UNIVERSIDAD DE CÓRDOBA

Facultad de Ciencias

Biología

Trabajo Fin de Grado

Could supplementary feeding promote wild rabbit translocations success?

Código del TFG: **BL20-78-BEF**
Tipología: **Trabajo de iniciación a la investigación**

Autor: Mara d'Arán Segovia Trufero

2 de Julio de 2021

Me gustaría aprovechar esta oportunidad para agradecer al Área de Ecología de la Universidad de Córdoba cuyos profesores han mantenido siempre las puertas abiertas, una sonrisa y disposición de ayudar y enseñar en todo momento. Quiero agradecer especialmente a Joaquín Reyes, Diego Jordano y Rafael Villar por mantener y transmitir su pasión por la rama de la Ecología y, sobre todo, a mi tutor Carlos Rouco, por animarme a luchar por lo que quiero desde el primer año y ser un ejemplo de que con esfuerzo e ilusión se llega a cualquier sitio.

Finalmente, quiero dedicar mi Trabajo de Fin de Grado a mi abuela Margarita, porque habiendo crecido en una época donde la vida era muy diferente, nunca ha dudado ni por un instante de que su nieta podía conseguir lo que quisiera como científica. Por apoyarme y animarme incondicionalmente, todo lo que consiga como profesional siempre irá por ti.

General index

Figures index

Tables index

Resumen

El conejo de monte es una especie considerada plaga en muchos países de Europa, pero en España la población ha sufrido un gran declive en las últimas décadas debido a la pérdida de hábitat, la sobrecaza y, especialmente, al efecto combinado de la llegada de dos enfermedades víricas: la mixomatosis y la fiebre hemorrágica. Esto tiene un gran impacto en nuestro país y en nuestro ecosistema mediterráneo, donde el conejo de monte juega un papel principal al ser una especie muy extendida y presa de al menos diez depredadores mediterráneos como el águila imperial ibérica y el lince ibérico. Por esta razón se han llevado a cabo numerosos estudios para recuperar sus poblaciones silvestres, siendo el manejo de hábitat y las translocaciones las técnicas más usadas, combinadas con otras medidas como la exclusión de depredadores, medidas de prevención de enfermedades o suplementación alimentaria. Teniendo en cuenta que las enfermedades víricas suponen la principal causa de mortandad, las campañas de vacunación han tenido gran relevancia combinadas con una dieta equilibrada utilizando suplementación alimentaria, ya que se ha demostrado que una mejor condición física reduce el impacto de estas enfermedades víricas a corto plazo. Pero que estas medidas funcionen a largo plazo es necesario para recuperar las poblaciones, y para esto es imprescindible un seguimiento constante. En este estudio, tras advertir un detrimento en la condición física de una población de conejos durante un proyecto de translocación, se decidió incluir heno de alfalfa como suplemento alimentario. Para comprobar su efecto comparamos los datos previos y posteriores al tratamiento respecto a la condición física de los ejemplares capturados, así como el número de cadáveres encontrados mediante transectos como posible indicador del impacto de enfermedades, habiendo encontrado diferencias significativas que sugieren que la suplementación favorece el éxito de las translocaciones de conejo de monte.

Palabras clave: Conejo de monte; *Oryctolagus cuniculus*; Translocaciones; Suplementación alimentaria

Abstract

The European wild rabbit is considered a pest in many Europe countries but in the Iberian Peninsula, loss of habitat, overhunting and in particular the combined effect of two viral diseases arrival: haemorrhagic disease and myxomatosis, are pushing these populations to decline. This has a great impact on our country and Mediterranean ecosystem where wild rabbit is a key stone species, as a widespread species which works as a prey for several predators as the Iberian Iberian lynx or the Spanish imperial eagle. Therefore, many studies have been carried out to increase their wild populations. Habitat management and translocations have been the most used techniques, combined with predator's exclusion, disease prevention measures and supplementary feeding. Given viral diseases are the biggest threaten, vaccination programs have been used as well as assuring a balanced diet using supplementary feeding as this is proved to decrease viral disease impact in short term translocations. Anyways translocations long term success is required to increase wild rabbit population, and this is only possible with a maintained tracking. In this study we realized a detriment of rabbits' physical condition during a translocation program and decided to implement lucerne hay as supplementary feeding. To prove the effect, we compared previous and after treatment data about physical condition as well as rabbit carcasses as diseases impact indicator and found significant differences that suggest supplementary feeding increase wild rabbit translocation success.

Keywords: European wild rabbit; *Oryctolagus cuniculus*; Translocations; Supplementary feeding.

Introduction

The European wild rabbit (*Oryctolagus cuniculus)* is considered as a pest in many countries where they have been introduced. In fact, in these countries large number of studies are carried out with the purpose of reducing and controlling rabbit populations (e.g. New Zealand or Australia, Norbury & Reddiex 2005; Henzell et al., 2008). On the other hand, in the Iberian Peninsula, where rabbits are native (Monnerot et al., 1994) they are a keystone species in the Iberian Mediterranean ecosystems (Delibes-Mateos et al., 2007) where the species plays an important role in sustaining a large number of predator species (Valverde 1967; Delibes-Mateos et al., 2008a) including threatened species such as the Iberian lynx (*Lynx pardinus*) or the Iberian imperial eagle (*Aquila adalberti*). However, its wild populations have undergone a dramatic decline during the last half century, and consequently, the European wild rabbit is considered an endangered species within its native range (Villafuerte & Delibes-Mateos, 2019). The main reasons for such decline are habitat loss, overhunting, but also the arrival of two viral diseases: myxomatosis in the 1950s and two different strains causative of the rabbit hemorrhagic disease (RHD) at the end of the 1980s and 2010, respectively (e.g., Delibes-Mateos et al., 2009; Rouco et al., 2018; 2020). The impact of these diseases caused and currently causes dramatic declines in rabbit populations, including the extinction of local populations (e.g., Villafuerte et al., 1995; Virgós et al., 2003).

Because of this situation, management measures have been applied aiming to the restoration of wild rabbit populations and to efforts to increase their resilience. Rabbit restocking success rate has been low in traditional attempts because the lack of other habitat management measures (Guerrero et al., 2013), reason why rabbit translocation and habitat management are the most frequently used strategies (Cabezas & Moreno, 2007; Rouco et al., 2008). Rabbit translocation have already been used for rabbit's management in many regions in southern-central Spain and its use have increased in the last decades (Delibes-Mateos et al., 2008) as it is efficient to translocate the populations from overpopulated areas to others where rabbit population is decreasing, aiming to increase population density as population viability is achieved at high density rates (Lande et al., 1997) Also, habitat improvement, predator removal, disease-prevention treatments as vaccination programs and supplementary feeding are some of the management measures applied more frequently to boost wild rabbit populations (e.g., Angulo & Villafuerte 2003; Rouco et al., 2008; Guerrero et al., 2013).

Given the fact that viral diseases are one of the main causes of the decline of wild rabbit population, vaccination campaigns or physical condition enforcement are often used in translocation programs (Calvete & Estrada, 2004). To improve and maintain an optimal physical condition ensuring an accurate diet is essential to prevent disease and increase of short term survival (Cabezas et al., 2006) but to increase long term survival and, therefore, success of a translocation program, a maintained monitoring is crucial to perceive incidents efficiently, and so, being able to act accordingly. However, most of the research carried out to improve the success of rabbit translocation programs are based on short term studies (e.g. < 6 months length: Calvete et al.,1997; Calvete et al., 2005; Calvete & Estrada 2006; Cabezas & Moreno 2007; Letty et al., 2000, 2005; Rouco et al., 2008, 2010, 2011). In this sense, long term studies have been generally scarce or neglected.

Objectives

In this study we monitored a wild rabbit translocation program carried out in the Sierra Norte de Sevilla Natural Park between 2002 and 2005 (Rouco, 2008). Through an intensive monitoring of the animals, we were able to detect a decline in rabbit's physical condition. So, the present study aim in testing how supplementary feeding may boost translocated rabbit's physical condition, overcome better the impact of disease, and ultimately increase the likelihood of success of the translocation program in a long term. If so, this will show how important is monitoring when carrying rabbit translocation programs to ensure as much as possible its success in a long term, and thus improve knowledge for wild rabbit recovery management.

Material and methods

Study area

The study was conducted in the area of Los Melonares, located in the south of the Sierra Norte of Seville Natural Park (south-west Spain) (Figure 1). The study area covers 1300 ha with the presence of two main biotopes: grassland and scrubland

(Figure 1). The scrubland covers ~30% of the total area and occupies the slopes of the hillocks. Grassland covers most (70%) of the area and oaks (*Quercus ilex*) are also dispersed throughout the area. Since rabbit population was so scarce in Los Melonares, and many endangered predators, such as the Spanish imperial eagle, a rabbit's translocation program was carried out to favor presence for prey for predators. The source population was located at a hunting estate ~300 km from Los Melonares (Cádiz province, southern Spain, see Figure 1).

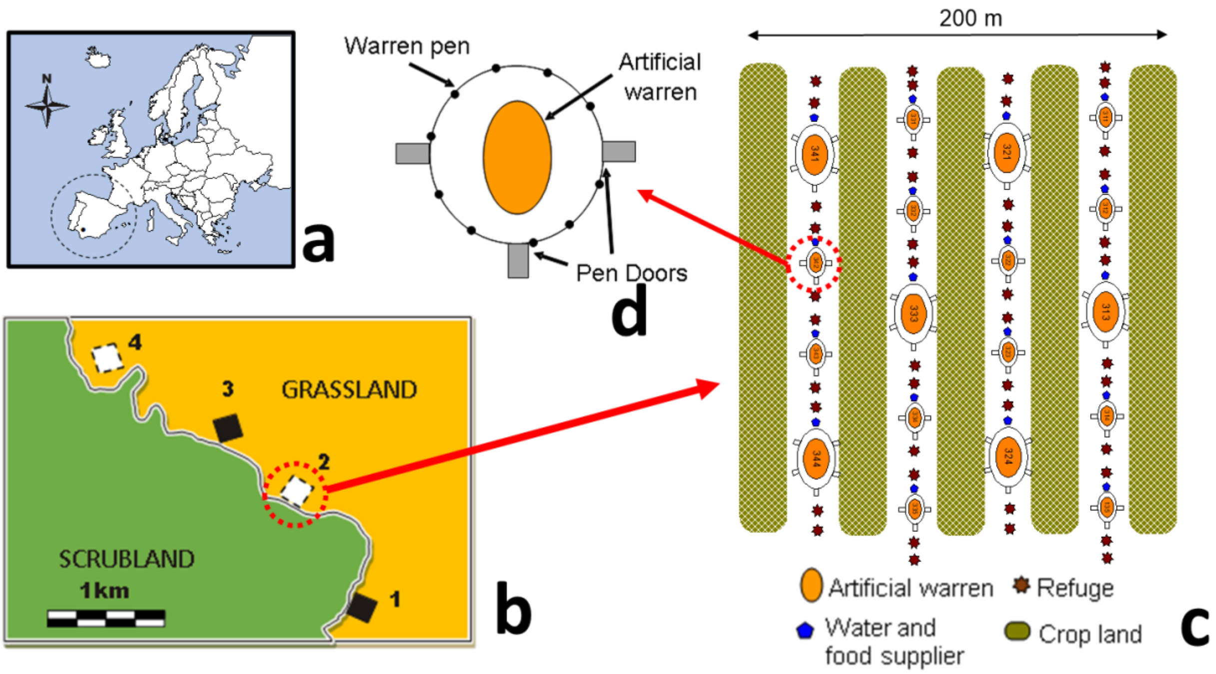

Figure 1 (a) Location of Los Melonares area (•) on the Iberian Peninsula. (b) Scheme of the main biotopes present in Los Melonares, and the location of the experimental translocation plots (Fenced plots in black, Unfenced plots in white). (c) Structure of a translocation plot comprising artificial warrens (large warrens, white; small warrens, black), refuges and water and food suppliers. (d) Detail of an artificial warren surrounded by a warren pen, with the location of the water and food suppliers.

Rabbits were flushed out of their natural warrens and driven into nets with the use of ferrets (*Mustela furo*) (Cowan, 1984). Immediately after capture, rabbits were placed in commercial wire cages (100 cm x 50 cm x 20 cm) and transported to the release site. In Los Menolares, four 'translocation plots' (4 ha each) separated by at least 1 km were prepared in the grassland area close to scrubland (Figure 1). No natural or artificial warrens were previously present in any plot. Two of the translocation plots were fenced during the whole study (1.0m below ground and 2.5m above ground with an electric wire on top) to completely exclude terrestrial carnivore predators. The other two plots were unfenced. On each plot, 18 regularly distributed artificial warrens were built above ground, consisting of piles of stumps and rocks covered with loam and branches. Near each warren, we added water and food suppliers that provided water and commercial pellets ad libitum. Additional refuges (heaps of wood branches, 2m in diameter, n = 44 per plot) and feeding areas (crop lands) were placed identically inside each translocation plot. At all plots, artificial warrens had an effective capture device consisting of a wire netting fence that extended from 50 cm below ground to 100 cm above the ground; this fence had between 3 and 5 entrances (15 cm x 15 cm) situated at ground level with metal traps attached. Capture involved activation of the capture devices at midday, when the rabbits were less active and most were underground (Villafuerte et al., 1993). The following morning, the rabbits trapped inside the cages were counted and handled. This trapping system permitted capture inside the warren of 50-60% of the rabbits on any one night (Rouco et al., 2011).

Precipitation data was recorded on the local meteorological station as well, this data was needed given dry or wet seasons are involved in rabbits physical condition as it determines the amount of food available as many other variables.

Experimental design

We carried out a total of 14 trapping sessions, starting in June 2003 and ending in May 2006. During each trapping session, all captured animals were weighed, hind foot lengths measures, sexed and ear-marked with numbered metal tags (Presadom nº3, France).

In September 2003, during an ordinary trapping session we realized an overall dramatic drop on the weights of the rabbit populations in comparison with the expected weight for that time of the year (post-breeding, see Results section). By then the crop lands inside the translocation plot were vanished, and despite that rabbit translocation plots were provided with food suppliers, it did not seem enough to keep on with their physical condition. Consequently, we decided to add supplementary feeding with lucerne hay. Furthermore, transects were carried out at least once a week to find and collect dead rabbits remains to account for diseases impact before and after supplementation. Every rabbit carcass or part of it found was identified, geo-referenced using a GPS (Garmin lll Pilot Plus, Garmin®) and death cause was determined if possible. Finally, a data of 26 monthly carcass record (11 before supplementary feeding addition and 15 after) from November 2002 to December 2004 was available to contrast the supplementation effect on survival.

Data analysis

To test our prediction that supplementary feeding would increase rabbits' physical condition (e.g. weight), we undertook a model selection approach using a generalized linear mixed model (GLMM) (package '*lme4*') with a normal error structure and an identity link function, using on this model the rabbit's weight as the dependent variable. The fixed factors were "Supplementary feeding" (two levels; Before and After), "Sex" (two levels; "Male" and "Female") plot type (two levels fenced and unfenced) to account for effect of terrestrial predators' pressure, warren size (two levels, large, small) and "foot length" (continuous variable) to account for the body size of the individuals. Rabbit identification was included as a random factor in the models. We only use adult individuals on this analysis given the young individuals were always going to have a lower weight independently of their physical condition. We considered as young individuals every female under the weight of 750 gr and every male under 810 gr (Villafuerte, 1994). Rest of packages used to complete the analysis and visualize plots were '*Matrix*', '*lmerTest*', '*carData*', '*car*', '*sjmisc*', '*sjPlot*', '*ggplot2*', '*usethis*', '*devtools'* and '*rstatix*'. Model selection was performed in accordance with the 'top-down strategy' of Zuur et al. (2009). Thus, selection of the best model was carried out by starting with the maximal model, and sequentially removing the effects farthest from statistical significance, starting with the highest order interactions (See Annexed 1).

Finally, we carried out a Pearson's correlation (package "*ggpubr*") where we explore if there were a relationship between the condition of the rabbits based on its weight in a given time and the number of carcasses found along time. We run such procedure for females and males separately.

All statistical analysis procedure was run in program R version 4.0.5 (R Core Team, 2020).

Results and discussion

A total of 1230 captures of 858 individuals were recorded during the study period; 1230 rabbits in the fenced plots and 268 rabbits in the unfenced plots. Recaptures ranged from one to eight captures per individual. The maximum number of captures within a trapping session was in June 2004 with 171 individuals whereas the trapping session with the smaller number of rabbits trapped was October 2004 with 38 individuals. Out of the total individuals captures, 423 (49%) and 453 (51%) corresponded to males and females, respectively.

Our results revealed that average rabbit weight started decreasing from the first trapping session (i.e. June 2003) until feeding supplementary treatment started in September 2003, where average rabbit weights started to increase (Figure 2). We also notice a drop in average rabbit weight during fall of 2004 rabbits suffered a low condition time period again, which was caused by a scarce of rain the autumn, leaving the animals with less amount of food available. This matches with the carcasses record, which decrease as physical condition increases excluding this dry period where more carcasses where eventually recorded. (Figure 2).

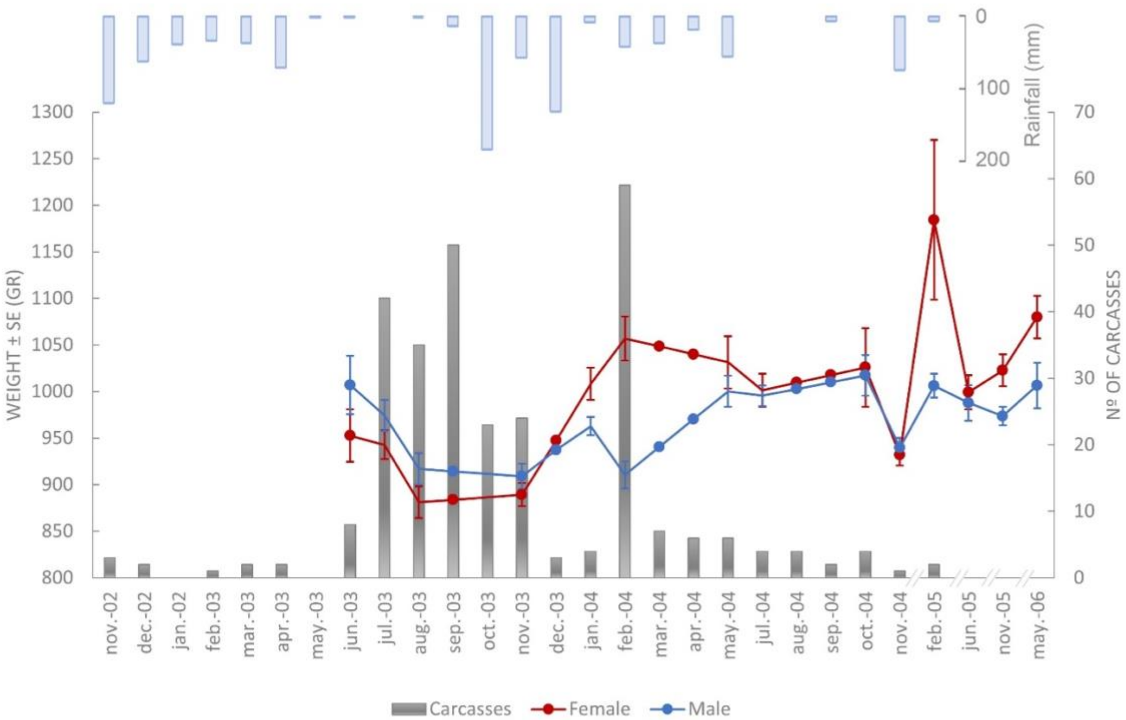

Figure 2. Average weight of female (red) and male (blue) wild rabbits, number of carcasses (bars) recorded per month and monthly average rainfall (mm) along the study period in Los Melonares area.

Our modelling results showed that “Sex” (p=0.003) and “Supplementary feeding” (p=0.009) explained the weight variance in our top model. (Table 1). Females overall weighted significantly more than males. In addition, our modelling also revealed a significantly effect on the supplementary feeding experimental treatment (Table 1). Rabbits overall had significantly better condition after starting with the treatment. This result is consistent with the idea that supplementary feeding addition increases physical condition (Lopez-Bao et al., 2009) which we expected to happen on the experimental population.

Table 1. Results of the top-ranked generalized linear mixed model (GLM) The category listed in brackets for each fixed factor variable analyzed is the reference category. Estimate of coefficient (Beta), standard errors (SE), t-value and associated p-values computed from a Satterthwaite's degrees of freedom me¡thod is shown.

Fixed effect	Beta	SE	t-value	p-value
(Intercept)	402.910	83.084	4.849	1.41e-06 **
Supplementary feeding (Before)	-26.643	10.294	-2.588	0.00977 *
Sex (Female)	22.841	7.685	2.972	0.00303 *
Foot length	10.530	1.530	6.882	9.67e-12 **

Signif. codes: p < 0.001 = **, p < 0.01 = *

A total of 291 carcasses were recorded during the study, where 31.3% (N = 90) were determined as predation, 14.6% (N = 42) as disease and 54,1% (N = 159) were classified as undetermined. However, undetermined carcasses origin was probably related to disease as we observed increased myxomatosis rates on summer 2003 and hemorrhagic disease outbreak in February 2004 (Rouco, 2008) (Figure 2).

Pearson’s correlation was used to find out how rabbits weight correlated with the number of carcasses recorded along the entire study period. Our results revealed that they correlate negatively but with some discrepancies between females and males (Figure 3). When analyzing males and females separately, we find out that males’ correlation was significant (R = -0.231, p = 0.003) as females’ correlation was not (R=

-0.641, p = 0.49). This could be explained due to neglecting when detecting pregnant females which would have overestimated their physical condition. This is supported by the increased female's weight on January and April (observed equally on 2003 and 2004 data, Figure 2) coinciding with rabbits' reproduction period (). These results are consistent with other studies that demonstrated rabbit's abundance, so survival, is determined by habitat characteristics related factors (Fa et al., 1999; Virgós et al., 2003; Calvete et al., 2004), In particular, supplementary feeding treatment was demonstrated to be the main factor among habitat characteristics (Cabezas & Moreno, 2007), therefore this reinforced the importance of habitat management once again in any long term attempt at improving wild rabbits population.

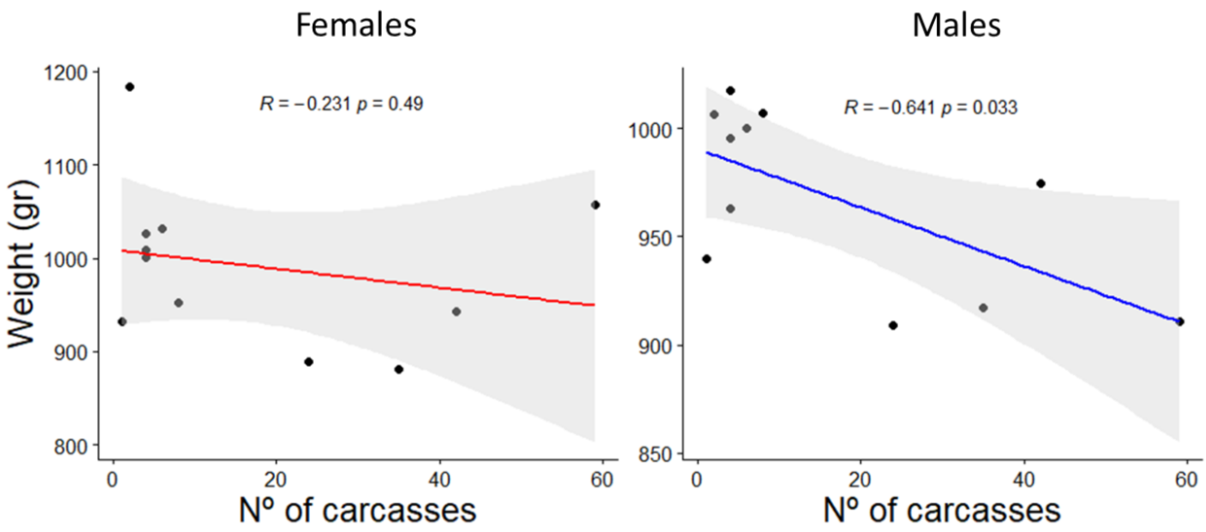

Figure 3. Pearson's correlation between females (in red) and male (in blue) rabbits' weights and the number of rabbit carcasses found along the entire study period.

Other studies determined predation by carnivores and disease as the main mortality causes on wild rabbit population (Calvete et al., 1997; Cabezas et al., 2011), being both factors related to food availability given when predators are present the more available food close to the warrens the less risk to be predated (Cabezas & Moreno, 2007) and when predators are excluded the supplementary feeding addition also increases the physical condition (Lopez-Bao et al., 2010) lowering the disease impact on the population (Cabezas et al., 2011). Therefore, long term habitat management, in particular supplementary feeding treatments, positively affect wild rabbits' population's likelihood of survival, therefore favoring translocations success.

Conclusiones

Nuestros resultados muestran que la suplementación alimentaria con heno de alfalfa mejora la condición física basada en el peso de las poblaciones de conejo de monte, y parece reducir el impacto de enfermedades víricas en consecuencia, por lo tanto, puede que favorezca así el éxito de las translocaciones. Por consiguiente, la alimentación suplementaria es una técnica efectiva para favorecer las translocaciones de conejo de monte, si se combina con otras técnicas como la exclusión temporal de depredadores para lograr una aclimatación, la vacunación o el seguimiento constante a largo plazo, cuando se pretende mejorar las poblaciones de conejo de monte en el ecosistema mediterráneo.

Conclusions

Our results showed that lucene hay supplementary feeding increases wild rabbits' population physical condition based on its weight and seems to decrease viral disease impact as consequence and therefore may favoring translocations success. Hence, supplementary feeding is an effective technic to favor rabbits' translocations, if combined with others as temporal predators' exclusion for acclimation, vaccination or consistent long-term tracking, when aiming to improve wild rabbit populations in Mediterranean ecosystem.

Bibliography

Angulo, E., and R. Villafuerte. 2003. Modelling hunting strategies for the conservation of wild rabbit populations. Biological Conservation 115:291–301

Cabezas, S. & Moreno, S. (2007). An experimental study of translocation success and habitat improvement in wild rabbits. Animal Conservation 10:340-348

Cabezas, S., Calvete, C. & Moreno, S. (2006). Vaccination success and body condition in European wild rabbit. Journal of Wildlife Management 70:125-1131

Cabezas, S., Calvete, C. & Moreno, S. (2011) Survival of translocated wild rabbits: importance of habitat, physiological and immune condition. Animal Conservation, 14(6), 665-675.

Calvete, C. & Estrada, R. (2004). Short-term survival and dispersal of translocated European wild rabbits. Improving the release protocol. Biological Conservation 120: 507-516.

Calvete, C., Villafuerte, R., Lucientes, J. & Osacar, J. J., (1997). Effectiveness of traditional wild rabbit restocking in Spain. Journal of Zoology 241: 271-277.

Calvete, C., Angulo, E., Estrada, R., Moreno, S. & Villafuerte, R. (2005). Quarantine length and survival of translocated European wild rabbit. Journal of Wildlife Management 69: 1063-1072

Cowan, D. P. (1984). The use of ferrets (*Mustela furo*) in the study and management of the European wild rabbit (*Oryctolagus cuniculus*). Journal of Zoology 204, 570–574.

Delibes-Mateos, M., Ferreras, P., & Villafuerte, R. (2009). European rabbit population trends and associated factors: A review of the situation in the Iberian Peninsula. Mammal Review, 39, 124–140.

Delibes-Mateos, M., Delibes, M., Ferreras, P., & Villafuerte, R. (2008). The key role of European rabbits in the conservation of the western Mediterranean basin hotspot. Conservation Biology 22, 1106–1117. doi: 10.1111/j.1523-1739.2008.00993.x

Delibes-Mateos, M., Redpath, S. M., Angulo, E., Ferreras, P., & Villafuerte, R. (2007). Rabbits as a keystone species in southern Europe. Biological Conservation 137, 149–156. doi: 10.1016/j. biocon.2007.01.024

Fa, J.E., Sharples, C.M. & Bell, D.J. (1999). Habitat correlates of European rabbit (Oryctolagus cuniculus) distribution after the spread of RVHD in Cadiz Province, Spain. J. Zool. (Lond.) 249, 83–96.

Guerrero-Casado, J., Carpio, A. J., Ruiz-Aizpurua, L. & Tortosa, F. S. (2013) Restocking a keystone species in a biodiversity hotspot: Recovering the European rabbit on a landscape scale. Journal For Nature Conservation, 21: 444-448.

Henzell Robert P., Cooke Brian D. & Mutze Gregory J. (2008) The future biological control of pest populations of European rabbits, Oryctolagus cuniculus. Wildlife Research 35, 633-650. https://doi.org/10.1071/WR06164

Letty, J., Aubineau, J. & Marchandeau, S. (2005). Effect of storage conditions on dispersal and short-term survival of translocated wild rabbits Oryctolagus cuniculus. Wildlife Biology 11: 249-255.

Letty, J., Marchandeau, S., Clobert J. & Aubineau, J. (2000). Improving translocations success: an experimental study of antistress treatment and release method for wild rabbit. Animal Conservation 3: 211-219.

Lopez-Bao, JV., Palomares, F., Rodríguez, A. & Delibes, M. (2010) Effects of food supplementation o home range size, productivity and recruitment in a small population of Iberian lynx. Anim Conserv 13:35-42.

Norbury, G., & Reddiex, B. (2005). European rabbit. In 'The Handbook of New Zealand Mammals'. (Ed. C. M. King.) pp. 131–150. (Oxford University Press: Melbourne.)

R Core Team. (2020). A language and environment for statistical computing. URL Available: Vienna, Austria: R Foundation for Statistical Computing https://www.Rproject.org/.

Rouco, C. (2008). *Restauración de las poblaciones de conejo de monte y mejora de la gestión para su conservación*. Departamento de Ciencia y Tecnología Agroforestal. Ciudad Real, Universidad de Castilla-La Mancha. PhD, 211.

Rouco, C, Abrantes, J. & Delibes-Mateos, M. (2020). Lessons from viruses that affect lagomorphs. Science 369(6502): 386.

Rouco, C., Ferreras, P., Castro, F. & Villafuerte, R. (2008). The effect of exclusion of terrestrial predators on short-term survival of translocated European wild rabbits. Wildlife Research 3(7): 625-632.

Rouco, C., Ferreras, P., Castro, F. & Villafuerte, R. (2010). A longer confinement period favors European wild rabbit (Oryctolagus cuniculus) survival during soft releases in low cover habitats. European Journal of Wildlife Research 56(3): 215-219.

Rouco, C., Villafuerte, R, Castro, F. & Ferreras, P. (2011). Effect of artificial warren size on a restocked European wild rabbit population. Animal Conservation 14(2): 117-123.

Rouco, C., Abrantes, J., Serronha, A., Lopes, A. M., Maio, E. & Magalhaes, M. J., et al. (2018). Epidemiology of RHDV2 (Lagovirus europaeus/GI.2) in free living wild European rabbits in Portugal. Transboundary and Emerging Diseases, 65(2), e373–e382.

Valverde, J. A. (1967). Estructura de una comunidad mediterránea de vertebrados terrestres. Monografía Estación Biologica de Doñana 1. Madrid: CSIC.

Villafuerte, R. (1994). Riesgo de predación y estrategias defensivas del conejo, Oryctolagus cuniculus, en el Parque Nacional de Doñana. PhD thesis, University of Córdoba, Córdoba.

Villafuerte, R., & Delibes-Mateos, M. (2019). Oryctolagus cuniculus. The IUCN red list of threatened species 2019. https://doi.org/10.2305/IUCN.UK.2019-3.RLTS.

Villafuerte, R., Viñuela, J., & Blanco, J. C. (1998). Extensive predator persecution caused by a population crash in a game species: the case of red kites and rabbits in Spain. Biological Conservation 84, 181–188. doi: 10.1016/S0006-3207(97)00094-3

Villafuerte, R., Kufner, M.B., Delibes, M. & Moreno, S. (1993). Environmental factors influencing the seasonal daily activity of the European rabbit (*Oryctolagus cuniculus*) in a Mediterranean area. Mammalia 57, 341–347.

Villafuerte, R., Calvete, C., Blanco, J. C., & Lucientes, J. (1995). Incidence of viral hemorrhagic disease in wild rabbit populations in Spain. Mammalia, 59, 651–659.

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

Annexed 1

Table A1: Results of all the generalized linear mixed model (GLM) run. Models are presented following a 'top-down strategy' by starting with the most parametrized model (Full model), and sequentially removing the effects farthest from statistical significance, starting with the highest order interactions. The category listed in brackets for each fixed factor variable analyzed is the reference category. Estimate of coefficient (Beta), standard errors (SE), t-value and associated p-values computed from a Satterthwaite's degrees of freedom method is shown.

Model	Fixed effect	Beta	SE	t-value	p-value
	(Intercept)	409.097	83.198	4.917	1.00e-06 ***
Full	Supplementary feeding	-26.024	10.303	-2.526	0.01167 *
	Sex (Female)	21.339	7.768	2.747	0.000613 **
	Plot type (Unfenced)	13.387	871.365	1.426	0.15422
	Warren size (Small)	-1.667	7.576	-0.220	0.82587
	Foot length	10.387	1.534	6.771	2.03e-11 ***
	(Intercept)	408.484	83.136	4.913	1.02e-06 ***
1	Supplementary feeding	-26.010	10.298	-2.526	0.0117 *
	Sex (Female)	21.281	7.757	2.743	0.0062 **
	Plot type (Unfenced)	13.494	9.368	1.440	0.1501
	Foot length	10.384	1.533	6.774	1.99e-11 ***
	(Intercept)	402.910	83.084	4.849	1.41e-06 ***
Final	Supplementary feeding	-26.643	10.294	-2.588	0.00977 **
	Sex (Female)	22.841	7.685	2.972	0.00303 **
	Foot length	10.530	1.530	6.882	9.67e-12 ***

Signif. codes: $p < 0.0001$ = ***, $p < 0.001$ = **, $p < 0.01$ *