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FACTORS AFFECTING WILD RABBIT PRODUCTION IN EXTENSIVE BREEDING ENCLOSURES: HOW CAN WE OPTIMISE EFFORTS?

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Abstract: The declining rabbit population in the Iberian Peninsula has led hunters and authorities to rear rabbits in captivity systems for their subsequent release. One alternative method to intensive rabbitry systems is the use of extensive breeding enclosures, since they produce animals of greater quality for hunting and conservation purposes. However, some of the factors that affect rabbit production in breeding enclosures are still unknown. The present study used partial least squares regression (PLSR) to analyse the effects of plot size, scrub cover, slope, initial rabbit abundance, the resources needed to dig warrens, predation and proximity to other enclosures on rabbit abundance. The results of our study show a positive effect of the number of other fenced plots within a radius of 3 km, a positive relationship with the availability of optimal resources for building warrens and a positive influence of intermediate values of scrub cover. According to our results, to maximise rabbit production in the enclosures it would be advisable to concentrate the restocking effort by ensuring that the restocking plots are close to each other, thus avoiding isolated enclosures. Furthermore, the selection of plots with an appropriate scrub cover and high availability of elements that favour the construction of warrens, such as large stones, sloping land or tall shrubs, may optimise results.

Key Words: captive breeding, *Oryctolagus cuniculus*, extensive system, wild rabbit.

INTRODUCTION

The decline in the wild rabbit population is a major concern in Mediterranean ecosystems, where rabbit is one of the principal game species and an important prey for over 30 Iberian predators. The interest in wild rabbit production for releasing purposes has therefore increased over the last few decades (Sánchez-García *et al.*, 2012). In fact, Sánchez-García *et al.,* 2012 reported that the proportion of rabbits released in Spain that had been reared in captivity might exceed 50% of the total number of wild rabbits released.

Captive breeding of wild rabbits is normally carried out in intensive systems, but this process is difficult and not very productive owing to high stress levels, behavioural problems (González-Redondo and Zamora-Lozano, 2008) and the low reproduction rate (González-Redondo, 2010). Semi-extensive breeding systems have attained higher productivity (Arenas *et al.*, 2006), but these smaller enclosures (500-800 m^2) fail to reproduce natural conditions and the animals reared in these enclosures might not therefore be appropriate for the purpose of release. In theory, the most appropriate system in which to produce wild rabbits for the purpose of release is extensive production in higher enclosures, since they simulate natural environmental conditions (food availability, soil type and aerial predator pressure), thus enabling the establishment of social interactions and the development of a dietary pattern and anti-predatory behaviour (Díez and Pérez-Garrido, 2003).

For these reasons, setting up extensive captive rabbit breeding enclosures has become a widely used technique in conservation projects over the last few years (Ferreira and Delibes-Mateos, 2010). However, the importance of certain logistic issues such as enclosure sizes, the number of enclosures to be created or the distances between them and their effect on further rabbit abundance, is not well known. These factors are undoubtedly of great practical importance in optimising rearing success, owing to the fact that the high cost of fenced plots makes it difficult for private owners to afford them. Here we show the results of a wild rabbit restocking project in which we analysed the

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data from 23 semi-extensive captivity breeding enclosures to evaluate the effect of the size of the plots, the distances between them, the presence of carnivores, the rabbits' ability to build their own warrens, the scrub cover and the slope on subsequent rabbit abundance.

MATERIAL AND METHODS

Study Area

This study was carried out in central Sierra Morena, Córdoba, in Southern Spain (Figure 1). The study area included different ecosystems: Mediterranean scrubland, pine forest and oak savannah (dehesa). There are 5 species of terrestrial predator: the red fox (*Vulpes vulpes*), the Egyptian mongoose (*Herpestes ichneumon*), the marten (*Martes foina*), the genet (*Genetta genetta*) and the wildcat (*Felis silvestris*); and 6 birds of prey: the Spanish imperial eagle (*Aquila adalberti*), the golden eagle (*Aquila hrysaetos*), the eagle owl (*Bubo bubo*), Bonelli's eagle (*Aquila fasciata*), the booted eagle (*Hieraetus pennatus*) and the buzzard (*Buteo buteo*).

Rabbit release protocol and enclosures features

Twenty-three fences (range: 0.5-7.7 ha) were built throughout the year 2008 in the study area (Figure 1). All plots were fenced 0.5 m below ground and 1.7 m above ground, with 2 electric wires at a height of 30 and 150 cm above ground level. Several artificial warrens made of pallets (3.5±0.4, mean±standard error) were built in each plot. Water and food (grain mixture) were also supplied *ad libitum* throughout the year. The donor rabbit population was high density and located in an agricultural area in the south of Córdoba province, and the release areas were located in the north of the same province (Figure 1). Both areas lie within the distribution limit of the genetic lineage traditionally associated with the sub-species *Oryctolagus cuniculus algirus* (Branco *et al.,* 2000). The rabbits were translocated in October 2008 and the animals were mainly adults. Ferrets were used to capture the rabbits from their warrens in the morning; they were then immediately transported in commercial boxes to the release fences with no vaccines, acclimation period or quarantine. The gender ratio was approximately 2:3 (males:females) in each fenced plot (0.62±0.01); the number of rabbits released ranged from 75 to 90 rabbits per hectare and the animals were released inside the artificial warrens. All capture, transport and release processes were carried out by the same staff from the Andalusian Government Environmental Service.

Rabbit abundance

Rabbit abundance was estimated from November 2008 to July 2009 through the use of monthly pellet counts in fixed 0.5 m^2 circular sampling points (Fernández de Simón *et al.*, 2011) in a 20 m^2 grid located in the centre of the

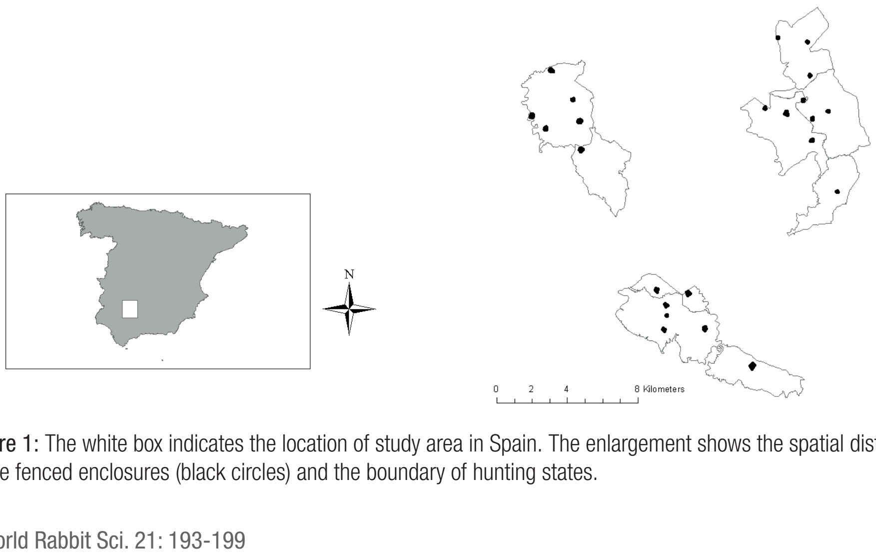

Figure 1: The white box indicates the location of study area in Spain. The enlargement shows the spatial distribution of the fenced enclosures (black circles) and the boundary of hunting states.

enclosure. The number of sampling points ranged from 15 in the enclosures of less than 1 ha to 30 in the largest one (more than 4 ha). Pellets were removed from the circular sampling plots after each count to ensure that only fresh pellets less than 1 mo old were counted. This way, a pellet abundance index was created through the average density of pellets per day and surface for each month and enclosure (pellets/m^2 per day). Since the objectives of the fenced areas were (1) to attain a high number of rabbits during the breeding season in order to permit them to later disperse into the surrounding area by opening the enclosures or by extraction, and (2) maintain a constant abundance to provide prey for endangered predators, the response variables selected were the maximum abundance achieved in each fenced plot (Model 1) and the mean rabbit abundance during the whole study period (Model 2).

Variables

Given that the rabbits released were slightly different in each enclosure, we included the initial rabbit density as the number of rabbits released per hectare. In the field, the critical period for rabbit restocking is the first few weeks after their release (Calvete *et al.,* 1997), so the abundance after this period of adaptation may be different in each fenced area and could affect further rabbit abundance. To account for this variation, the rabbit abundance 1 mo after release was also included in the statistical analysis.

The number of artificial warrens per hectare was also included in the models. The size of each enclosure was obtained by geo-referencing the corners using GPS and ArcGIS software (ERSI, Inc, Redlands, CA, USA). Since the rabbit enclosures had different slopes, the average slope of each fenced plot was included in the analysis, which was calculated through Horn's method (Horn, 1981), using the Digital Terrain Model of Andalusia (DTM, 10×10 m. resolution). To quantify the coverage of bushes, we performed 4 transects 50 m in length per hectare within the enclosures, where vegetation was characterised at intervals of 50 cm. The percentage of cover occupied by the scrub stratum was calculated by applying the point-line intercept method (Canfield, 1941). However, we included the scrub cover in the models as a categorical variable (1: 0-25%, 2: 25-50%, 3: >50%). To record the availability of optimum resources for warren building, we defined a categorical variable with 4 levels according to the presence of appropriate structure and protection (rocks, tall scrub or sloping land) in the enclosures: 1, low (<10%); 2, medium (10-25%); 3, abundant (25-50%) and 4, very abundant (>50 %).

Although the enclosures had 2 electric wires, they did not always prevent the entry of terrestrial predators. All the fenced areas were visited once per week during the study period and during these visits carnivore scats were annotated and removed. Model 1 shows the total number of scats found until maximum rabbit abundance and Model 2 included the total signs during the whole study period. In all cases, the mammalian predators were removed from the rabbit enclosures using live cage-traps.

An aerial predation index was also created. This was done by dividing the set of enclosures into 3 zones, in which a census of birds of prey was carried out at fixed points in the spring of 2009, with a total number of 21 h of observation in each zone over 3 d (Redpath and Thirgood, 1997; Rouco, 2008). The total amount of flight time of the birds of prey was divided between the total number of observation hours, thus obtaining the average flight time for each zone (Rouco, 2008). This variable was then included in the models. Finally, to test the effect of the presence of other restocking fenced plots in the surrounding areas, we applied different models that included the number of fenced areas within a 1, 2, 3 and 4 km radius of each enclosure.

Statistical analysis

Statistical analysis was carried out using partial least squares regression (PLSR). PLSR is a useful regression calibration technique when the number of predictor variables is similar to or higher than the number of observations and/or the predictors are highly correlated (Carrascal *et al.,* 2009), and it reduces the exploratory variables into a few components that have maximum covariance with the dependent variable. A PLSR should therefore be used to deal with the structure of our data with 23 cases and 10 exploratory variables. The number of significant components to be included in the model was selected following the cross validation test described in (Umetrics, 2012), through the cross-validation index (Q2), which was used to assess model significance (Q2>0.05 for significant model). Moreover, the regression coefficient (R^2Y) and the predictor set variance (R^2X) used for the PLSR model were also used to interpret the PLS regression model. To determine the influence of individual variables as predictors of maximum annual abundance in the PLSR model, we used the variable importance in the projection (VIP; Eriksson *et al.*, 1999; Umetrics, 2012). Exploratory variables with a VIP value of over 1 were considered to be more relevant in explaining the variation observed in the variable response (Eriksson *et al.*, 1999). In the 1st model, the response variable used was the maximum rabbit abundance reached in each breeding enclosure, and in the 2nd model, the response variable was the mean rabbit abundance throughout the period of study. Differences in rabbit abundance during the study period were tested by general linear models (GLM), with the month as categorical predictor and the enclosures as random factor. Post-hoc Tukey tests were conducted to illustrate differences among the monthly counts. All variables fitted a normal distribution (P>0.05; Shapiro-Wilk normality test). We used SIMCA-P software (version 13.0; Umetrics AB; Umeå, Sweden) to perform the PLS regression. Normality tests and GLM analysis were carried out with Statistica 7.0 software.

RESULTS

The GLM revealed that rabbit abundance was different during the study period ($F_{8, 32}$=30.87; P=0.001). Indeed, the dynamics of the confined populations showed the typical oscillations of the species in a Mediterranean environment, with the onset of reproduction at the end of winter, reaching a maximum abundance at the end of spring and beginning of summer (June and July) (Figure 2). In the set of enclosures, the maximum abundance oscillated between 1.65 and 9.9 pellets/m^2 per day, with an average of 4.67±0.46.

Firstly, the model that best explained the maximum rabbit abundance (Model 1) included the number of enclosures within a radius of 3 km (R^2Y=0.78; R^2X=0.31; Q2=0.42). In contrast, models including radii of 1, 2 and 4 km showed lower R^2Y values (R^2Y=0.6, R^2Y=0.63 and R^2Y=0.67 respectively). Similarly in Model 2, the model with greatest value of R^2Y also included the number of enclosures in 3 km (R^2Y=0.61; R^2X=0.27; Q2=0.18), since the models that include the number of enclosures in 1, 2 and 4 km showed lower R^2Y values (R^2Y=0.51, R^2Y=0.52 and R^2Y=0.54 respectively). Whatever the case, only 3 variables affected the rabbit abundance (VIP>1): the number of rabbit enclosures at a distance of 3 km, the availability of optimum resources for warren building and the percentage of scrub cover (Table 1). The regression coefficients showed a positive effect of number of enclosures, a positive relationship with the availability of optimum resources for warren building and a positive influence of medium values (25-50%) of scrub cover (Table 1). Conversely, the models showed an adverse effect of lower values of warren resources and scrub cover on rabbit abundance.

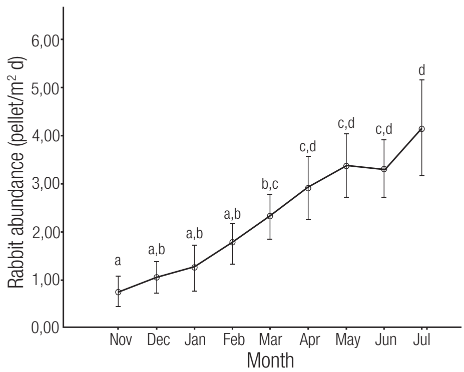

Figure 2: Average monthly rabbit abundance inside fenced plots expressed as a pellet abundance index (pellet/m^2 d) during the study period. Error bars represent a confidence interval of 95 %. Small case letters indicate significant differences ($P < 0.05$) between groups, as assessed using post-hoc Tukey tests.

Finally, we found 30 scats of terrestrial predators during the study period: 10 from common genet, 18 from stone marten and 2 from wild cat, in 12 of the 23 surveyed plots (54.5%).

DISCUSSION

Our result showed that the rabbit abundance was proportionally higher in enclosures next to each other, with great availability of optimum resources for warren building and intermediate scrub cover values. The increase in rabbit abundance during the study period bears witness to wild rabbit reproduction inside the enclosures. This might therefore be an appropriate tool with which to produce wild rabbits, since these semi-extensive systems avoid the usual problems related with the intensive rearing of wild rabbit and produce animals with a greater ability to adapt to local conditions (Piorno, 2007b), which would then be highly adapted for their release into the wild. On the other hand, these enclosures also avoid genetic risks caused by

Table 1: Influence (VIP) and coefficient of the exploratory variables used in the PLS regression models.

Variables	Model 1		Model 2	
	VIP	Coefficient	VIP	Coefficient
Number of enclosures in 3 km	2.09[a]	0.47	1.47[a]	0.23
Warren resources (4)	1.70[a]	0.31	1.74[a]	0.18
Warren resources (1)	1.28[a]	–0.32	1.87[a]	–0.48
Scrub cover (2)	1.14[a]	0.22	1.18[a]	0.08
Scrub cover (1)	1.11[a]	–0.10	1.08[a]	–0.07
Warren resources (2)	1.06[a]	0.10	0.92	0.01
Raptors time flight	0.71	0.10	0.76	0.13
Average slope	0.71	0.04	0.67	0.02
Initial rabbit density	0.65	–0.16	0.43	0.05
Artificial warren per hectare	0.65	0.15	0.87	0.21
Size of enclosures	0.45	0.11	0.37	0.05
Rabbit abundance on month after release	0.42	0.04	0.65	0.08
Warren resources (3)	0.25	–0.03	0.45	0.12
Scrub cover (3)	0.16	–0.03	0.23	–0.05
Carnivore signs	0.16	–0.02	0.60	0.17
R^2Y	0.78		0.61	
R^2X	0.31		0.27	
Q2	0.42		0.18	

VIP: variable importance in the projection. R^2Y: explained variance by the PLS model. R^2X: variance in the set of predictors used for the PLS model. Q2: cross-validation index. [a] Significant correlation coefficients (P<0.05).

the hybridisation with domestic rabbits that often occurs on commercial wild rabbit farms (Piorno, 2007a). Finally, extensive systems also reduce human handling and improve the animals' welfare (Arenas *et al.*, 2006).

Our results suggest that the spatial concentration of the enclosures favours wild rabbit production, since the number of enclosures in a radius of 3 km was positively correlated with the maximum and mean rabbit abundance (Figure 3). This could be attributed to the scattering of the predators in nearby enclosures, in which the set of enclosures might have enabled the rabbits to escape from the predation pit with greater ease, and this result prompted us to consider that an isolated enclosure is not viable, since it cannot support the impact of aerial predation. Furthermore, a radius of 3 km forms a circumference of approximately 28 km^2 around the enclosure, similar to the spatial scale (25 km^2) often used at the home range level in studies on birds of prey (Martínez *et al.*, 2003; López-López *et al.*, 2006). The low rabbit density in the study area, the large number of rabbit predators and the elevated abundance achieved in the enclosures, where the rabbits are highly vulnerable, might have attracted birds of prey (Rouco, 2008). Indeed, the aerial predation index showed a positive relationship with rabbit abundance in both models, which may be due to a higher raptor concentration in those spots with higher rabbit abundance.

As expected, the availability of optimal sites for the rabbits to dig warrens also had an important weight in both models. Several works have reported the rabbit's preference for building warrens under protective structures, such as trees, tall scrub and rocks (Palomares, 2003b; Barrio *et al.*, 2009). This may be because heavy rain can cause the death of juveniles as a result of flooding and/or tunnel-collapse, thus making unprotected warrens much more vulnerable to these phenomena (Palomares, 2003a). Likewise, protected warrens are less affected by predation (Villafuerte,

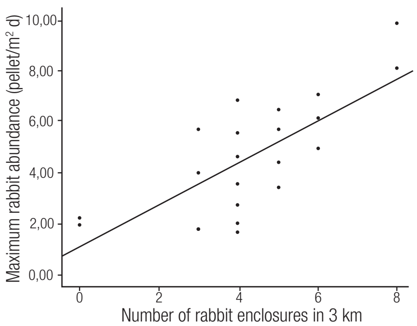

Figure 3: Correlation between the number of enclosures in a radius of 3 km and the monthly maximum abundance reached in each fenced plot.

1994). In our experiment, the relatively low number of artificial warrens provided for rabbits in the enclosures might be monopolised by the dominant rabbits (Mykytowycz and Gambale, 1965). As a result, the subordinate animals would have to dig their own warrens, so a greater number of favourable places where the rabbits can build their warrens would therefore allow secondary females to breed and thus contribute to higher offspring production.

The percentage of scrub cover in each enclosure also had an important effect on rabbit production. Indeed, the PLS models showed a positive influence of intermediate values (25-50%) and a negative correlation with low bush coverage (0-25%). These results highlight the role of habitat features in wild rabbit abundance, as rabbits in the wild reach high abundance in those places where shelter (scrub) and food resources (pastures) are widely available. The highest scrub cover values (more than 50%) showed no significant effect, as the range of rabbit abundance in these plots was very broad. Hence, the breeding enclosures should be built in places with optimum shelter availability, while enclosures with very low or very high bush cover should be avoided.

Our data showed that the electric fence was not completely effective in preventing the entry of terrestrial predators, although the entry of some carnivores did not affect rabbit abundance. We consider that a small curved overhang on the top of fences (Moseby and Read, 2006) could prevent the entry of mammalian predators. Finally, the slope, the size of the fenced plots, the initial rabbit density and the abundance 1 mo after release did not affect further rabbit abundance, perhaps because the distances between plots and the presence of elements that favour the construction of warrens and shelter played a more relevant role in the model.

CONCLUSION

In agreement with the findings, we suggest that new semi-extensive rabbit captive enclosures should be created less than 3 km apart from each other in order to minimise aerial predation, and that isolated enclosures should be avoided, thus minimising the impact of predation. Our results also suggest that the availability of optimum resources for digging warrens and the scrub coverage would appear to be other crucial factors, so the selection of plots with an appropriate structure and protection such as large stones or the presence of tall shrubs might therefore optimise the rearing results.

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