern half), and one dominated by slates and quartzites (the northern half). Large game is the main land use, with high densities of red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*), and lower densities of fallow deer (*Dama dama*) and mouflon (*Ovis musimon*). Roe deer (*Capreolus capreolus*) and Spanish ibex (*Capra pyrenaica*) present very localized populations with only a few individuals. The area is partially protected by two Natural Parks, Cardeña y Montoro and Sierra de Andújar (Fig. 1). This area is one of the most well-preserved natural landscapes of southern Europe. In fact, apart from the Iberian lynx other threatened species are present in the study area such as the Iberian wolf (*Canis lupus signatus*), the Spanish imperial eagle (*Aquila adalberti*), the black vulture (*Aegypus monachus*) and the black stork (*Ciconia nigra*).

Material and methods

Population distribution

Population distribution was studied by two complementary methods: sightings and field surveys. Firstly, sighting data was used to evaluate former and present distributions of lynxes. This method has been used to estimate distribution and abundance of elusive carnivores over large areas [9-11] such as the Iberian Lynx both in Spain [5,6,12,13] and in Portugal [14]. A field survey based on interviews was carried out during autumn 2001 and autumn 2002. Participants were questioned about presence – absence, abundance, breeding and tendencies of lynxes within the area systematically used by each person (about 1,500 ha per person). Ability to assess oral report consistency has been suggested as a limitation of field interviews dedicated to the Iberian lynx [15]. The sighting data allowed building 3 maps, divided in 10x10 km UTM quadrats, representing 3 different periods (1965-1974, 1975-1984, and

1985-1988), for comparison with the Rodríguez & Delibes [6] estimates. Information previous to 1965 was disregarded since it was insufficient to design proper distribution maps. Considering the significant amount of information, we divided UTM quadrats into the following categories: 1) isolated reports, 2) stable presence of lynx within less than 50% of the quadrat, and 3) stable presence of lynx within more than 50% of the quadrat. The 1990s distribution map presents 5x5 km UTM quadrats to allow for comparisons with the lynx sign searching (scats) survey.

Sign searching surveys

Field surveys based on lynx sign searching were carried out at two spatial scales: 1) medium scale (5x5 km UTM quadrats), which covered the whole 1980s distribution according to Rodríguez and Delibes [12], and 2) small scale (1x1 km UTM quadrats), which was developed within the range obtained by the medium scale survey.
Following Palomares et al. [16], a first field survey was undertaken between September 2001 and April 2002, using a 5x5 km UTM quadrat grid (n = 72), with a searching effort of 4 man-hours per cell. We concentrated our attention in scats since the substrate of the study area was mostly unsuitable for tracks, and snow is usually absent. For estimating the adequate sampling effort we chose 7 quadrats where lynx presence was known, both in low and high densities (determined by camera-trapping as explained bellow) and we determined the minimum effort required to detect at least one scat in each quadrat, which was estimated in 2 man-hours (i.e applying this effort per quadrat lynx should be detected). Moreover, in five quadrats where breeding had been confirmed by camera-trapping, the first scat was found within the first 0.5 man-hours. Only typical scats of lynx identified by experimented persons were considered valid for our study, but at least one scat per quadrat was sent to Doñana Biological Station and identified by molecular techniques [17]. Relative abundance of rabbits was estimated during samplings by recording the number of latrines, a valid method to estimate rabbit abundance [18,19].
Once the lynx distribution had been assessed at a 5x5 km scale, a more detailed annual sampling (2002 to 2006) was carried out using a 1x1 km UTM grid. Only 5x5 km quadrats within the known lynx distribution and some periphery quadrats were used. Each 1x1 km quadrat was sampled with a minimum effort of 2 man-hours; once the first signal indicating regular presence (lynx latrines) was found no more sampling effort was performed.

Camera-trapping

We used camera-trapping techniques to estimate population size [20-24] (Table 1). CANON PRIMA® compact cameras were modified by installing a 2-meter long electric cable connecting the shutter button of the camera to an aluminum plate of 20x20 cm, which replaces it. This plate is composed by two symmetrical parts separated by a rubber strip of 2 cm wide and 1 cm height, which is fixed along the internal perimeter of both square parts. One of the 2 aluminium parts has five metal studs (one in the center and one in each corner). When an animal steps on the plate,

both parts meet, the circuit becomes closed (one stud is enough) and the camera takes a photograph. As the animal steps on, more photographs are taken. This camera trap was developed in 1999 and tested in Doñana and East Sierra Morena with adequate results (P. Pereira and N. Guzmán pers. comm.). We chose this camera-trapping system over commercial infrared-triggered cameras because of its high detection rates and low prices. We used two types of lures to attract lynxes: 1) lynx urine, and 2) live bait (usually domestic pigeons within cages), which were placed together with the plate, about 2 m away from the camera. Lynx urine was obtained from captive Iberian lynxes of the Ex Situ Conservation Center of Acebuche (Doñana National Park). Each camera station was constituted by one camera protected from rain within a wooden box and connected to one shutter plate. The behaviour of lynxes at the camera stations as they explored the bait allowed us to obtain photographs of both flanks. The individual identification of Iberian lynxes was based on their distinct pelage patterns (Fig. 2). Each photograph was examined for subject orientation, resolution and framing to detect unique markings that might be useful for identification (Fig. 2; see e.g. 20, 24). Following Karanth and Nichols [20] and Jackson et al. [24], in order to maximize detection camera traps were placed on sites with known lynx signs (latrines) or over potential lynx routes such as deer paths. Each camera trap was checked once or twice a week for film collection and replacement, replenishing the urine and taking care of live bait. Camera trap density was about 1 trap/km^2 in order to cover properly the study area. Although annual sampling campaigns began in 1999, it was not until 2004 that all the distribution range was covered, since the study area is mostly private and there were some preliminary difficulties to obtain legal access. Each camera trap was set up in the field between 2 to 6 months, usually between May and November in order to avoid rain and to detect cubs. Although the accumulated results curve reaches a constant value after three months of sampling (Fig. 3), frequently we enlarged trapping periods in order to obtain complementary data, like health status of individuals or monitoring some litters located at conflict areas. So, the described method was used not only as a way to estimate population size, but also as a method of long-term individual monitoring. Differences among annual effort were caused by both logistical limitations and inter-annual changes in lynx distribution (Table 1). Moreover, the decrease of camera traps in 2006 was mainly due to the removal of camera traps installed during previous years in areas with no lynx detections (Fig. 4 and Table 1).

Table 1. Annual sampling effort and results of camera trapping of Iberian lynx in eastern Sierra Morena. Since annual campaigns of 1999-2001 covered a small area, data are poled in the table. The camera-trapping effort of 1999-2003 is not given due to negligence of some field teams resulting in loss of data.

sampling year	camera traps	camera-days	captures	pictures	camera-days/captures
1999-2001	-	-	68	182	-
2002	119	-	145	533	-
2003	260	-	420	2488	-
2004	323	33 727	623	2789	54.1
2005	314	34 813	853	3958	40.8
2006	227	28 393	1062	5324	26.7

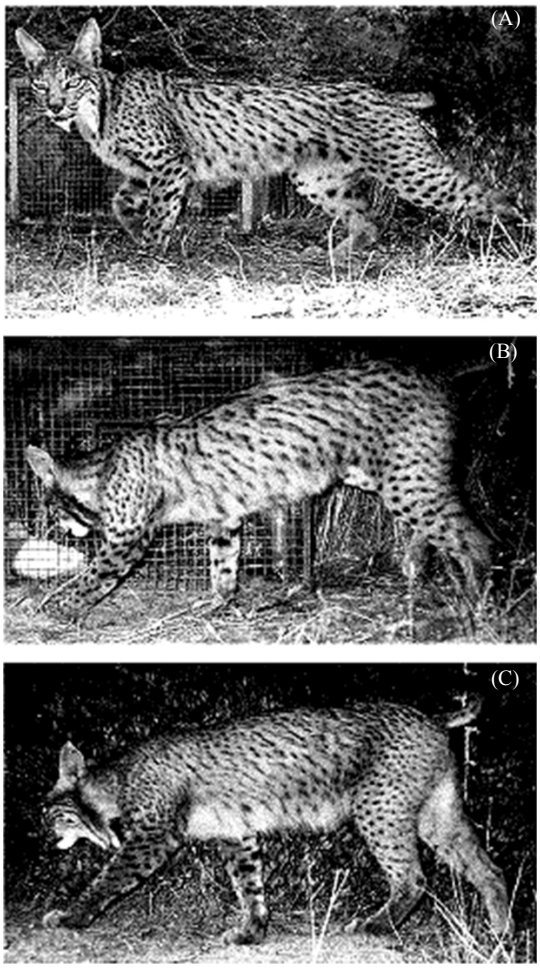

Fig. 2. (A) and (B), repeated photographic captures of the same female Iberian lynx (H9, ref. 7 in Table 3); (C), another Iberian lynx female (H26, ref. 26 in Table 3).

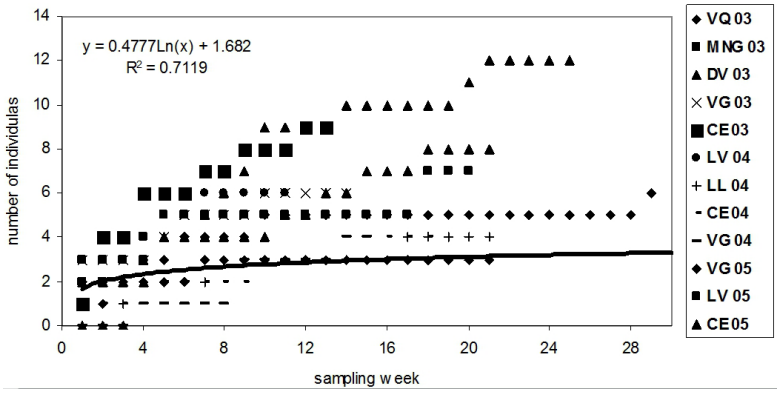

Fig. 3. Curve of accumulated results (number of detected lynx) from data of 12 camera trapping samplings carried out in 7 land properties (capital letters) from 2003 to 2005.

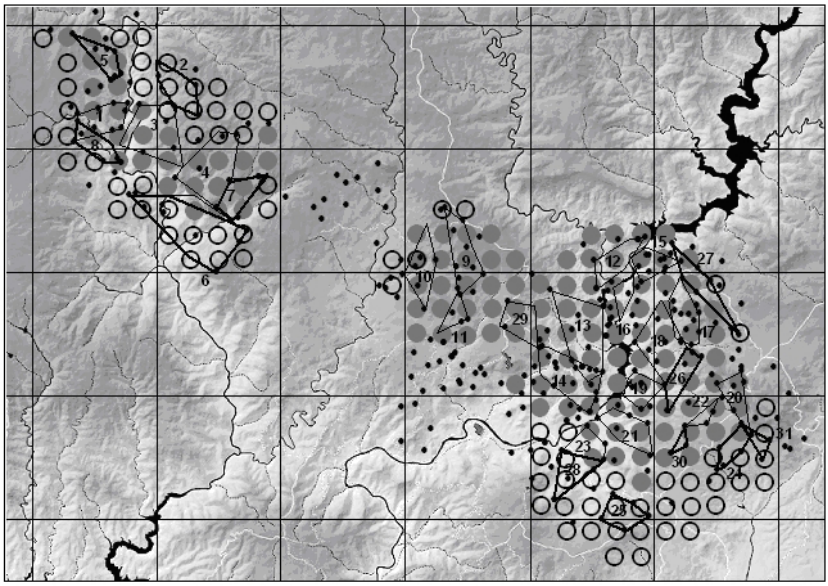

Fig. 4. Example of camera trap sampling design (distribution of 2005) (black points), distribution of lynx at 1x1 km UTM scale (circles) and female territories (polygons): grey circles 2002 distribution; open circles increased distribution from 2002 to 2006; thick-line polygons show the new territories colonized during the study period; reference number for each territory is given (see Table 3). Territories 15, 16, 19, 22 and 29 were built by using not only female camera-trap captures but by adding cubs camera-trap captures and/or pictures from direct observations (see methods). Due to annual changes in boundaries (size decreasing and/or removing), territories 1, 4, 13, 22, 23 and 28 have been updated by using only captures of 2005 and/or 2006. No geographical references are shown for the security of this highly threatened population, following wildlife conservation Spanish laws.

Population estimates

From 2004 till 2006, we covered the entire distribution range with a high sampling effort (average of 31,603 camera days/year, SE = 3,210), which is considerably higher than that applied in other camera-trapping studies (usually 563-5,030 camera/day/year) using closed population capture-recapture models, usually in short capture periods, such as 2 month periods [20-24]. We obtained inter-annual recapture rates of 97% between 2004 and 2005, and 96% between 2005 and 2006 (captured lynxes older than 1-year old). On the other hand, from the 67 lynxes (older than 6-month old) recorded by methods other than camera-trapping (30 from photographs and films of field teams, 40 from live captures and 3 well-preserved dead animals found in the field), only 3 were previously unidentified animals by camera trapping. Moreover, two of them were found in 2003 when there were still uncovered areas. So, considering both the high inter-annual recapture rates from camera trapping and the high recapture rates from another sources (98.2% since 2004), population size was annually estimated directly from capture records at the end of each year. It is important to assume that this kind of estimate represents an annual cumulative value. Some individuals were not re-captured in all years, (average of 4.5 individuals/year; range = 2-8). So, an individual that was captured during the year n+1 was added to the year n for population estimate even though it had not been captured during the year

n. On the other hand, not all kittens are captured by cameras, specially those less than 3-month old, since they are still in the dens [25]. The camera capture probability of this age class is very low, and some of these cubs, detected directly by the field teams, will not be detected by camera-trapping due to natural mortality. So, for estimating population size only animals over 3-month old were considered. Recaptures of adult female lynxes were used to mark out the territories by using the 100% Minimum Convex Polygon (MCP100). A "territory" was defined as a more or less exclusive area defended by an individual in a land tenure system [26]. The number of female territories is a suitable estimator of the population conservation status [27-29], so it was also used for the inter-annual evaluation of the studied population. Captures of kittens of known mother as well as photographs from direct observations were also used for obtaining the MCP100 of 6 female territories of which we had low capture rates. If different females had successively occupied a territory, only the data from the most recent individual was considered to mark out the polygons. The MCP100 of 2 radio-tracked adult females was used to test the MCP100 built from camera trapping data. These individuals were captured by double-entrance, electro-welded-mesh box traps (2x0.5x0.5 m) baited with rabbits, and then they were fitted with VHF radio-collars. The radio-tracking routine consisted in obtaining one location by triangulation each one or two days, so data can be assumed as independent. The program LOAS was used to obtain the location from the field data and the Home Range extension of the program ARCVIEW was used to produce the MPC100. Home ranges obtained from radio-tracking were compared with camera-trapping polygons of both radio-collared females and the neighbouring females, in order to assess the overlap among them.

To estimate population size from camera trapping in the eastern subpopulation, only data from 2004 was used, because of the lack of effort data and overall sampling before this year (Table 2). However, data before 2004 were useful to mark out female territories covered by camera-trapping during this earlier period. In order to mark out the insufficiently sampled territories before 2004 (see Table 3), once all the area was covered by camera-traps, we assumed stability of its boundaries since 2002. Direct observations (including direct field photos and detection of cubs), and/or indirect data (presence of latrines outside the known territories) supported the prior assumption.

Table 2. Lynxes detected during the inter-annual camera trap samplings. Age classes: adults 3 or >3 years old; subadults 2 or <3 years old; juvenile 9 months or <2 years old; kittens < 9 month old lynxes. ** one lynx detected in both sub-populations.

year	2001	2002	2003	2004	2005	2006
EASTERN SUB-POPULATION						
Adult males	-	-	-	9	11	11
Adult females	-	-	-	16	21	21
Unknown sex adults	-	-	-	0	1	1
Sub-adult males	-	-	-	4	3	6
Sub-adult females	-	-	-	5	3	4**
Unknown sex sub-adults	-	-	-	0	0	0
Juvenile males	-	-	-	4	7	5
Juvenile females	-	-	-	3	5	10
Unknown sex juvenile	-	-	-	2	0	1
Male kittens	-	-	-	9	4	13
Female kittens	-	-	-	12	6	15
Unknown sex kittens	-	-	-	1	5	7
TOTAL	**-**	**-**	**-**	**65**	**66**	**95**
WESTERN SUB-POPULATION						
Adult males	1	3	3	3	3	5
Adult females	4	3	5	4	4	6
Unknown sex adults	0	0	0	0	0	0
Sub-adult males	1	0	0	0	3	2
Sub-adult females	0	0	0	1	2	2
Unknown sex sub-adults	0	0	0	0	0	0
Juvenile males	0	1	0	2	3	4
Juvenile females	0	0	1	2	4	3**
Unknown sex juvenile	0	0	0	0	0	0
Male kittens	1	1	2	2	4	9
Female kittens	0	1	3	5	4	7
Unknown sex kittens	0	0	0	0	0	2
TOTAL	**7**	**9**	**14**	**19**	**27**	**40**
TOTAL POPULATION						
Adult males	-	-	-	12	14	16
Adult females	-	-	-	20	25	27
Unknown sex adults	-	-	-	0	1	1
Sub-adult males	-	-	-	4	6	8
Sub-adult females	-	-	-	6	5	5
Unknown sex sub-adults	-	-	-	0	0	0
Juvenile males	-	-	-	6	10	9
Juvenile females	-	-	-	5	9	13
Unknown sex juvenile	-	-	-	2	0	1
Male kittens	-	-	-	11	7	22
Female kittens	-	-	-	17	7	23
Unknown sex kittens	-	-	-	1	9	9
TOTAL	**-**	**-**	**-**	**84**	**93**	**135**

Table 3. Summary of territorial females detected by camera trapping. See Fig. 4 for territory mapping; ns, not sampled; e, empty territory; R, confirmed reproduction. * confirmed presence by other data sources; ** from 2000 to 2003 H36 overlapped with H27 (ref. 21).

Territory reference	individual (year of territory tenure)	captures – breeding attempt							Total captures
		1999-2000	2001	2002	2003	2004	2005	2006	
1	H1 (01-02), H4 (03-06)	ns	1-R	3	44-R	10-R	48-R	8-R	114
2	H 32 (03-05)	e	e	e	4	7-R	2	4-R	17
3	H2 (01-02), H5 (03), H6 (04-06)	ns	3	2-R	1-R	4	7	2-R	19
4	H3 (01-06)	ns	2	8	40-R	42-R	54-R	48-R	146
5	H7 (05-06)	e	e	e	e	e	19-R	33-R	52
6	H8 (05-06)	e	e	e	e	e	40	33-R	73
7	H9 (06)	e	e	e	e	e	e	17	17
8	H10 (06)	e	e	e	e	e	e	23-R	23
9	H11 (03-06)	ns	0	0	28	8	2	9-R	47
10	H12 (01-03), ¿? (04-06)	ns	1	0	3	0	0*-R	1	4
11	H13 (01), H14 (05-06)	ns	1	0	0	0	2-R	2-R	5
12	H15 (04-06)	ns	ns	ns	ns-R	2-R	1	0*-R	3
13	H16 (99-06)	4-R	2	1	0-R	2-R	4	9-R	22
14	H17 (99-01), H18 (04-06)	3-R	2	0	0	4-R	7	6	22
15	H19 (01-04); H20 (05-06)	ns	3	0	0	0*	10	11-R	24
16	H21 (01-06)	ns	1	0	1-R	0*-R	1-R	0*	3
17	H22 (02-06)	ns	0	1	1	4	1-R	1-R	8
18	H23 (01-05), H24 (06)	ns	1	2	11	13	20	18-R	65
19	H25 (00-06)	1	0	2-R	1	2	2-R	6	14
20	H26 (02-06)	0	0	3	5	2-R	8-R	2-R	20
21	H27 (02-06)	0	0	4	7	2	3	3-R	23
22	H28 (01-06)	ns	1	1-R	5	7	2	4-R	20
23	H29 (01-05), H30 (06)	2	5	2	17	6	32	22-R	86
24	H31 (02-06)	e	e	1	1-R	2-R	1-R	4-R	9
25	H33 (04-06)	e	e	e	e	8	4	8-R	20
26	H34 (04-06)	e	e	e	e	5	9	2-R	16
27	H35 (05-06)	e	e	e	e	e	6	6	12
28	H36 (05-06)	e	e	e	e	e	15	7	22
29	¿? (04-06)	ns	ns	ns	ns	0*-R	0*	0*-R	0*
30	H37 (05-06)**	1-e	1-e	0-e	2-e	0-e	1	4-R	9
31	H38 (06)	e	e	e	e	e	e	11	11

Results

Population distribution

Former distribution

Gamekeepers, landowners and forest guards, who lived permanently in the study area, provided first-hand reports. Sixty-nine people were contacted in the field with an overall average density of 4.6 interviews per each 10x10 km UTM quadrats (range = 3-6/ 10x10 km UTM quadrat), which is a higher density than that applied by Rodríguez & Delibes [5] for all the Spanish area (3.2 interviews/10x10 km UTM quadrat).
Sighting data indicated that the distribution of the Iberian lynx had no variations until 1988, being limited to the south-west of the study area (Fig. 5). Seven 10x10 km UTM quadrats were total or partially occupied by lynxes. Outside this area, some isolated reports were registered (Fig. 5) but they were considered as exceptional data. All interviewed people except one reported that lynxes just inhabited the granite area at least since the early 1970s. Sighting data of Rodríguez & Delibes (2002) presented a similar distribution to that found in the present study (5), although only three 10x10 km UTM quadrats had more than 2.1 reports/year and quadrats with less than 2 records/year were more abundant than in our study.

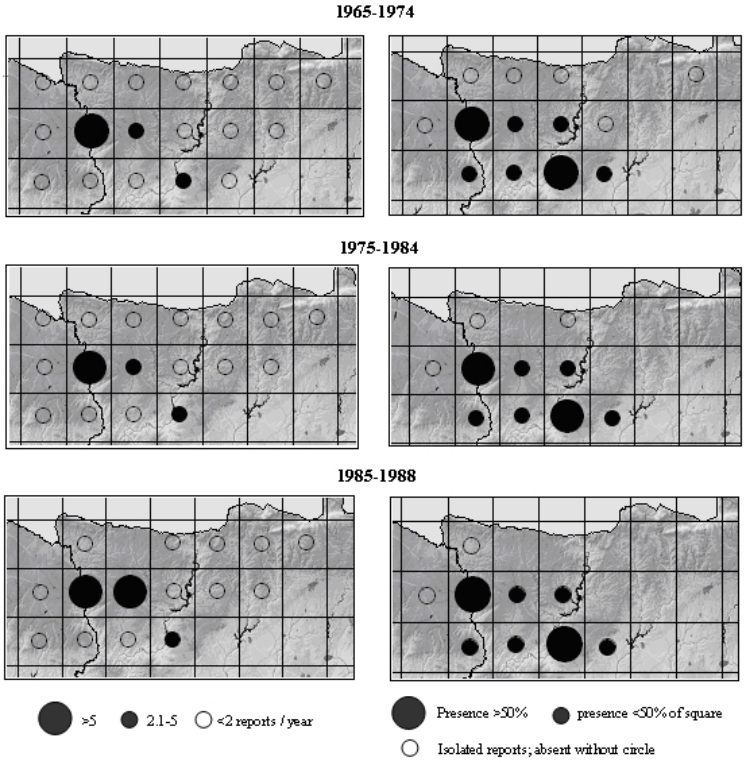

Fig. 5. Left: abundance of lynx reports by Rodríguez & Delibes (2002); Right: results of field interviews in the present study. Data are shown on UTM 10x10 km squares.

Recent distribution

At the beginning of the 1990s, based on our interviews, lynxes occupied 17 UTM 5x5 km quadrats of the study area, all of them within the granite area, but at the same time, a fast decline was reported by local people, with the abandonment of seven quadrats (Fig. 6). This was confirmed by field surveys (sign searching) carried out between 2001 and 2002. In fact, lynxes were found only in 11 quadrats (-38.8%), distributed within two separated subpopulations with three and eight occupied quadrats respectively (Fig. 6). Both subpopulations are currently separated by six linear kilometers (Cabrera river valley, Fig. 6).

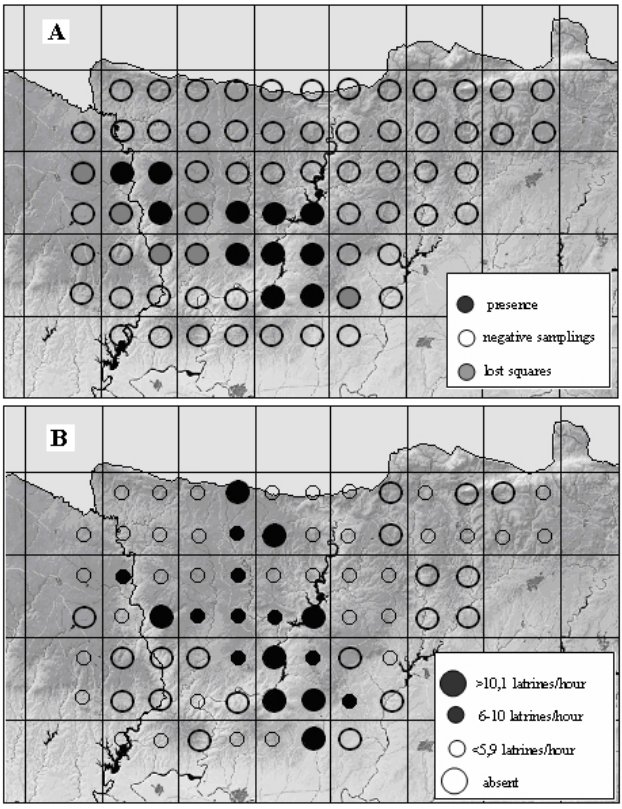

Fig. 6. Results of field sampling on the UTM 5x5 km scale (2001-2002): A- lynx distribution range; B- rabbit distribution and relative abundance.

During 2002 lynxes were detected in 125 1x1 UTM quadrats, 97 and 28 quadrats respectively for the eastern and western subpopulations (Fig. 4). Since 2003 an increase in lynx distribution was detected (Fig. 4), and in 2006 lynxes were detected in 203 1x1 UTM quadrats (+62.4%), 137 quadrats for the eastern subpopulation (41.2% increasing) and 66 for the western subpopulation (+135.7%).

According to the survey of rabbit populations conducted during 2001-2002 rabbit abundance was 4.4 times higher in quadrats occupied by lynx than in quadrats

without lynx (10.36 latrines/hour versus 2.33 latrines/hour, Mann-Whitney U test: $U = 42.5$, $Z = -4.24$, $P = 0.00002$. Granite areas also registered a higher abundance of rabbit than non-granite areas (7.10 latrines/hour versus 2.00 latrines/hour, Mann-Whitney U test: $U = 282.5$, $Z = -2.47$, $P = 0.013$). A significant positive relationship was found between the abundance of lynx scats and abundance of rabbit latrines ($r_s = 0.68$, $P<0.05$).

Population size

Overall, 3,171 lynx captures and 15,274 lynx photos were obtained from the camera trapping campaigns. Table 3 shows the number of captures (n = 922) and breeding events (confirmed reproduction) for each territorial female. The MCP100 showed low female overlap , resulting in 31 territories in 2006 (Fig. 4), 27 of them confirmed by well-defined breeding events. Both radio-tracked females (H36, 137 locations; H31, 97 locations) were captured during 2006 in all camera stations set up within the radio-tracking home-range (MCP 100) (October 2006-October 2007, Fig. 7). Moreover, the MCP100 obtained by radio tracking exhibited low overlap with neighbouring camera-trap territories (Fig. 7). There was one territory with insufficient data and it was considered "probably occupied territory", which had a low sampling effort (ref. 29 Table 3, Fig. 4) and only data from cubs and juveniles captures were obtained. During 2001 13 adult females were detected by camera-trapping (Table 3); field data (see methods) pointed out that another 6 adult females not detected in 2001(Table 3) were actually present that year. Therefore, 19 territories (two females with overlapping territories; Table 3) were assumed to be present in 2001. An increase of the Iberian lynx population had been observed: the number of detected lynxes increased 60.7% between 2004 and 2006 (Table 2) and the number of female territories increased 63.1% between 2001 and 2006 (from 19 to 31, Table 3 and Fig. 4). Out of the 12 new territories, 10 were colonized by juvenile and sub-adult females, 9 of which came from known birthing territories (ref. 2, 5, 6, 7, 8, 26, 27, 28, and 31, Fig. 4). Territory expansion was mainly due to the colonization of bordering areas (Fig. 4). As it was expected from the sign-searching survey using 1x1 km UTM quadrats, the most important relative increase was detected in the western subpopulation. In this nucleus, from 2001 till 2006, we observed an increase of 471% in the number of detected individuals (Table 2), and an increase of 166% in female territories, from 3 to 8 territories: in 2001 there were two adult females with overlapping territory (ref. 4, Fig. 4) resulting in a total of 3 territories; in 2006 two sub-adult females became territorial (ref. 7 and ref. 8, Fig. 4), resulting in 8 territories. Data from female territory tenure suggested that the eastern subpopulation remained stable from 2001 to 2004, and then increased by 46% (Table 2) with respect to the number of detected individuals in 2004 and by 53.3% (from 15 to 23 territories) with respect to female territories from 2001 to 2006 (Fig. 4). One territory (ref. 13) was occupied in 2001 but became empty in 2002. Fortunately, it was re-occupied in 2003. The density of female territories was 6.7 km^2 / territory both for 2001-2002 and for 2005-2006. For the eastern sub-population these values were 5.2 and 6.2 respectively, and for the western subpopulation 9.3 and 8.2 respectively.

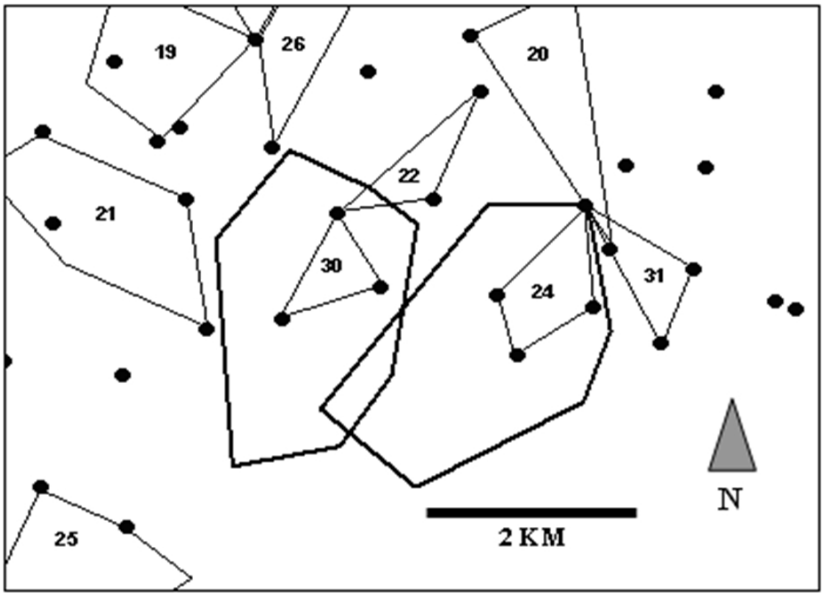

Fig. 7. Adult female MCP100 territories from 2006 camera trapping (thin lined polygons) and MCP100 radio-tracking since October 2006 to October 2007 (thick lined polygons: 24 and 30) of two adult females (H31 and H36, see Table 3). Black points represent the 2006 available camera stations.

Discussion

When comparing lynx distribution estimated in 1988 by Rodríguez & Delibes [5] with that found in the present study, a dramatic decline might be deduced, with 15 10x10 UTM quadrats of stable lynx presence in 1988 versus 6 UTM 10x10 quadrats occupied in 2002 (-60%). However, our sighting data (Fig. 5) suggested that the 1988 distribution [5] could be overestimated, as previously pointed out [7]. In fact, distribution maps of Rodríguez & Delibes [5,12] were prepared assuming no significant changes in range boundaries for the period between 1979 and 1988, and as pointed out by the authors themselves, their results might be over-optimistic. On the other hand, several observations of lynx and breeding females are annually registered by gamekeepers inhabiting quadrats with regular presence (> 10 observations / year per10 km^2). In our study area we considered that one 10x10 km UTM quadrat with less than two reports per year from inhabiting people cannot be assumed as a quadrat of stable presence. It should however be considered as a quadrat of occasional presence, probably occupied by individuals moving from the main source population. Moreover, the distribution presented by Rodríguez & Delibes [5,12] does not seem to be congruent with their own data, since there is one 10x10 km UTM quadrat with no reports between 1985 and 1988 (see sighting maps in Rodríguez & Delibes [12]), which the authors considered as a medium lynx density. Rodríguez & Delibes [5,6,12,13] obtained more positive reports than we did in the present study (Fig. 5), probably because they used both field interviews and a postal enquiry to hunters, forest guards, naturalists and taxidermists living in the southern two-thirds of Spain. So, two different sources were polled: data from people inhabiting the

study area and data from visitors (hundreds of non local hunters visit this area). Data from our interviews of local people were consistent with data from field surveys of scats at a 5x5 km scale (100% consistent, once 6 quadrats from where the felid had disappeared since the 1980s were excluded), suggesting that local people have a very good knowledge regarding lynx distribution. The accuracy of isolated reports from a postal inquiry is normally impossible to assess and the records sent by mail were subjectively quantified by Rodríguez & Delibes [5,6,12,13], as the authors recognized. Summarily, the overestimation by Rodriguez & Delibes [5,6,12,13] might have been due to: (a) assuming a temporal stability in lynx distribution during the period 1979 –1988, (b) assuming quadrats with very few reports as areas of stable presence, and (c) assuming the postal inquiry data as reliable information.

An important lynx decline has been registered within the study area since the early 1990s, probably related to Rabbit Haemorrhagic Disease (RHD) outbreaks as people interviewed cited. This lethal disease reached the Iberian Peninsula during that time producing important mortality events [30]. Rabbits are the staple prey of Iberian lynx both in Doñana National Park [31,25] and Sierra Morena [32,33], playing a key role in lynx ecology [25]. As sighting data suggests, it is likely that only areas traditionally presenting the highest densities of rabbits support nowadays acceptable rabbit abundance for lynxes. The decline of rabbit populations was more important in the western subpopulation (Fig. 6), and data of lynx capture for research [25] and photographic sampling from 1999 [34] suggest both rabbit and lynx decline until the year 2000. Currently, preliminary data of rabbit monitoring point out a possible end of the decline [35], but more information is needed. Both subpopulations of Iberian lynx are separated by an area of very low rabbit abundance (Fig. 6), although the areas are connected by Mediterranean forest and shrub in a distance of about 5 km.

The present lynx distribution in 5x5 km UTM quadrats was correlated with rabbit distribution and abundance (Fig. 6), as it was known for Doñana National Park [25]. Rabbits were very rare or even absent within quadrats without lynx presence, with densities lower than 0.1/ha (pers. obs.). Rabbit densities of 0.2-0.3 to 2.5 individuals/ha during the season of lowest (autumn) and highest (spring) density respectively cannot maintain a stable lynx population in Doñana area [25]. A recent study based on habitat modelling [8] predicted the existence of the two described subpopulations of lynxes, although both subpopulations overlapped the distribution of the western subpopulation, largely failing to detect the main eastern subpopulation (see Fig.1 and Fig. 6). The prediction map made by these authors to estimate lynx range included non-granite areas, which did not contain breeding territories according to our data and where no lynx signs had been detected for the last five years. The distribution proposed by Fernández et al. [8] included areas of Andújar-Cardeña Natural Parks with very low rabbit availability or where rabbits were absent (see Fig.1 and Fig. 6).

Nowadays the density of the surviving lynx population may be evaluated as high by comparison with the information from the Doñana population, where the mean MPC100 of females inhabiting the highest density subpopulation was 9.5 km^2 [25]. The population size estimated in our study area in 1988 was 370 lynxes (without cubs), but this data is based on the previously discussed distribution obtained from the postal inquiry, which probably showed over-estimated numbers [5]. So, it is not

possible to know the exact value of the negative tendency observed since the 1980s. Anyway, the present population size is too low, even when considering the positive tendency from 2002 on, since the number of breeding individuals (< 50) is set under security values to avoid inbreeding depression effects [36]. The extinction risk in the next 100 years, for this population, should be lower than that for Doñana [28,29], if a population viability analyses (PVA) was applied for the largest Sierra Monena population, where both sub-populations are sources (both had high adult survival and breeding success from camera trapping recaptures). However the Doñana PVA did not include genetics. In this case, inbreeding depression could increase greatly the probability of extinction over 100 years [36,37]. The effective population size (N_e) required to retain 95% of heterozygosis for 100 years would be about 200 individuals for the Iberian lynx, if we assume a generation interval of 4-5 years [36]. Carnivores have less severe inbreeding depression than other mammal species [38] and, in fact, no negative effects have been observed for the studied population based on field data: 1) it remains a clear phenotypic variation, since the three pelage-patterns described for the species [39] are represented, whereas only one of them remains in Doñana population since 1960 [39]; 2) the litter size (2.01 detected cubs per breeding female) and kitten survival rates (81.4% of cubs of year n were detected during year n+1; unpublished data from the present monitoring program) are similar to healthy populations of another lynx species [40,41]. Therefore, the genetic status of the population may be not as bad as it seems to be, but anyway there is no doubt that the population size is presently set within a dangerous position (see [27] for tigers *Panthera tigris*, [37] for Florida panthers *Felis concolor coryi* and [42] for the grizzly bear *Ursus arctos*). Moreover, during 2006 a great mortality due to RHD affected the local population of rabbits probably halting the good evolution of lynxes [43].

The positive tendency observed during the monitoring program may indicate the success of the conservation program developed between 2001 and 2006 at a great scale (LIFE 02 NAT/E/8609). There are large areas with good quality habitat (Mediterranean scrub on granite substrate), and problems identified for the Doñana population such as poaching and road kills [44] are actually rare or even absent from the main breeding territories in our study area. Since no information about stochastic factors [15] is available, conservation actions have been focused on recovering the rabbit population within the area occupied by lynxes in the 1990s, in order to increase the carrying capacity. Only two out of six actions proposed by the Action Plan for the Iberian Lynx in Europe for rabbit recovery [15] are possible within this area: habitat restoration [45] and rabbit restocking [46,47]. Habitat recovering at landscape scale has been carried out, including dense scrub clearing and implementation of artificial dens. Simultaneously a lot of rabbits have been restocked on fenced areas. All of these actions have been complemented with food supplying of some females living in areas with low rabbit availability. These results are still under analysis, but preliminary data suggests at least some success of the conservation management action, being especially notorious in the western subpopulation case [32]. The conservation program has been more important for this subpopulation due to its undoubtedly worse situation. This may be the reason for the differences observed in the dynamics of both subpopulations (regarding distribution and size), which was

relatively better for the smallest one.

Conclusions and management implications

The most important population of Iberian lynx was constituted by about 43 breeding individuals (males and females) in 2006, occupying an area of 200 km^2. Here we have presented a monitoring program based on non-intrusive methods that are useful to detect the main demographic parameters on an annual basis, which need to be used when developing conservation programs. In this sense, a deterministic factor as the decline of the rabbit population seems to be the main problem for lynxes within this area of Sierra Morena. So, the continuous monitoring of lynxes and rabbits is quite important, especially to detect drastic prey declines, since RHD and myxomatosis still occur. In that case, artificial food supplies and even lynx captures would be considered if necessary. Although breeding areas are well protected, little is known about dispersing individuals. Research on dispersal is necessary to know what is happening to individuals dispersing along the large area of sub-optimal habitats surrounding the metapopulation. As camera trapping is revealing, both subpopulations may be considered as sources. So, based on adequate research, some dispersers may be used on reintroduction programs or captive breeding projects [15]. Finally, a priority objective is to recover the carrying capacity by rabbit management, in order to achieve spatial connectivity between both subpopulations and also to reach a more secure population size to avoid inbreeding problems [36].

Acknowledgements

The study was supported by the project LIFE NAT //E//8609 "Recuperación del Lince Ibérico en Andalucía", and all data presented belong to the project. We are especially grateful to people of different teams who collaborated in camera trapping: Gregorio Fernández, Fernando Silvestre, Juan Figueredo and Sandra Agudí (CBD-Hábitat Fundation), Germán Garrote, Ramón Pérez, Concepción Iglesias and Nicolás Guzman (TRAGSA-MIMAM), Alfonso Moreno and Jesús Cobo (Adena-WWF), Aquilino Duque (CMA Junta de Andalucía) and Antonio Leiva, Manuel Ruiz, Maribel García-Tardío, Santiago Lillo, Gerardo Valenzuela, Joaquín Pérez, Miguel Diaz and Rafael Arenas Jr. (EGMASA-CMA Junta de Andalucía). Roberto García, Rafael Solano, Ana Pello, Magdalena Vara and Inmaculada Tenorio (EGMASA-CMA Junta de Andalucía) helped in the office with the 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. Cristina Sanchez helped with GIS management and David Dobinson revised the English.

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