






Original Article

Population parameters of an expanding Iberian wild goat population in Southern Pyrenees, Spain

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Abstract: The escape and establishment of Iberian wild goats, *Capra pyrenaica*, from an enclosure in the 1990s marked the beginning of the recovery of the species in the Pyrenees. This population has occupied part of the Prepyrenees and has contacted another population reintroduced in France since 2014. It coexists with other wild ungulates, including the feral and domestic goats *Capra hircus* that has been living free since the 1960s. Today it's the largest Iberian wild goat Pyrenean population. Between 2006 and 2022 we monitored the population and its expansion based on vantage points, itineraries and testimonies. The results indicate: (i) a population, of uncertain genetic origin, in numerical (15% average annual growth) and areal expansion, with the capacity to connect with other populations; (ii) an estimate of at least 500 individuals; (iii) in the process of expansion in contact with Iberian wild goats from France; (iv) sympatry with feral and domestic goat population in its main nucleus whose estimate exceeds 2000 specimens and (v) hybridization with feral and domestic goats. In 2022 sustainable hunt started with a hunting quota of 20 individuals. Genetic characterization and the

establishment of an international coordinated monitoring are two of the current priorities.

Keywords: Escape; Reintroduction; Recovery; Hybridization

1 Introduction

The Iberian wild goat *Capra pyrenaica* is an endemic Caprinae whose populations today occupy many areas of the Iberian Peninsula. Two subspecies were extinguished, *C. p. lusitanica*, in the 19th century and *C. p. pyrenaica* in the year 2000 (García-González et al. 1999). The current living subspecies are *C. p. victoriae*, which occupies the center and NW of the peninsula and *C. p. hispanica* which lives in the E and S (García-González et al. 2022). The bases of this taxonomic classification were the body size, the shape and size of the horns, and the pattern of the black coat in males (Cabrera 1911). Currently, various studies point the need for a new classification in which the existence of subspecies is not accepted by specialists (Villalta et al. 1997; Manceau et al. 1999). Most of its

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populations are expanding throughout their range (García-González et al. 2022).

It can be described as a gregarious, polygynous species with marked sexual dimorphism, which is characterized by its high adaptability to different types of environment. It inhabits from sea level to 3,000 m a.s.l. and the only characteristics common to the habitat of all its populations is the dependence on the slope or the rocky substrate (Fandos 1991; Alados and Escós 1996; Pérez et al. 2002; Lucas et al. 2016; Ganados et al. 2007).

It has been a species very persecuted by man, either indirectly through the pressure of livestock or through indiscriminate hunting, reducing dramatically its numbers and populations. These population bottlenecks have resulted in one of the main causes of threat that the species currently faces: the low genetic variability of its populations, which produces a high vulnerability to diseases (Granados et al. 2007), particularly sarcoptic mange *Sarcoptes scabiei*. It is considered as Least Concern (LC) by the International Union for the Conservation of Nature (IUCN) and is a huntable species in Spain, but not in Andorra, France and Portugal. Its exclusive hunt produces important revenues to local hunting grounds and private owners (García-González et al. 2022).

At the end of the seventies of the last century (1977-80) an indeterminate number of Iberian wild goats (more than 20) were transferred from the Sierra de Cazorla (Region of Andalusia) in the south of the Iberian Peninsula, to a hunting enclosure in the current Sierra and Cañones de Guara Natural Park (GNP) (Fandos et al. 2022), Region of Aragon (Fig. 1). If there have been more releases and if they were of different genetic origin, remains unknown. Since at least the nineties a population established outside the enclosure and from 2006 onwards it is monitored annually (Herrero et al. 2013).

From 2014 to 2022, the Region of Madrid has sold Iberian wild goats to the Parc National des Pyrénées (PNP), to the Parc Naturel Régional des Pyrénées Ariégeoises (PNA), both in France, and Aran, in Spain (Garnier et al. 2021). These animals came originally from the Central Mountain range of the Iberian Peninsula, so they had a different genetic origin. Some of the individuals released in France have spread to the Southern slope of the Pyrenees, in Spain, and established there. Releases are expected to continue in the coming years.

The objective of this work is to describe the

demographic characteristics and the colonization process of the species in the Aragonese Pyrenees between 2006 and 2022 and contribute with this information to its sustainable use.

2 Material and Methods

2.1 Study area

The study area was the GNP ($42^{\circ}16'38''N$; $0^{\circ}7'59''W$) and as the consequence of the expansion, the rest of the Aragonese Pyrenees (Fig. 1).

GNP covers a 40-km-long S Prepyrenean E-W mountain range of 81,494 ha, ranging between 430 m and 2077 m. The landscape has a steep rough relief. Half of the surface consists of shrubs (*Echinospartum horridum*, common juniper *Juniperus communis*, common box *Buxus sempervirens*), one fourth consists of forest (mainly holm oak *Quercus ilex*, Scots pine *Pinus sylvestris*, Austrian pine *Pinus nigra*, downy oak *Quercus cerroides*, mountain pine *Pinus uncinata* and beech *Fagus sylvatica*, in decreasing order of importance), and one-fourth has rocky substrate. Hunting is not allowed in about one-fourth of the park, and the remainder comprises hunting grounds managed by local hunters. The origin of the wild goats' escape was a fenced hunting ground. Other huntable wild ungulates in the area are wild boar *Sus scrofa*, roe deer *Capreolus capreolus*, red deer *Cervus elaphus*, European mouflon *Ovis aries*, fallow deer *Dama dama* and feral goat *Capra hircus*.

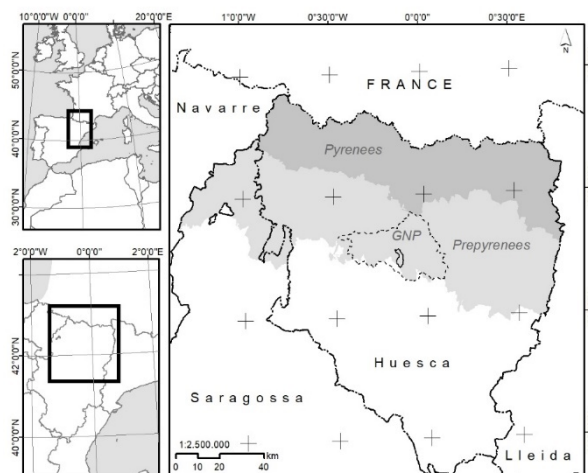


Fig. 1 Aragonese Pyrenees. Dark grey: High Pyrenees; Light grey: Prepyrenees; GNP: Guara Natural Park. The polygon inside the GNP is the fenced hunting ground, origin of the Iberian wild goat population.

2.2 Field survey

Field surveys were undertaken by rangers of the Regional Government of Aragon and ourselves with the occasional help of volunteers. Three kinds of samplings were done filling up a specific sheet: occasional sightings, additional surveys and coordinated survey. Occasional sightings reported animals seen randomly which represented valuable data (new areas, large groups). Additional surveys were done specifically to explore new areas or confirm testimonies. Testimonies of non-professionals played a key role in the localization of new occupied areas.

For the coordinated survey we followed vantage points (Reiger and Robson 1967; Nievergelt 1981) and itineraries (block counts) to localize Iberian wild goats using binoculars and spotting scopes. Surveys were done when Iberian wild goats were more active (Escós and Alados 1988) during 3 h after dawn (2006-2022) and in late afternoon (only in 2006 and 2007). The vantage points were selected considering spots with good accessibility and visibility (Fig. 2).

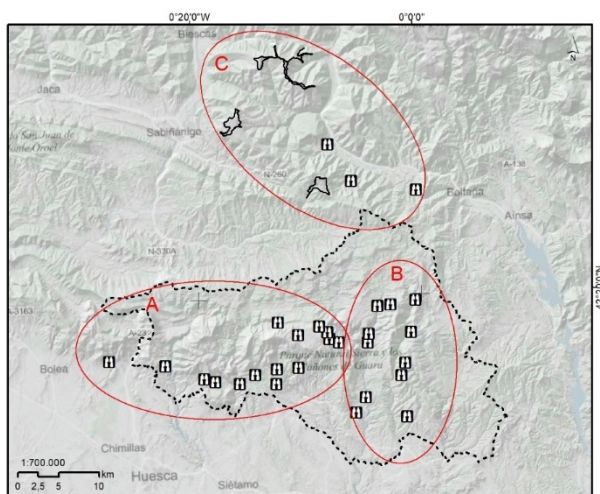


Fig. 2 Vantage points and itineraries for Iberian wild goat monitoring in Guara Natural Park (GNP) and neighbouring areas in 2022. Red circles indicate the three subpopulations considered for the estimation: A-Guara, B-Balced, C-Sobrepuerto.

Sex and age of the animals were recorded, assigning individuals to one of the following age-sex classes, based on horn size and shape and other physical characteristics: kids, 1- and 2-year-old yearlings, adult females, young males (3 – 6 years), middle age males (7-10 years), and old males (> 10 years). This allowed to describe population structure, productivity in June (kids/adult females) and sex-ratio in November (adult males/adult females).

Between 2006 and 2012 four annual surveys were undertaken (before parturition, April; after parturition, June; before rut, October, and during rut, November-December). Due to economic restrictions between 2013 and 2017 three annual surveys were done (after parturition, before rut and rut). Since 2018 and because of population increase the number of annual surveys was reduced to after parturition and rut, but the number of fixed points were increased, Iberian wild goats were counted from 29 vantage points and five itineraries (Fig. 2).

Three main subpopulations areas were defined: Guara, Balced and Sobrepuerto (Fig. 2). For the estimation of the minimum number of living animals for each of them we combined the results of all the counts in each annual survey. This allowed to calculate the trend. Guara, the source, was colonized since the early ninties, probably before, Sobrepuerto and Balced since at least 2007.

2.3 Trend

Changes in the annual number of Iberian wild goats as a function of time were analyzed using Poisson regression (Kleinbaum et al. 1988; Doménech and Navarro 2005), in which the dependent variable was a count that followed the Poisson distribution. We defined a generalized linear model fit with the GLM procedure of R (R Development Core Team 2012), with the response variable given by the annual count of Iberian wild goat, a Poisson error distribution, and a natural log link function for the exponential growth model, for which the parameter b can be interpreted as r or the intrinsic rate of increase, and λ coming from the r neperian antilog (Herrero et al. 2013).

2.4 Cartography

To carry out the cartography that illustrates the study area, various thematic layers of digital cartography provided by the Government of Aragon were used. From these layers, some parameters have also been calculated using a Geographic Information System (GIS). Pixel size defined the resolution with which we have worked with the layers in Raster format of the digital elevation model (DEM), 20 m on each side. The slope was calculated from that DEM of the study area. The maps of the itineraries were made using the 1:25,000 scale sheets of the National Geographic Institute in digital format, which occupy

the study area, and using orthoimages belonging to the National Plan of Aerial Orthophotography of the Ministry of Development of Spain (2006). The digitization of the goat locations has been carried out directly on the screen on these maps or by calculating the coordinates with the help of the orthoimages of the SIGPAC Viewer.

2.5 Population estimation

A minimal count has been made and divided by the observed area, resulting in a minimal density. The viewshed area was calculated, with a limit of 2,500 m, for each of the vantage points (VP) located within the GNP. To calculate the total area, the existing overlaps in the individual VP were eliminated. The average density after the parturition and during the rut was calculated, and it was multiplied by the area of the GNP with a slope >30% (28,966 ha), following the methodology proposed by Prada et al. (2019), who considered this surface as suitable habitat for the presence of Iberian wild goats. To this estimation we added the results of block counts in Sobrepuerto and testimonies of animals localized at great distances.

2.6 Colonizing process

The colonization process is described from the information generated by the testimonies and its verification as well as that of the participants in the survey (occasional sightings). The annual Maximum Convex Polygon (MCP) was calculated annually

including all the sightings.

2.7 Coordination meetings

Every year during the spring and before the beginning of the field work, the follow-up was the subject of an annual meeting for coordination and presentation of results. The attendees were: rangers, technicians and ourselves. Demographic and sanitary results were discussed together with the field work calendar.

3 Population Parameters

3.1 Population trend

The average annual growth rate (λ), calculated with the minimum number of Iberian wild goats observed from the vantage points in the GNP and surrounding areas, was 15.6% (95% CI: 14.5-16.8) (Fig. 3).

3.2 Sex-ratio, productivity and MCP

Table 1 shows the main demographic parameters and the trend of sex ratio (Fig. 4), (without significant trend, mean of 1.4 males per female; 95% confidence interval 1.1 to 1.6; $n=8$) and productivity (decreasing significantly; mean of 0.48 kids per female; 95% confidence interval 0.37 to 0.59; $n=8$), since 2015, when the population was higher than 100 animals. The MCP surface has increased steadily since 2015 mainly

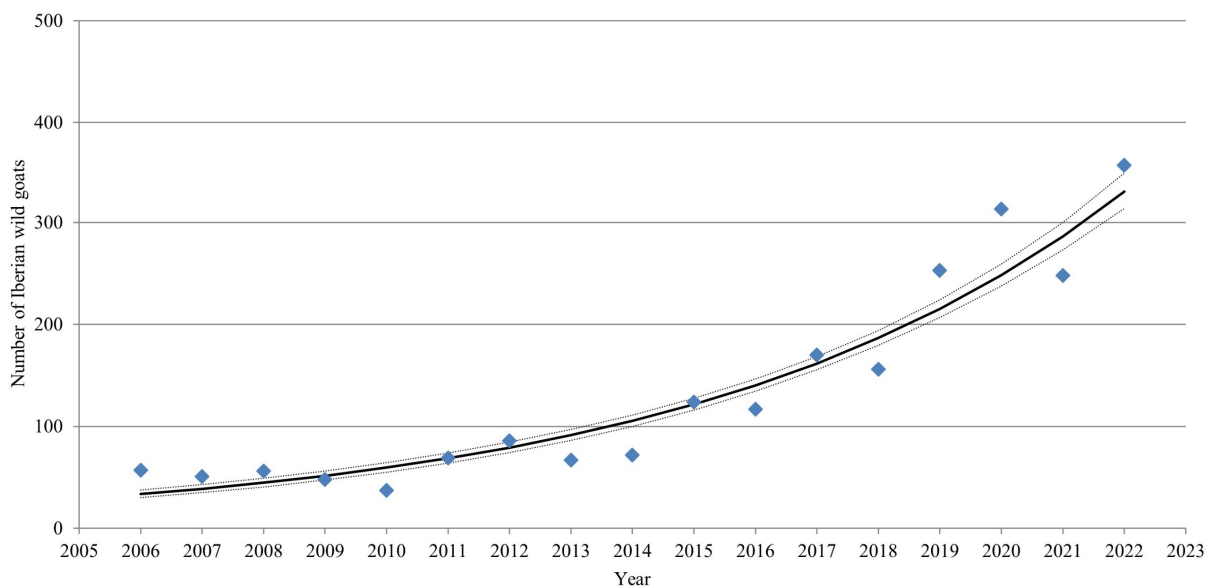


Fig. 3 Iberian wild goat trend in GNP and surrounding areas, 2006-2022.

due to the presence of Iberian wild goats of French origin in the N (19% average annual increase rate; $r^2=0.5$; $p<0.001$; $n=17$; Fig. 5).

3.2 Density estimation for Iberian wild goat and feral goat

It was calculated between 2018 and 2022 for the GNP using the 25 vantage points and its viewshed area truncating at 2,500 m of distance. The total sampled surface was 9,779 ha of its 47,638 ha (20%) with 289.66 km² of suitable habitat (slope over 30%) (Table 2). The variation in numbers show oscillation in density estimation, not a real decrease or increase of the population.

3.3 Sympatry with other wild and domestic ungulates

Iberian wild goats form groups on their own but can coincide with other wild ungulates. This happens with animals living alone and with normal herds during the rut (Fig. 6). In the first case, they can gather with cows *Bos taurus* in summer pastures (1 case), domestic goats (1 young female), domestic goats and sheep (1 young male) or feral goats (1 young male, 2 cases). In the case of feral goats' relation lasted several years in 1 case. No competence interactions were observed between domestic and Iberian wild goats.

Table 1 Population structure and Maximum Convex Polygon (MCP) of Iberian wild goat in GNP and neighboring areas, 2006-2022

Item	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Males	14	25	28	25	17	31	35	22	14	40	42	71	84	116	136	126	143
Females	22	17	16	13	12	22	35	30	24	46	37	53	37	82	104	73	120
Yearlings	6	1	5	6	2	10	9	11	8	11	10	11	9	11	26	17	25
Kids	15	8	7	4	6	6	7	4	4	27	27	26	18	26	44	31	42
Undetermined									22		1	9	8	18	3	1	26
Total	57	51	56	48	37	69	86	67	72	124	117	170	156	253	313	248	356
Sex ratio	0.6	1.5	1.8	1.9	1.4	1.4	1	0.7	0.6	0.9	1.1	1.3	2.3	1.4	1.3	1.7	1.2
Productivity	68	47	44	31	50	27	20	13	17	59	73	49	49	32	42	42	35
MCP (km ²)	35	79	176	231	191	380	171	471	93	132	790	500	400	788	1,490	3,425	2,132

Table 2 Population estimation of Iberian wild goat and feral goat in GNP, 2018-2022

Item	Iberian wild goat					Feral goat				
	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
Density (km ⁻²)	1.6	1.9	2.4	1.4	1.7	6.6	6.6	7.2	4.3	2.5
95% confidence interval of the mean	0-3.4	1-2.8	1.2-3.6	0.6-2.3	0-3.6	2.2-11	3.6-9.6	1-13	1-8	1.4-3.7
Total goats	456	544	689	416	499	1,925	1,911	2,085	2,245	1,063

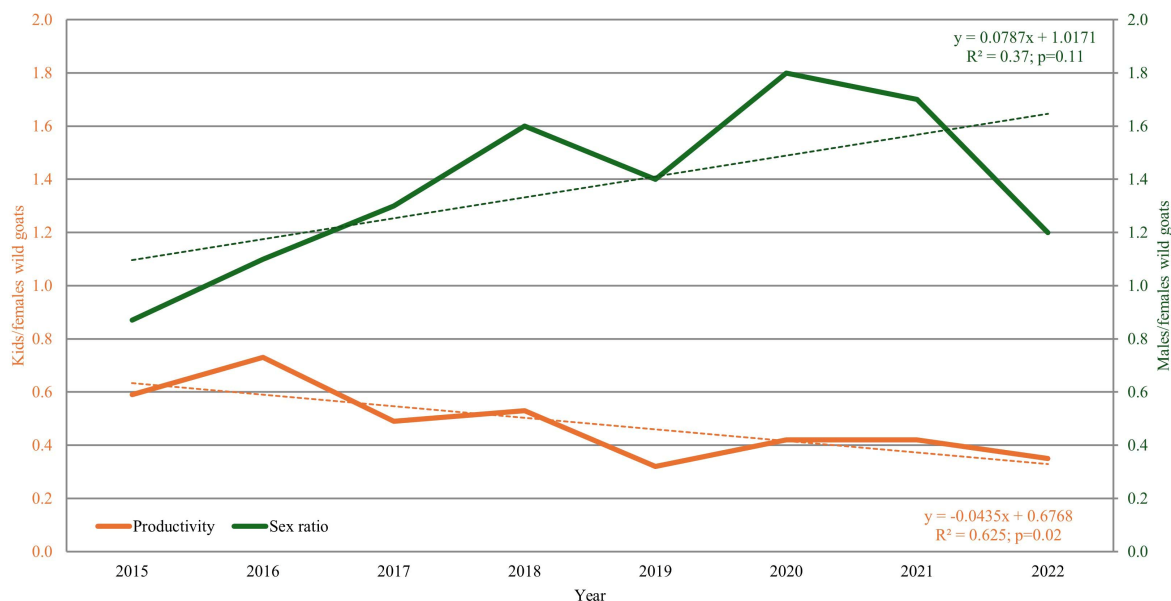


Fig. 4 Iberian wild goat sex ratio and productivity in Guara Natural Park (GNP) and neighbouring areas, 2015-2022.

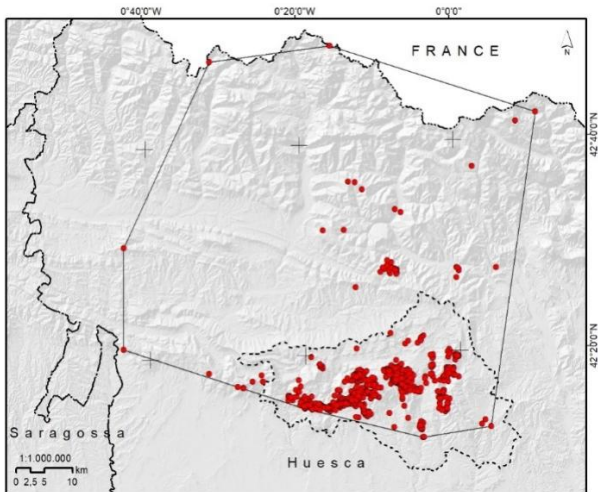


Fig. 5 Maximum Convex Polygon (MCP) of Iberian wild goats in the Aragonese Pyrenees, 2006-2022. Red spots represent all the sighted groups.



Fig. 6 Coexistence of a young Iberian wild goat male together with domestic goats and sheep. Photo: Carlos Puyuelo.

3.4 Hybrids between Iberian wild goat and domestic goats

A possible hybrid female with kid (Fig. 7) and the first record of a leucistic male for the species (Fig. 8) were observed. See Fig. 9 for a herd of Iberian wild goat to compare both species.

3.5 Hunting quota of Iberian wild goat

In 2022 due to the population increase in number, a hunting quota of 20 Iberian wild goats was decided for the GNP.

4 Discussion

The demographic characteristics (sex ratio, density, productivity trend) of Iberian wild goat living in southern Pyrenees appear to be in the range of the



Fig. 7 A possible hybrid female with her kid. The female has intermediate characteristics between domestic goat and Iberian wild goat. Photo: Alicia García-Serrano.

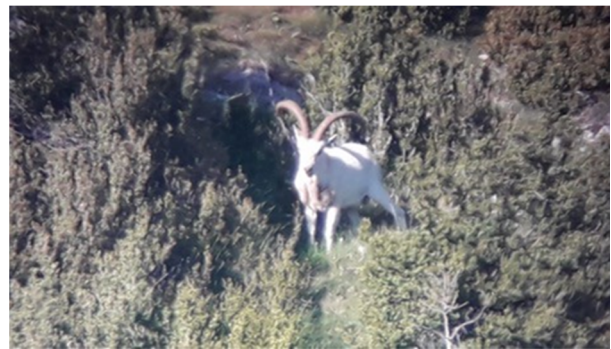


Fig. 8 A leucistic Iberian wild goat male in the GNP. Photo: Rafel Vidaller.



Fig. 9 Iberian wild goats with kids, females and males. Photo: Alicia García-Serrano.

rest of populations of the species (García-González et al. 2022; Refoyo et al. 2025a, b; Granados et al. 2020; Garnier et al. 2021; Ruíz-Olmo et al. 2023). It has increased in number and distribution, has contacted the population coming from France and it is the most abundant in the Pyrenees. The decrease of productivity could be due to the stabilization of the population in its main nucleus, the GNP. The expansion to the north of

the population from the Iberian mountain range and the Middle Ebro Valley leaves this population at less than 50 km from the Pyrenean one so they will contact the near future, following a stepping stone dynamic (Lucas et al. 2016). This will represent a mixture of at least three different genetic origins.

The existence of hybrids with domestic goats has been reported for Alpine ibex (Giacometti et al. 2004) and for free Iberian wild goats (Nores and Vázquez 1987; Cardoso et al. 2021). Even if this seems to be an old process due to the more than 7,000 years of sympatry, the existence of an abundant feral goat population, may represent a problem for the genetic integrity of Iberian wild goat in the Pyrenees. The control or eradication of ferals in the Pyrenees should represent a priority in order to favour the conservation and recovery of the Iberian wild goat (Pérez et al. 2012).

The population structure is comparable to that of other populations of the species. Productivity is stable, with annual oscillations, and the sex ratio does not vary significantly. Old males are scarce. The population is increasing in number and expanding and has already contacted the introduced wild goats from France. The Iberian wild goats of the Middle Ebro Valley are less than 50 km away and are also expanding, so both populations will contact in the future.

Iberian wild goats coexist with domestic and feral domestic goats. There are hybrids of both species. Feral goats are more abundant than Iberian wild goats in GNP. This is a new and potentially important problem for Iberian wild goat genetic integrity. There is no information on the genetic characteristics of Iberian wild goats of the Aragonese Pyrenees, in terms of diversity, origin and domestic goat interbreeding. Moreover, it should be considered that feral goats and even domestic goats may be a limiting factor for the growth of the Iberian wild goat population, since they presumably compete for the same habitat and trophic resources.

This new dynamic situation deserves both national and international attention in order to promote coordinated efforts for its monitoring (demographic, sanitary, genetic) conservation and sustainable use. Our results contribute to the conservation of the Iberian wild goat population in the Pyrenees providing updated information on its population which allows its sustainable use.

5 Conclusions

Iberian wild goats escaped from an enclosure in

Southern Pyrenees, Spain during the 1990s. Since then the population has increased in number and colonized the mountain range, reaching at least 500 individuals in 2023. This recovery process continues nowadays. The species lives in sympatry with other wild ungulates, including feral and domestic goats, representing the largest Iberian wild goat Pyrenean population. Population characteristics are in the range of the rest of Iberian populations, showing the adaptation to this new environment. The genetic origin is of at least one population coming from southern Spain, but other origins cannot be discounted. After 2014 Iberian wild goats have been released on the Northern part of the Pyrenees, in France, and both populations have contacted. The coexistence of both domestic goats and Iberian wild goats has led to the existence of hybrids process, as occurs with other wild goat species. The sustainable hunt of the population started with a hunting quota of 20 individuals.

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Author Contributions

Conceptualization, JH and AGS; methodology, JH and JHS; software, AGS; cartography, CP; formal analysis, AGS; field work, JH and AGS; resources, AGS; data curation, AGS; writing—original draft preparation, JH; writing—review and editing, JH, AGS, CP, RGG; project administration, AGS; funding acquisition, AGS. All authors have read and agreed to the published version of the manuscript.

Ethics Declaration

Availability of Data/Materials: Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest: The authors declare no conflict of interest.

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