

# New data on the status and ecology of a galliform at risk of extinction: the Pyrenean grey partridge (*Perdix perdix hispaniensis*) in the Iberian System (Soria, Spain)

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## Abstract

*New data on the status and ecology of a galliform at risk of extinction: the Pyrenean grey partridge (Perdix perdix hispaniensis) in the Iberian System (Soria, Spain).* A study was conducted in 2008–2010 to gain knowledge on the status and ecology of the endangered subspecies of grey partridge (*Perdix perdix hispaniensis*), at its southernmost range edge. From an historic breeding range of 28,300 ha, 15 different coveys (adults with juveniles) were observed in an area comprising 5,550 ha, with an estimated minimum autumn population size of 103–113 birds and a maximum of 163–181 birds. Spring pair density was estimated at 2.3 pairs/1,000 ha, and when considering only coveys, 6.8 partridges/1,000 ha. The majority of birds were located at an altitude above 1,690 m a.s.l., mainly in mountain shrubland (especially *Calluna vulgaris* and *Erica* spp.). Habitat loss was the most important threat for the species' conservation. In conclusion, efforts should prioritize urgent habitat recovery and monitoring in order to change the fate of the species.

Key words: Conservation, Habitat selection, Management, Radio-tracking

## Resumen

*Nuevos datos sobre la situación y la ecología de un ave galliforme en peligro de extinción: la perdiz pardilla (Perdix perdix hispaniensis) en el sistema Ibérico (Soria, España).* Se realizó un estudio entre 2008 y 2010 para conocer la situación y la ecología de la perdiz pardilla (*Perdix perdix hispaniensis*), que se encuentra en peligro de extinción, en el extremo meridional de su distribución geográfica. De una superficie de reproducción histórica de 28.300 ha, se confirmó la observación de 15 grupos familiares (adultos con juveniles) en una superficie de 5.550 ha con un tamaño de población estimado en otoño de entre 103 y 113 perdices como mínimo y de entre 163 y 181 como máximo. Se estimó una densidad de 2,3 parejas/1.000 ha en primavera y, al considerar únicamente grupos familiares, de 6,8 perdices/1.000 ha. La mayoría de las aves se encontraban a una altitud superior a 1.690 m s.n.m. y usaban principalmente matorrales de montaña (especialmente *Calluna vulgaris* y *Erica* spp.). La pérdida del hábitat fue el factor más perjudicial para la conservación de la especie; en este sentido, se concluyó que se debería dar prioridad a la recuperación urgente del hábitat y al seguimiento, lo que podría cambiar el destino de la especie.

Palabras clave: Conservación, Gestión, Selección de hábitat, Radioseguimiento

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## Introduction

The grey partridge subspecies *Perdix perdix hispaniensis* (hereafter referred to as Pyrenean grey partridge, PGP), is a galliform occurring in three mountain ranges, the Cantabrian Mountains and the Iberian System in Spain, and the Pyrenees between Andorra, France and Spain (Lucio et al., 1992). As these mountains are isolated, they represent the south–western limit of grey partridges occurrence within its entire range (Potts, 2012). The PGP shows genetic and phenotypic characteristics (Castroviejo, 1967; Lescouret et al., 1987; Martin et al., 2003; Bech et al., 2020) that differentiate it from other subspecies, and it inhabits uplands from 1,300 to 2,700 m a.s.l., depending on the time of the year. It selects habitats dominated by shrublands and steep slopes (Lucio et al., 1992), in contrast with the vast majority of the species' range in Eurasia and North America, where grey partridges mainly occur in lowland and farmland habitats (Potts, 1986). PGP form pairs in winter–spring and family coveys from summer to winter, as do their lowland counterparts (Potts, 2012).

Research has covered aspects of the biology and ecology of PGP (Llamas and Lucio, 1988; Novoa et al., 1999, 2002, 2006), demographics (Junco Ruiz and Kilchenmann, 1998; Bro and Crosnier, 2012), controlled burning effects (Novoa et al., 1998), monitoring (Novoa, 1992; González et al., 2017) and hunting (Besnard et al., 2010). PGP is a game species in the French Pyrenees (Novoa et al., 2008) and Catalonia (Pagés, 2011) and both populations show favourable conservation status when compared to others (Martínez-Vidal, 2011).

While the population from the Pyrenees is relatively well–studied, there is a lack of research for PGP occurring in the Cantabrian Mountains and the Iberian System. According to the review conducted by Purroy and Purroy (2016), the majority of studies on PGP from these populations were conducted before the year 2000. Few studies have provided knowledge on the species in the last 20 years (Herrero et al., 2009) with the exception of monitoring conducted by regional wildlife departments.

In Spain, the PGP population size was estimated at 2,000 to 6,000 pairs in the late 1990s (Lucio and Sáenz de Buruaga, 1997). It is included in Annex I within the Directive 2009/147/EC of the European Parliament and of the Council on the conservation of wild birds and the species is categorized as 'Vulnerable' (VU C1), owing to the decline recorded during the last decades (Onrubia et al., 2004). This unfavourable trend seems to be especially severe in some peripheral areas of the Cantabrian Mountains and in the entire population of the Iberian System (Lucio et al., 1992), where local extinctions had occurred in recent times. In December 2020 the Iberian System population was declared 'at risk of extinction' by the Spanish Red List of Endangered Species (Orden TED/1126/2020).

Aiming to gain knowledge on the status and ecology of PGP in the Iberian System, we conducted field surveys and radio–tracked birds in the Soria province (where the species is known as 'Serreña'),

the southernmost range limit of the Iberian System population (Lucio et al., 1992). Our results may help to understand conservation problems and develop targeted management to improve the status of PGP populations.

## Material and methods

### Study area

This research was conducted in the Iberian System from 2008 to 2010, in the province of Soria (Castilla y León region, fig. 1). PGP had historically occurred in the study area in open mountainous areas dominated by shrublands, ranging from 1,400 to 2,000 m a.s.l. The distribution of PGP in the Soria province is spread across six mountain ranges: Urbión, Cameros, Sierra Cebollera, up–River Tera, up–River Cidacos–Alhama and Sierra del Moncayo. Most of this area is included in the Special Protection Areas (SPA) of 'Sierra de Urbión' (ES4170013) and 'Sierra del Moncayo' (ES4170044).

### PGP surveys

We aimed to identify the areas where PGP occurred during the breeding season (from March to October), and to gain knowledge on the breeding success of the species, paying special attention to coveys (adults with juveniles, family groups). We were aware of the possible movements during autumn–winter to areas of lower altitude (especially after heavy snow) (Lucio et al., 1992) but it was not possible to cover all these areas; however, they were partially studied using radio–tracked birds.

We considered the areas of historic occurrence of PGP and created 283 UTM individual grids of 1 km<sup>2</sup>. A first visit was conducted to identify whether the habitat was suitable for PGP breeding, excluding grids where the only habitat was dense forest (Purroy and Purroy, 2016). At the same time, we conducted face–to–face surveys ( $n = 210$ ) with wildlife rangers, game managers, hunters, shepherds, ornithologists and bird watchers in all the study area to evaluate past and current presence of PGP. After the first visits and face–to–face surveys, we estimated that the PGP potential breeding habitat area in Soria province comprised 12,500 ha (44% of the historical range). Field work was thus focused on this area. After considering the land that could be surveyed in one day of field work, we created 57 survey plots (size range: 150–250 ha) covering a total of 12,500 ha.

We combined several methods to detect PGP during 2008 and 2009:

(1) Playback calls from March to June, following the methods of Novoa (1992) in a total area of 3,100 ha that was chosen after considering the first visits and information gathered from the face–to–face surveys; playback–calls from birds from the same area were used.

(2) Walked transects in July and August covering all survey plots. Each transect was surveyed at least

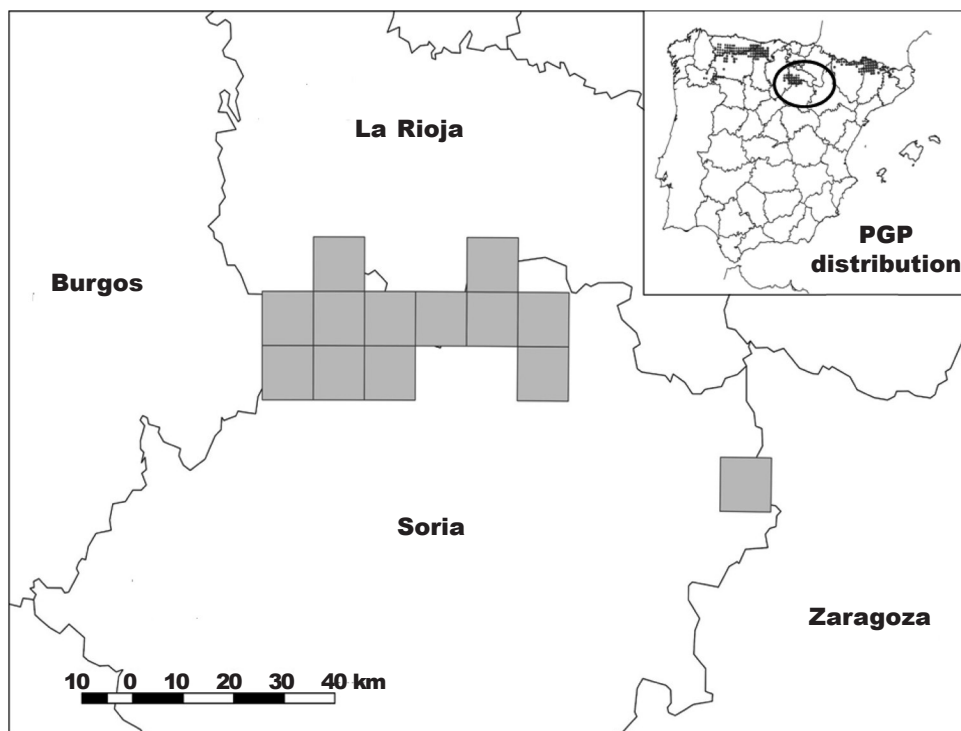


Fig. 1. Study area in the Iberian System, showing 10x10 km grids covering the former and current distribution of grey partridges (*Perdix perdix hispaniensis*) in the province of Soria (showing the neighbouring provinces) (Onrubia et al., 2003). As the species is 'at risk of extinction' it is not possible to show the current distribution of the species at a lower scale.

Fig. 1. Zona del estudio en el sistema Ibérico, donde se muestran las cuadrículas de 10x10 km que cubren el área de distribución histórica y la actual de la perdiz pardilla (*Perdix perdix hispaniensis*) en la provincia de Soria (se muestran las provincias limítrofes) (Onrubia et al., 2003). Dado que la especie se ha declarado como "en peligro de extinción", no es posible mostrar su distribución actual a menor escala.

once by three observers, aiming to detect signs of PGP presence (tracks, faeces, feathers), make direct observations, and gather data on habitat characteristics and possible threats, either natural or anthropogenic such as natural forest expansion, physical structures (tracks, roads and wind farms), and sources of disturbance from human activities; transects were conducted during the morning (9:00–12:00 a.m.).

(3) Pointing dogs in September and October. We hired a professional dog-trainer to cover those areas where coveys may occur (considering the information gathered from previous methods, and covered 2,200 ha using 4–5 dogs (English setter) and 3–4 observers during the morning (from 9:00–12:00 a.m.). When PGP were seen or flushed, we attempted to distinguish between adults and juveniles, and estimate the age of juveniles.

And (4) transects in winter: this method was used in areas with at least 90% of surface snow (23 transects in total, mainly up-River Tera and up-River Cidacos-Alhama). Access was difficult (González et al., 2017), and the PGP could be confounded with red-legged partridges (*Alectoris rufa*).

Survey plots were categorized into three categories: (1) 'confirmed breeding', when coveys were seen/flushed; (2) 'probable breeding', when indirect evidence was found such as pairs; 'incubation faeces' and small faeces attributed to juveniles (but no juveniles observed), together with adult 'distraction displays'; and (3) 'not detected'.

The number of days per method invested in each mountain range varied according to surface and habitat characteristics. In total we conducted surveys on 248 days (table 1). The efficiency of each method was evaluated by conducting surveys in the plots with known presence of the radio-tagged birds and coveys (associated to these birds) (table 2). As red-legged partridges occurred in the areas, we also recorded birds seen or flushed.

#### Radio-tracking and home range analysis

During May 2008 and 2009, we captured PGP for radio-tracking using a corvid cage-trap and a female PGP decoy from a French game farm (fig. 2). Once the presence of birds was confirmed through the play-

Table 1. Grey partridge surveys conducted in the different mountain ranges, showing the number of survey plots, surface area covered and number of surveys conducted per method, together with density of spring pairs, coveys in autumn and size of the area where breeding was confirmed: T, total; Ur, Urbión; Ca, Cameros; Ce, Cebollera; Up-T, up-River Tera; Up-C; up-River Cidacos-Alhama; Mo, Moncayo; n.a., not available.

*Tabla 1. Muestreos de perdiz pardilla realizados en los distintos macizos montañosos, donde se puede observar el número de sectores y la superficie de muestreo, el número y el tipo de muestreos, la densidad de parejas en primavera y de bandos en otoño y la superficie donde se había producido reproducción. (Para las abreviaturas de los distintos macizos montañosos, véase arriba).*

	T	Ur	Ca	Ce	Up-T	Up-C	Mo
Survey plots	57	11	2	9	13	15	7
Breeding habitat surveyed (ha)	10,300	1,800	500	1,800	1,900	2,500	1,800
Face-to-face surveys (days)	21	3	2	3	4	6	3
Playback calls	72	8	4	10	20	25	5
Walked transects	76	10	6	14	20	21	5
Pointer dogs	56	12	5	11	12	12	4
Transects in winter	23	1	3	3	7	8	1
Total	248	34	20	41	63	72	18
Spring pairs/1,000 ha	2.3	3.8	2	2.7	3.1	1.6	0.5
Number coveys	15	5	1	3	2	4	0
Confirmed breeding (ha)	5,550	1,800	300	1,650	1,100	500	200
Birds in coveys/1,000 ha (autumn)	6.8	14.14	6	7.2	4.2	8	n.a.

Table 2. A, efficiency of the survey methods for grey partridges, showing the number of surveys conducted per method with the real presence of radio-tracked birds or coveys (n) and the percentage of surveys with confirmed detection (%): Rt birds, radio-tracked birds; n.c., not conducted. B, size of the PGP population in Soria province, considering the detectability percentages: Min, minimum; Max, maximum; D, detectability; \* calculated considering the average number of juveniles per covey (3.5).

*Tabla 2. A, eficiencia de los distintos métodos de muestreo de perdiz pardilla, donde se observa el número de muestreos realizados de cada método, la presencia real de aves marcadas con emisores de radiofrecuencia o de grupos familiares (n) y el porcentaje de muestreos con detecciones confirmadas (%): RT birds, aves marcadas; n.c., no realizado. B, tamaño de la población de perdiz pardilla en la provincia de Soria, considerando los porcentajes de detectabilidad: Min, mínimo; Max, máximo; D, detectabilidad; \*calculado teniendo en cuenta el número medio de juveniles por grupo familiar (3,5).*

A	Rt birds		Coveys		B	Min	Max	D(%)
	n	%	n	%				
Face-to-face surveys	60	20	60	20	Coveys	15	18–20	75–85
Playback calls	4	75	n.c.	n.c.	Breeding adults	17	20–23	
Walked transects	20	5	8	38	Probable breeding adults*	6–8	8–9	
Pointer dogs	4	50	8	88	Unsuccessful breeders	30–35	72–81	40–45
Transects in winter	6	16	6	33	Juveniles	50–53	63–68*	
					Total	103–113	163–181	



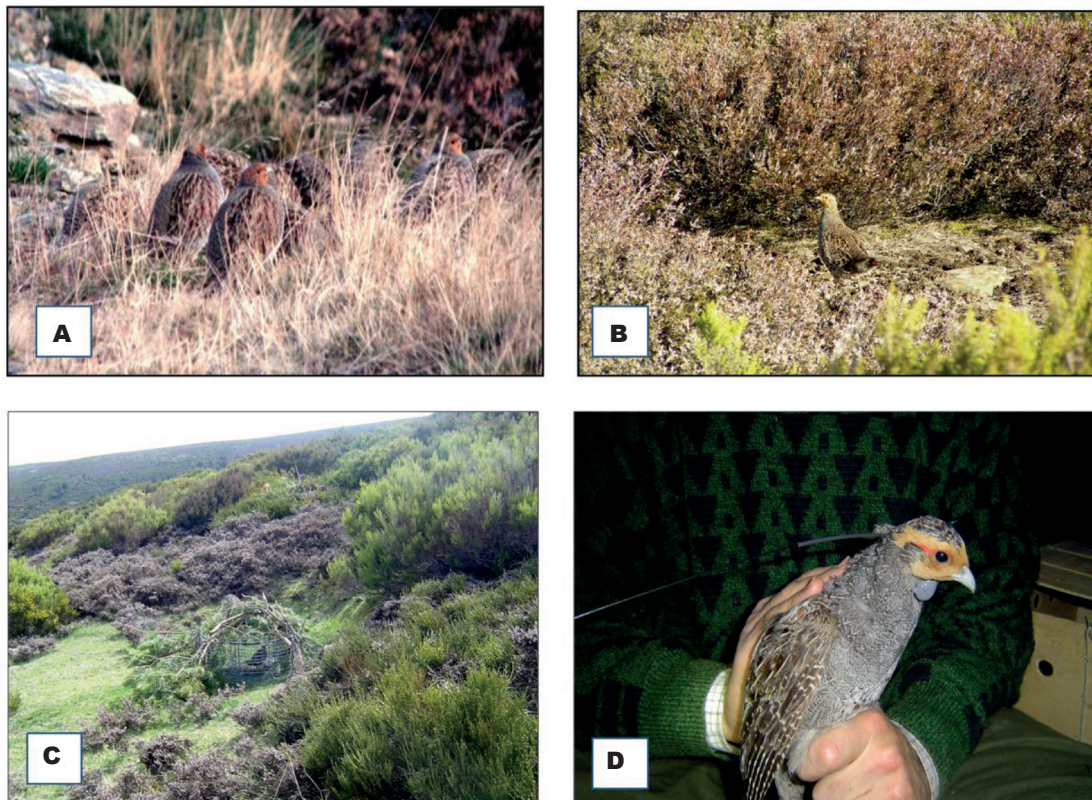


Fig. 2. A covey seen during the surveys in autumn (A), a single bird detected with the playback call (B), the cage-trap with the live decoy (C), and the first bird caught for radio-tracking (D).

Fig. 2. Un grupo familiar observado en otoño (A), una perdiz 'soltera' detectada mediante la emisión de cantos (B), la trampa de jaula con un reclamo vivo (C) y la primera ave capturada para marcarla con un emisor de radiofrecuencia (D).

back calls, cage-traps were set and checked daily (Besnard et al., 2010).

The age of the birds caught ( $n = 2$ ) was determined by inspection of primary feathers and biometrics were taken (wing length, weight, tarsus width). Birds were ringed and fitted with collar radio-tags (8 g, RI-2D-M, Holohil Systems Ltd., Ontario, Canada), with an approximate life-span of 300 days and mortality switch. Birds were released on the same day at the same location where they had been caught, and radio-tracking lasted until the battery ended. Radio-tracking was more frequent in May–November (from 1 to 5 fixes/week). During the snow period (December–March) it was difficult to access the study areas and radio-tracking was conducted once every fortnight. While conducting radio-tracking, we tried to observe the bird when possible, especially during the breeding season to assess whether it was paired or with other adults. Locations of radio-tracked birds were georeferenced after conducting triangulation, and home ranges were calculated using the minimum convex polygon (arithmetic mean algorithm excluding 5% of fixes from the harmonic centre, MCP 95%) (Harris et al., 1990) using

ArcView © (program version 3.2., Esri, Redlands, CA). When possible, we calculated movements between consecutive days (daily inter-fix distance).

#### Habitat use

We recorded the habitat characteristics of the location of PGP coveys (habitat used), considering a 200 m buffer from the point where they were seen/flushed, recording in situ the main habitats and the canopy cover fractions of the vegetation present. Assuming that birds could have moved while being approached, a further GIS analysis was conducted considering a 500 m buffer to evaluate habitat availability in the context of each survey plot. Rather than using broad habitat categories, we decided to identify and evaluate the dominant ( $\geq 50\%$  of the surface) habitat in the 500 m buffer as follows: *Calluna vulgaris*, *Erica (arborea or australis ssp. aragonensis)*, *Cytisus scoparius*, *Vaccinium myrtillus*, *Rubus ideaeus* and *Pinus* spp., together with grassland (mainly Poaceae), and including 'screes' as a category. We also considered

Table 3. Habitats used by untagged PGP coveys in Soria province (from the analysis of the 200 m buffer and dominant habitat 500 m buffer): N, covey number; BR, bilberry/raspberry (*Vaccinium myrtillus*/*Rubus idaeus*); C, Pyrenean broom *Cytisus oromediterraneus*; F, forest; Fp, forest plantation; G, grassland (mainly Poaceae); H, heather *Calluna vulgaris*; HR, heath *Erica* spp.; J, junipers *Juniperus* spp.; S, screes.

Tabla 3. Hábitats utilizados por grupos familiares sin marcar de perdiz pardilla en la provincia de Soria (a partir del análisis de la zona de influencia de 200 m) y el hábitat dominante (zona de influencia de 500 m): N, número de grupo familiar; BR, arándano y frambuesa *Vaccinium myrtillus* y *Rubus idaeus*; C, piorno *Cytisus oromediterraneus*; F, bosque; Fp, bosque de repoblación; G, pasto (principalmente Poaceae); H, biércol *Calluna vulgaris*; HR, brezo *Erica* spp.; J, junípero *Juniperus* spp.; S, canchal o pedregal.

N	200 m buffer	500 m buffer	N	200 m buffer	500 m buffer
1	HR-J-S	HR	9	HR-S-Fp	HR
2	HR-BR-S	HR	10	HR-G-Fp	HR
3	HR-J-S	HR	11	H-S-Fp	H
4	H-HR-BR	HR-H	12	HR-J-G	HR-C
5	HR-J-S	HR	13	H-C-F	H-C
6	H-HR-F-G	HR-H	14	HR-C-G	HR-C
7	H-G	H	15	C-HR	C
8	H-S-BR	H			

combinations of habitats when they were present in similar proportions. The number of locations of birds seen during the surveys (either as individuals or in coveys) was limited (< 60 during the whole study, and sometimes at the same location). We therefore conducted a descriptive analysis, pooling all habitat locations of seen/flushed coveys, and compared the habitat where birds were seen with the dominant habitat (table 3). With regard to radio-tracked birds, we recorded the habitat characteristics as described for birds seen in the surveys. We also recorded the percentage of cover and the height of the dominant vegetation (cm) (Novoa et al., 2002), together with altitude and slope, calculated as percentages. Owing to the small number of radio-tracked birds, we merged data and presented the main results for both birds.

## Results

### PGP surveys

From an initial potential breeding area of 12,500 ha, after surveys we estimated that 10,300 ha were suitable, with breeding confirmed in 5,550 ha, representing 54% of the species' suitable habitat in Soria province (table 1). Out of 57 plots surveyed, PGP occurred in 34, and possible breeding was detected in 24 (confirmed in 15 and probable in 9). Additionally, we documented evidence of breeding during the last 40 years in 21 plots, and during the last 10 years in 12 plots where no PGP were detected during the surveys (33 in total, fig. 3). The most efficient survey methodologies, after comparisons considering plots

with known presence of radio-tagged birds or coveys, were playback calls for unsuccessful breeders and pointer dogs for coveys (table 2). Combining methods, we estimated that the detectability of unsuccessful breeders was 40–45% and for coveys 75–85%.

During 2008 and 2009, we detected 15 coveys at the study area. A total of 103–113 birds were observed in autumn as follows; 17 breeding adults, 6–8 probable breeding adults, 30–35 unsuccessful breeders and 50–53 juveniles. Considering detectability, we calculated a maximum autumn population size of 163–181 PGP (and minimum of 53–60 in spring) (table 2). For the whole study, mean partridge density in the breeding habitat (considering plots with confirmed and probable breeding) was 2.3 pairs/1,000 ha, and when considering birds seen in autumn coveys it was 6.8 partridges/1,000 ha (table 1). The average number of juveniles per covey was 3.5 (range 2–7). Using the number of birds seen during the counts with pointers, (53 juveniles and 17 adults), we found the age ratio was 3.1.

With regard to phenology, the observation of faeces from incubating birds and the size of the juveniles when seen/flushed allowed us to estimate that in 2008 the hatching period lasted from July 10<sup>th</sup> to the end of August. We observed chicks of small size at the beginning of September, probably from second or third nesting attempts. In 2009, first hatchings were estimated to occur by June 25<sup>th</sup>, with no evidence of late clutches.

### Habitat use

Overall, coveys were observed at a mean altitude of 1,781 m a.s.l. (range 1,550–2,010 m) and non-breeding birds at a mean altitude of 1,690 m a.s.l. (range

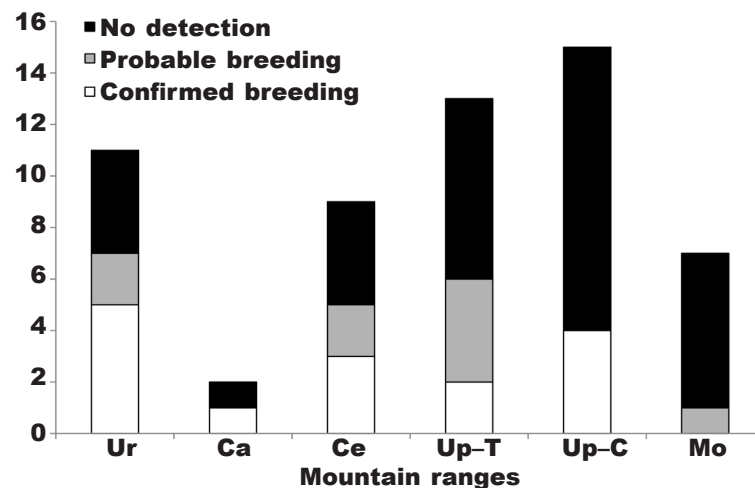


Fig. 3. Number of survey plots considering the mountain ranges where PGP breeding was confirmed, probable breeding occurred and plots with no detections: Ur, Urbión; Ca, Cameros; Ce, Cebollera; Up-T, up-River Tera; Up-C; up-River Cidacos-Alhama; Mo, Moncayo.

Fig. 3. Número de sectores considerando los macizos montañosos donde se había producido reproducción, donde la reproducción era probable y donde no se detectaron individuos. (Para las abreviaturas de los macizos montañosos, véase arriba).

1,525–2,000 m). The dominant habitat in the survey plots where coveys occurred is shown in figure 4. With the exception of one survey plot, the dominant habitat was heather *Calluna vulgaris*, heath *Erica* spp., their combinations or combinations of heather and Pyrenean broom (*Cytisus oromediterraneus*). All coveys showed use of heather, heath or both categories, with other categories in minor proportions: screes (40% of the coveys), junipers (26%), grassland (33%), bilberry (*Vaccinium myrtillus*) and raspberry (*Rubus idaeus*), forest plantations and Pyrenean broom (20%) and natural forest (13%) (table 3, fig. 1s in supplementary material).

At the 24 plots where breeding birds occurred, we established different levels of extinction risk considering habitat quality, the number of threats identified and their impact, recording high risk of extinction in 6 plots (25%), high-medium risk in 9 (37.5%), and low-very low risk in the remaining 9 (37.5%). The most important threats considering those of high impact within the 24 plots were: natural forest expansion ( $n = 9$ ), pine tree plantations ( $n = 7$ ), tracks and roads ( $n = 7$ ), fragmented and reduced habitat ( $n = 7$ ), wind farms ( $n = 5$ ), red-legged partridge walked-up shooting at hunting grounds within (or very close to) plots where accidental/illegal hunting may occur ( $n = 4$ ), human disturbances related to outdoor activities coming from tracks and roads ( $n = 4$ ) and pigeon hunting ( $n = 3$ ) (fig. 2s in supplementary material). We detected 21 different coveys of red-legged partridges, which were observed at a mean altitude of 1,610 m (range 1,450–2,050 m). We recorded a mean brood size of 5.5 (range 3–9). Red-legs showed a different pattern

of habitat use compared to PGP, as they were detected in open habitats such as grassland and crops, but also in shrublands and even forest.

#### Movements and home ranges

The cage-traps were set in the mountains of Cameros, and we caught two adult male birds for radio-tracking: the first in May 2009 ('bird 1' after 32 days of trapping) and the second in May 2010 ('bird 2' after 7 days of trapping) (fig. 2).

For both birds, radio-tracking lasted until the battery ended (approximately 300 days), and 77% of fixes were recorded within 100 m from bird's real location. Neither of the birds paired up, though bird 1 joined a covey of 5 PGP in autumn. Both birds were located in areas where breeding was confirmed.

We obtained 164 locations for bird 1 from May–November, and during this period the bird had a total home range of 1,770 ha. However, bird 1 used mainly three areas and conducted three movements between them (4.5, 7.1, and 10.1 km), hence we calculated home range values (MCP 95%) for each of the areas: 64.43, 38.57 and 0.12 ha respectively. For bird 2, we obtained 84 locations during the same period, and the bird used a main area of 60 ha, conducting two movements of 8.5 and 4 km within the same area, and staying in the upper parts of the mountains for brief periods of time (< 7 days) (table 4). Regarding shorter movements between consecutive days (daily inter-fix distance,  $n = 52$ ), the average distance merging both birds was 220 m (range 0–1,105 m). Birds were located at an altitude between 1,790 m



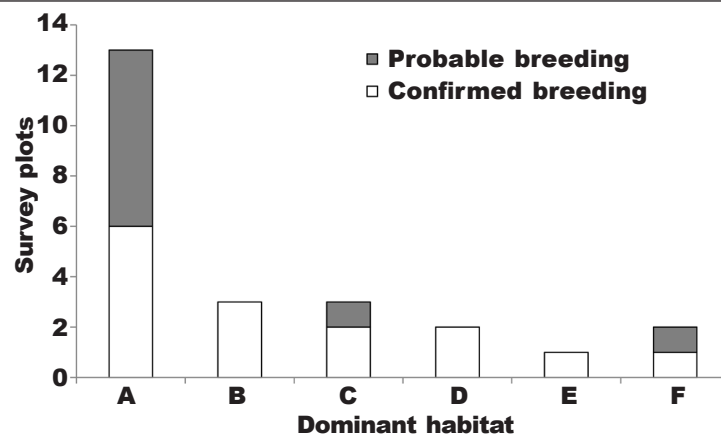


Fig. 4. Dominant habitat in the survey plots where confirmed and probable breeding occurred: A, *Calluna vulgaris*; B, *Erica* spp.; C, *Calluna–Erica* spp.; D, *Calluna–Cytisus*; E, *Erica–Cytisus*; F, *Cytisus*.

Fig. 4. Hábitat dominante en los sectores en los que se registró reproducción segura o probable. (Para las abreviaturas de hábitats dominantes, véase arriba).

and 2,000 m, and in winter both birds remained in areas covered by snow, including summits, and conducted small altitudinal movements. The exception was a location of bird 1 during a brief period of time at 1,500–1,600 m, after heavy snow. Radio-tracking continued during the winter months, but owing to the limited access, fixes were conducted once every fortnight. The habitat used by radio-tracked birds was in general mountain shrublands with a height higher than 50 cm and a percentage cover higher than 70%. In 51% of locations the habitat used was heath (mainly *E. australis* and but also *E. arborea*), followed by heather (36.5%), Pyrenean brooms (8%) and the remaining 4.5% were locations in open habitats, i.e. grassland and screes. No locations were recorded in dense forest. Birds were mainly located on slopes ranging in incline from 25–50% (44% of locations) and 10–25% (35% of locations), with the remaining 21% of locations on slopes shallower than 10%, with no locations above 50%.

## Discussion

The population of PGP in the Soria province has undergone a marked decline, as at the time this study was conducted, the species occurred in 20% of the historic range. It was estimated that from 1998–2008, the species became extinct in 30% of the territory. The fact that breeding was confirmed in only 5,550 ha is concerning and supports the recent change of conservation status to 'at risk of extinction'. We do not know whether this negative trend has continued, but the last monitoring conducted in 2017 in the mountains of Urbión confirmed the occurrence of the species in half of the survey plots where birds were detected during the study presented here.

We agree with previous studies evaluating the PGP populations in Spain and in Castilla y León (Lucio et al., 1992; Robles et al., 2002), which also suggested that the conservation status of the Iberian System PGP population was worse than that of the populations in the Pyrenees and the Cantabrian Mountains. As is well known for other species at the limit of their range (Sexton et al., 2009), PGP in the Soria province would be especially sensitive to habitat changes and disturbance, and hence the conservation of these populations should be prioritized.

In the breeding habitat of Soria province where PGP still occur, the mean spring partridge density was 2.3 pairs/1,000 ha, and the autumn density was 6.8 birds/1,000 ha. These values were lower than those recorded in the north-western part of the Iberian System (Burgos province) by Ansola et al. (1990), 7.5 pairs/1,000 ha, and far from the values for the Cantabrian Mountains and the Pyrenees, which are around 10–20 spring pairs/1,000 ha and above 100 birds/1,000 ha in autumn (Birkan and Jacob, 1988; Llamas and Lucio, 1988; Novoa et al., 2008). The age ratio was 3.1, the average number of juveniles per covey was 3.5, and both values were within the range of those recorded in the Pyrenees (Novoa, 1999; Novoa et al., 2008), where in recent decades the age ratio lay between 1.3 and 4.7 young per adult. Interestingly, around 50% of adult birds detected did not reproduce, and breeding was not confirmed in the two radio-tracked birds. We do not know whether this was a year effect, but we cannot exclude that this population is affected by a demographic trait hampering breeding success, possibly attributed to isolation and the lack of exchange of individuals from other sub-populations (Eberhard, 1991).

The combination of survey methods proved effective at detecting birds in our study site, with the most



Table 4. Main results from radio-tracked birds, including the characteristics of the sites where birds were located: \* bird located outside site D, but it was not possible to calculate home range.

Tabla 4. Principales resultados obtenidos de las aves marcadas con emisores de radiofrecuencia y características de los lugares en los que fueron localizadas: \* ave localizada fuera del lugar D y cuya área de campeo no se pudo calcular.

	Bird 1	Bird 2	Bird 1			Bird 2
			A	B	C	D
Catching date	May–2009	May–2010				
Survival (d)	300	300				
Number fixes (May–Nov)	164	84				
Home range (ha)	64.63	38.57	0.12			64.63
Altitude (m)	1,790	1,897	1,839			1,801
Period (days)	211	82	7			300*

effective methods being playback calls and pointing dogs. This is not surprising as PGP is elusive and inhabits mountains in which walked transects may not be practical, though a study conducted on Cantabrian PGP showed that snow transects were efficient as long as paved roads existed (González et al., 2017). Hence, those aiming to conduct accurate PGP surveys should prioritize playback calls in spring and pointing dog surveys in summer–autumn, while not discarding snow transects.

The majority of PGP detected during the surveys and the radio-tracked individuals were located above 1,690 m, with few locations in lower altitudes, except for movements during the breeding season and heavy snowfall (as recorded for the radio-tracked bird 1). The historic data from the Iberian System in this regard is limited, with observations from 1,100 to 1,960 m a.s.l., and the higher pair densities at a range of 1,700–1,800 m recorded 30–40 years ago (see the review in Lucio et al., 1992). It seems that PGP are now distributed in upper areas, especially coverts which may need the best possible habitat. This finding could be related to the habitat loss and fragmentation in lower areas.

As shown by Ansola et al. (1990), PGP mainly used mountain shrubland, i.e. *Calluna vulgaris*, *Erica* spp. *Cytisus* and their associations. Moreover, radio-tracked birds selected *E. australis* and *E. arborea*, followed by *Calluna vulgaris*, and these shrublands were at least 50 cm in height and the shrub canopy cover was > 70%.

Neither the radio-tracked birds nor the PGP seen during the surveys used open habitats (grassland) and forest, despite sparse trees being present within the areas where they occurred. According to the review of Purroy and Purroy (2016), the dominant vegetation in the PGP habitats in the Cantabrian mountains are broom (*Genista polygaliphylla* and *G. obtusiramea*) and fern (*Pteridium aquilinum*), together with *Erica australis* ssp. *aragonensis* and *Daboecia cantabrica*, while in the eastern Pyrenees breeding PGP select open and dense shrublands, including *Cytisus purgans* and *Juniperus communis* with a canopy cover higher

than 40% (Novoa et al., 2002). From our results, it is clear that PGP habitat requirements in the Iberian System differ slightly from those in other subpopulations.

Although only two birds were radio-tracked, the results provide valuable knowledge on PGP ecology, being the first published data of radio-tagged PGP outside the Pyrenees. In both birds, the radio-tracking was conducted until the battery ended, indicating 100% survival during the study period. With just two birds it is difficult to draw conclusions as previous studies have shown that the species can be affected by high levels of natural and non-natural mortality (Besnard et al., 2010). Regarding the home range of our birds, rigorous comparisons with data from Pyrenean birds are difficult because of the different study periods, as Novoa et al. (2006) calculated a MCP for spring pairs ranging from 118 to 126 ha (March–September), and core areas of 6.2–14.4 ha, finding differences before and after hatching and between paired and 'unpaired' birds. However, our results on movements are similar to those calculated by Novoa et al. (2006), who reported daily interfix distances ranging from 126 to 249 m, and also recorded longer movements up to 20 km (Novoa, 1999). As suggested by the studies from the Pyrenees, we agree that the long movement distances in spring/summer could be explained not only by migration from the wintering to the breeding habitats, but also by weather changes, though we detected only one movement related to heavy snowfall. Interestingly, in winter and during the snow period (when radio-tracking was difficult to conduct), birds tended to remain on summits and conduct short altitudinal movements. To obtain a better understanding of their behaviour, more birds should be radio-tracked (including hens and juveniles).

During the study, we identified anthropogenic threats within the survey plots. These included forest tracks, wind farms, hunting grounds and pigeon hunting, all possibly leading to disturbance and direct mortality at certain times of the year. These threats were already identified decades ago for the Iberian System, and they have been also identified in other PGP populations (Lucio et al., 1992). The overlap with

red-legged partridges at certain areas could have conservation implications for PGP as we cannot rule out the possibility that direct mortality and disturbance may occur on hunting grounds in which walked-up shooting is conducted. Hunters could perhaps be involved in the conservation of PGP through monitoring with pointers, as conducted in other PGP populations in France and Spain. Finally, the range overlap of these galliforms could favour inter-specific competition, as suggested in farmland habitats of France where red-legged and grey partridges occur and compete (Rinaud et al., 2020). However, this hypothesis would have to be further explored for the Iberian System.

Undoubtedly, the most important threat for PGP in Soria province was habitat loss and fragmentation. We confirmed that the historic breeding habitat area of 28,300 ha has been reduced to 10,300 ha, and just a half of this area held PGP at the time this study was conducted. This might be explained by the forest plantation policy conducted in many areas 20–50 years ago, together with the natural growth of existing forest, which has dramatically reduced the optimal breeding habitat for PGP in its entire range in Soria province, which is similar to the situation in other parts of the Iberian System (Lucio et al., 1992).

Radio-tracked birds clearly used mountain shrubland, now restricted to 'patches' surrounded by vast areas of unfavourable habitats, dominated by pine tree forest and grasslands, with poor or absent shrub coverage. Partridges moved between these patches, sometimes covering several km, using summits of high altitude as 'stopovers' where they were frequently observed. The severe habitat changes in recent decades have dramatically reduced the former suitable habitat. Partridges are now restricted to sub-alpine areas, avoiding areas that were suitable in the past, such as valleys and hills, where the species rarely occurs nowadays. Additionally, we observed that in some locations, mountain shrubland had been recently cleared to increase available grass for grazing cattle (supported by public subsidies), ultimately reducing the key habitat for PGP in the Iberian System. However, it has been shown that in other PGP territories where dense shrubland has been cleared, partridges are favoured by a more diverse habitat (Lucio et al., 1992). It is true that among the mountain ranges considered, the conservation status of PGP was better in Urbión and Cameros, possibly because these areas hold more favourable habitats than the others, and in the Moncayo, the species could be on the verge of extinction (or is already extinct) owing to the fact that this mountain is completely isolated from the others.

From 2009 onwards, several habitat management interventions dedicated to PGP conservation at small scale (< 100 ha) and promoted by the regional government, have been conducted at the study site and could be replicated in the current and former PGP distribution area. These interventions have consisted of: (1) protection of mountain shrubland (mainly *Calluna vulgaris* and *Erica* spp.) where breeding PGP occur; (2) clearing of planted pine tree forest to restore the former optimal shrubland; (3) clearing of pine trees in summits which act as natural corridors between the

different breeding areas; (4) restricted track access to vehicles within the breeding areas during the breeding season; and (5) dissemination campaign targeting hunters and other stakeholders who conduct activities in the breeding areas (conferences, project brochure and poster) (fig. 3s in supplementary material).

## Conclusion

In summary, to avoid grey partridge extinction in the Iberian System, the priority should be to protect the mountain shrublands in those areas where they still occur. To increase optimal habitat, it would be possible to restore shrublands in those areas that have been planted with pine trees or changed to grassland for livestock in recent times. Because the regional government in Soria has already conducted targeted management actions for the species and as the former distribution area has been mapped and fully analysed, the key areas in which actions must be taken are already known. From a practical point of view, efforts to restore the habitat of the PGP remain worthwhile and may be the most cost-effective way to halt the population collapse and increase the chances of its recovery. Additionally, monitoring should be conducted to evaluate the short- and mid-term effects of these actions on the population dynamics of the species, together with further studies to gain knowledge on the biology and ecology of this endangered galliform.

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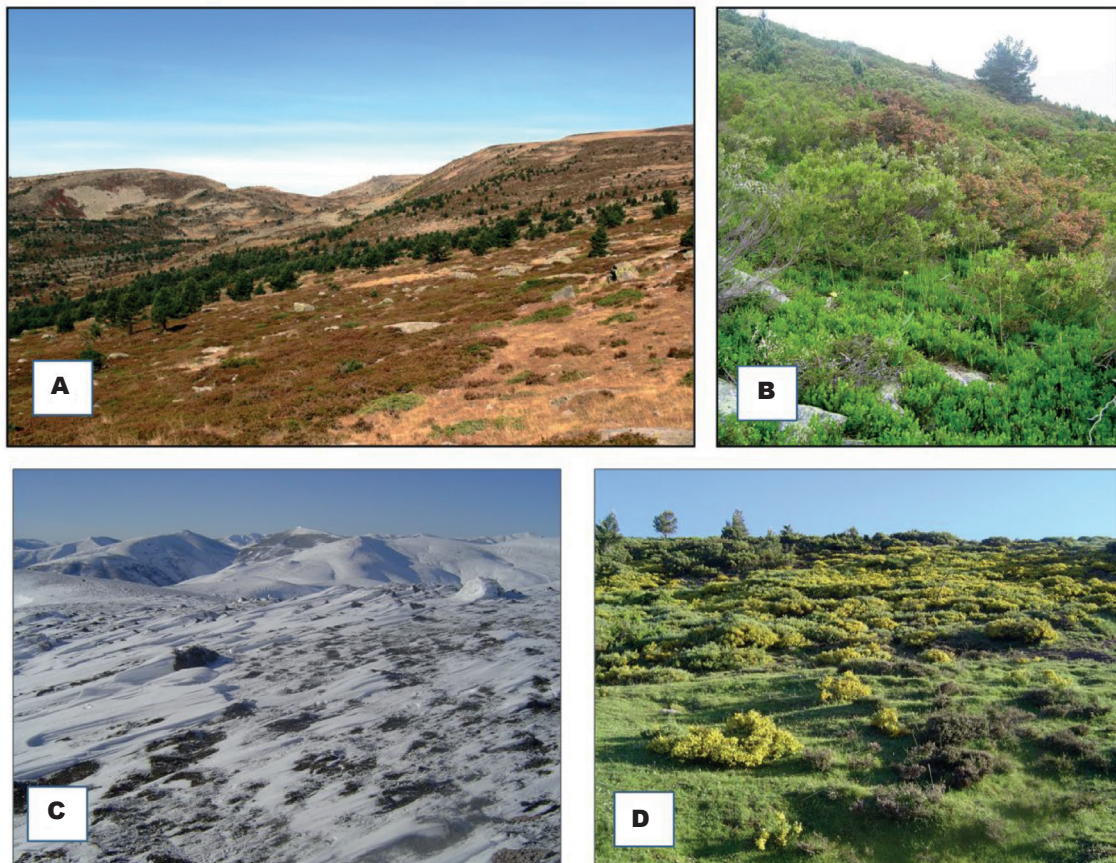
**Supplementary material**

Fig. 1s. Grey partridge habitat in the Soria province: quality breeding areas in Urbión (A), and up–River Tera (B), dominated by mountain shrubland (*Erica* spp. and *Calluna vulgaris*), and sparse pine trees as subdominant vegetation. View of the mountains of Cameros in winter (C), and suboptimal habitat dominated by *Cytisus* spp. in Cebollera (D).

*Fig. 1s. Hábitat de la perdiz pardilla en la provincia de Soria. Zonas con hábitats de calidad en Urbión (A) y alto Tera (B), dominadas por matorral de montaña (*Erica* spp. y *Calluna vulgaris*) y árboles dispersos como vegetación subdominante. Vista de las montañas de Cameros en invierno (C) y hábitat subóptimo dominado por *Cytisus* spp. en Cebollera (D).*

PLOT	WS	HB	TP	NF	TR	D	WF	OG	IS	RH	RISK
1				1							VL
2				1	2	1					LOW
3					1	1					VL
4				2							VL
5				2							VL
6				3							L
7		2		3	3	1		1		3	VH
8				1	1						VL
9				3		2		2	1	2	H
10				2					1	1	L
11				1		1					VL
12			2	1	2	1		1		2	H
13		3	3		3	2		1	1	3	VH
14			2	2	1	1		2	1	3	VH
15			3		2	1		1	1	3	VH
16*			3	2	1	1				1	H
17*	3	3	1		3	2	2	1	1		VH
18*		1	1	1	2	1		2	1		H
19*			1		1	1	1	1	1		M
20*	2		3	2	1		2		1	2	VH
21*	3		2		1		2		1	1	H
22*			1		1	1	2	1	1		M
23*	3				1	1	2		2		H
24*	1		1	1	1				3		M
<b>Total</b>	<b>12</b>	<b>9</b>	<b>23</b>	<b>28</b>	<b>27</b>	<b>19</b>	<b>11</b>	<b>13</b>	<b>16</b>	<b>21</b>	

Fig. 2s. Threats identified at each plot where coveys were detected and probable breeding occurred (\*): WH, walking-up hunting; HB, hunting blinds; TP, tree plantation; NF, natural forest expansion; TR, tracks and roads; D, disturbance; WF, wind farms; OG, overgrazing; IS, isolation; and RH, reduced and fragmented habitat. Each threat in each plot was categorized as low (score 1), medium (score 2) and high (score 3) depending on the possible impact on PGP. The risk of extinction was calculated as the sum of scores: VL, 0–2 very low; L, 3–5 low; M, 6–7 medium; H, 8–10 high; and VH, >10 very high.

Fig. 2s. Amenazas observadas en cada sector donde se detectaron grupos familiares y la reproducción era probable (\*): WH, caza en mano; HB, palomeras; TP, plantación de árboles; NF, expansión del bosque natural; TR, pistas y caminos; D, molestias; WF, parques eólicos; OG, sobrepastoreo; IS, aislamiento; RH, hábitat reducido y fragmentado. Las amenazas se clasificaron como bajas (puntuación de 1), medias (puntuación de 2) y altas (puntuación de 3) dependiendo de los efectos que pudieran tener en la perdiz pardilla. El riesgo de extinción se calculó como la suma de las puntuaciones: VL, 0–2 muy bajo; L, 3–5 bajo; M, 6–7 medio; H, 8–10 alto; y VH, > 10 muy alto.



Fig. 3s. Management measures for the conservation of Iberian grey partridges in Soria province, promoted by the *Junta de Castilla y León*. Clearing of pine trees in an area with suitable habitat for partridges (showing cleared patches in the background view) (A), manual clearing at the same area (B), restricted access to breeding areas (C) and the brochure of the project (D).

*Fig. 3s. Medidas de gestión para la conservación de la perdiz pardilla en la provincia de Soria promovidas por la Junta de Castilla y León. Clareos de pinos en un área óptima de reproducción (se pueden observar los "parches" al fondo) (A), clareos manuales en la misma zona (B), restricción de acceso a las zonas de cría (C) y folleto del proyecto (D).*