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SHORT COMMUNICATION

The short-term effect of total predation exclusion on wild rabbit abundance in restocking plots

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Abstract About half a million rabbits are translocated in southwestern Europe every year for conservation and hunting purposes. However, the success of traditional rabbit restocking is generally extremely low, and this has been attributed to short-term predation by mammalian carnivores. Hence, recent recovery programs have tackled the problem of terrestrial predators with the use of exclusion fences, but no additional measures have been employed to avoid aerial predation. In this study, we have therefore conducted a field experiment to test the short-term effect of total predation exclusion in rabbit restocking enclosures, comparing rabbit abundance in plots which are only accessible to raptors (top-open plots) and plots which are accessible to neither carnivores nor raptors (top-closed plots). The results showed that the top-closed plots had higher rabbit abundance in the short term, and the highest difference in rabbit abundance between the two kinds of fences was attained in the first 2 weeks. We therefore conclude that the top-closed plots were an effective tool to increase rabbit abundance during the first weeks after release through the exclusion of raptor predation.

Keywords *Oryctolagus cuniculus* · Predator exclusion · Rabbit conservation · Raptors · Restocking

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Introduction

After their decline, around half a million European wild rabbits (*Oryctolagus cuniculus*), within its native range, are translocated each year in order to boost rabbit population (Letty et al. 2008). This is done because the scarcity of rabbits in Iberia and France constitutes a serious problem due to their economical and biological value (Delibes-Mateos et al. 2008), since they are considered to be the primary small-game species in sport hunting (Calvete and Estrada 2004) and are additionally a keystone species in Mediterranean ecosystems (Delibes-Mateos et al. 2007). Nevertheless, several scientific studies (Calvete et al. 1997; Letty et al. 2002) show a very low success rate in rabbit restocking. In lagomorphs, some works have highlighted that the crux of the problem is the high short-term mortality (Calvete et al. 1997) as a consequence of predation by terrestrial carnivores, environmental novelty, and stress (Calvete et al. 1997; Moreno et al. 2004; Letty et al. 2008; Misiorowska and Wasilewski 2012). Because of this, to prevent the impact of predation and rabbit dispersal after release, the construction of predator exclusion fences, within which the rabbits are released, is one of the most frequent actions in recent rabbit recovery programs (Ferreira and Delibes-Mateos 2010; Ward 2005).

Although some authors have suggested that the impact of raptors on rabbit enclosures could be very high and may therefore decrease restocking efficiency (Rouco et al. 2008; Cabezas et al. 2011), wildlife managers hardly ever carry out measures to tackle the problem of avian predation, other than providing more shelter. Thus, in this study, we aim to test the short-term effect of total predation exclusion in rabbit restocking enclosures. This is done by comparing the most common plots which are only accessible to birds of prey with those which are accessible to neither mammalian predators nor raptors. To date, this is the first study that reported on the effect of total predator exclusion in a rabbit translocation program.

Material and methods

Field work was carried out in central Sierra Morena, in southern Spain, where six of the main raptors that consume rabbit (Delibes-Mateos et al. 2007) were present in the study area: the Spanish imperial eagle (*Aquila adalberti*), the golden eagle (*Aquila chrysaetos*), the eagle owl (*Bubo bubo*), the Bonelli's eagle (*Aquila fasciata*), the booted eagle (*Hieraaetus pennatus*), and the buzzard (*Buteo buteo*). Five fences were built close to each other in an area of 3 ha, three of which had no top net and were therefore only accessible to raptors (top-open plots), and two enclosures with no access to either raptors or terrestrial carnivores (top-closed plots), which were also equipped with a fence on the roof to prevent birds of prey from gaining access. All the fenced plots were of 0.5 ha, had the same number of artificial warrens (five per plot), and had similar vegetation, structure, and cover. All the plots were fenced 0.5 m below the ground and 2 m above the ground with two electric wires and a floppy overhang to exclude terrestrial carnivores (Moseby and Read 2006). Additionally, water and food were supplied ad libitum during the study period. In each plot, 25 adult rabbits were released inside the artificial warrens in February 2010, in the same sex ratio: four females and one male in each warren (total: 20 females and 5 males per plot). All the rabbits were captured with the use of ferrets in a high rabbit density area in the south of the Córdoba province, and they were immediately transported to the release fences (in the north of the Córdoba province) with no vaccines, no confinement period, or quarantines.

Rabbit abundance was estimated through the use of pellet counts at fixed sampling sites in 0.5-m^2 circular sampling (Fernández-de-Simón et al. 2011). Within each plot, 20 fixed points (4×5 grids) were set 20 m from each other, where pellets were removed in all visits to ensure that only fresh pellets of less than 1-week-old were counted. To standardize all pellets counts, a pellet abundance index (PAI) was estimated in each sampling site by dividing the number of pellets at each counting station by the number of days since the last count (Rouco et al. 2011). The counts were repeated on a weekly basis for 6 weeks after release. To evaluate the effect of top fences, we used generalized linear mixed models (GLMM), where pellet abundance index in the counting points was the dependent variable, with Poisson error distribution and logit link function. "Treatment" (closed and open plots) and "week" (each weekly pellet count) were regarded as fixed factors; and "plot" (each individual plot) and "sampling site" (each counting point) were included as random factors. Finally, to compare rabbit abundance between weeks of sampling and treatment, we used Bonferroni's test for pairwise multiple comparisons within the mixed-model analysis. We used SPSS 20.0 software (IBM corp. Chicago, USA) to perform the mixed models.

Table 1 Results of the generalized linear mixed models (GLMM) of the effect of treatment (closed and open top plots) and week on the rabbit abundance

Variables	*F*	$d.f._n$, $d.f._d$	*P*
Intercept	35.82	11, 288	<0.001
Treatment	16.86	1, 288	<0.001
Week	75.59	5, 288	<0.001
Treatment × week	0.26	5, 288	0.932

$d.f._n$ degrees of freedom of numerator, *$d.f._d$* degrees of freedom of denominator

Result and discussion

We found a significant effect of treatment (Table 1): the "week" factor had a statistically significant effect (Table 1), but the interaction between "treatment" and "week" was not significant (treatment × week, Table 1). Bonferroni pairwise test showed that rabbit abundance was higher in closed-top plots than open-top plots ($P<0.05$) at all times after release (Fig. 1). Rabbit abundance was different from the first to the third week in both plots (Bonferroni, $P<0.05$), this being more stable since the fourth week, when the rabbit abundance remained constant (Bonferroni, $P>0.05$).

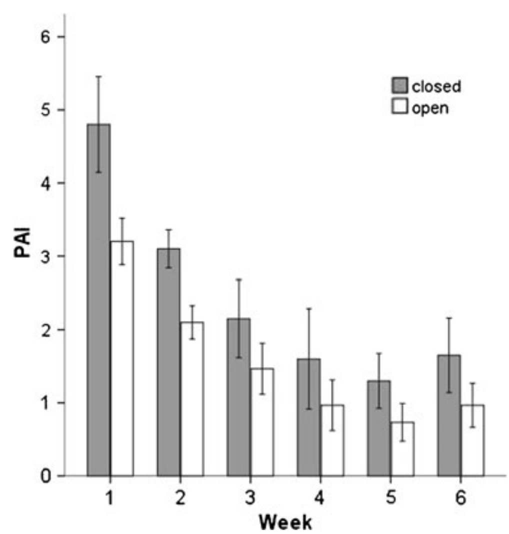

Fig. 1 Effect of experimental treatment (open or closed plots) regarding rabbit pellet abundance index (PAI) during the first 6 weeks after release. *Bars* represent mean values and 95 % intervals are shown

Our results show that the top-closed plots had higher rabbit abundance than the top-open plots at all times after release, although the highest difference was recorded during the first 2 weeks, which could be due to raptor predation in the short term. Indeed, various authors (Rouco et al. 2008; Cabezas et al. 2011) have suggested that aerial predation could be focused upon the rabbit enclosures, in which the rabbits are more vulnerable to predation due to the high rabbit concentration within them. On the other hand, five enclosures in a small area could attract birds of prey much more than independent enclosures. We detected ten carcasses with clear signs of predation by birds of prey (evidence of feathers, tufts of hair, or remains of long bones) in the open-top plots during the study period, which represented a 76.92 % of the total individuals found dead in the top-open plots ($n=13$) although raptors may have consumed sick, weak, or dead animals as carrion. In addition, the highest difference in rabbit abundance between both kinds of plots occurred in the first 2 weeks after release (Fig. 1), when the movements as a consequence of exploratory behavior (Letty et al. 2008) and the stress caused by capture, handling, transport, and release in an unfamiliar environment (Letty et al. 2003; Cabezas et al. 2011) might have increased the rabbits' vulnerability to death by birds of prey.

Our results further showed that the difference between open and closed plots remained constant after the third week (Fig. 1), suggesting that raptor predation of rabbits did not cause an important effect after this time. Indeed, despite the initial predation rate, Rouco et al. (2008) concluded that the predation by raptors cannot prevent rabbits from achieving a high abundance in fenced plots during the reproductive season. However, the landscape structure may determine the rate of predation, and therefore, the effect of raptor predation on restocking success may play a different role depending on habitat type (Ontiveros et al. 2005; Kamieniarz et al. 2013) and should be evaluated locally.

Nevertheless, both types of enclosure had an abrupt decrease in rabbit abundance during the first 2 weeks, and hence, causes of death other than predation (mainly stress) also affected rabbit survival (Rouco et al. 2008; Cabezas et al. 2011). In our study, the high density of released rabbit (50 individuals/ha) and a big bias in the sex ratio could have induced a huge social stress, thus increasing rabbit mortality. Therefore, although predation by raptors does not have a high effect on rabbit restocking success in the short term, our results suggest that the use of nets to roof the fences plots could improve rabbit survival in small enclosures (less than 0.5 ha). However, due to the high cost of a top fence, particularly in bigger plots, roofed enclosures may not be a cost-effective measure for raptors conservation and other measures, as confinement of rabbits by warren fencing appear to be a more cost-effective measure to enhance rabbit survival. Moreover, an increase of refuge cover by distribution of pallets within the fenced plots could help prevent the aerial predation and therefore improve the short-term rabbit survival, although further research in long-term and large-scale in this topic is necessary to assess the trade-off between the cost and benefit of excluding aerial predation.

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