

Rabbit populations and game management: the situation after 15 years of rabbit haemorrhagic disease in central-southern Spain

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Abstract Over recent decades wild rabbit populations have undergone a sharp decline in Spain with consequent negative impact both on a game-based economy, and on the conservation of threatened species that depend on rabbits. We investigated the relationships between rabbit population change and habitat and game management in central-southern Spain. To determine recent rabbit population changes we revisited 60 localities during summer 2002 to repeat surveys previously carried out in 1993. Each survey consisted of 4-km walked transects to record indices of rabbit abundance. The percentage of vegetation cover and of different soil types were also estimated during these transects. In the same areas, the type and intensity of game management practices were obtained by interviewing hunting managers, hunters or gamekeepers. Rabbit populations were stable or increasing only in 26.6% of the studied populations, more commonly in areas with soft soils where warren building is easier for rabbits and where rabbits were an important game species and managed to increase their numbers. Although we could not establish causality, habitat management and predator removal were the main management practices related to rabbit population change. Rabbit scarcity in Spain constitutes a serious problem for conservation, so hunters, researchers and policy makers need to reach a consensus to establish a long-term program to monitor rabbit population trends and share results obtained, especially when intense manage programs are being carried out to improve rabbit abundance.

Keywords Conservation · Game management · Habitat management · *Oryctolagus cuniculus* · Predator control · Rabbit recovery · Spain

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Abbreviations

RHD	Rabbit Haemorrhagic Disease
GAME	Categorical variable regarding the importance of rabbits as game species: (1) big game hunting areas; (2) areas where at least two other small game species were more important than rabbits; (3) localities where rabbits were considered the second important game species; and (4) hunting areas where rabbits were the main game species.
HUNTY	Categorical variable regarding the type of hunting area: public, private or non-hunting estates.
RDI	Relative Density Index. Principal Component Analysis was used to express four correlated variables (the number of rabbits seen, the number of latrines, the number of warren entrances and the number of scrapes) as a single rabbit abundance index.
RATE	The rate of rabbit population change $RATE = \frac{RDI_{2002} - RDI_{1993}}{RDI_{1993}}$

Introduction

The wild rabbit *Oryctolagus cuniculus* is a very important native species in the Mediterranean communities of the Iberian Peninsula (Monnerot et al. 1994). They are a keystone species in the Iberian ecosystem (Delibes-Mateos et al. 2007), being the staple prey of at least 29 predators (Delibes and Hiraldo 1981), including the most endangered raptor (Spanish imperial eagle, *Aquila adalberti*) and carnivore (Iberian Lynx, *Lynx pardinus*) species in Europe (Ferrer and Negro 2004). Additionally, rabbits are economically important as small game in Spain (Angulo and Villafuerte 2003), where over 30,000 private hunting areas cover more than 70% of the country (Villafuerte et al. 1998).

Over the last 50 years, rabbit populations have declined dramatically in the Iberian Peninsula (Virgós et al. 2007), mainly due to the arrival of the Myxomatosis in the 1950s (Ratcliffe et al. 1952) and then Rabbit Haemorrhagic Disease (RHD) at the late 1980s (Villafuerte et al. 1995). The additive effect of Myxomatosis and RHD reduced rabbits over most of their historical range, especially in ecologically less-favorable areas where some local extinctions have been recorded (Blanco and Villafuerte 1993). Five years after the arrival of RHD, Spain's wild rabbit population was found to be half of its original level (Blanco and Villafuerte 1993). Moreover, other factors such as habitat changes, over-hunting and climatic variation also appear to have contributed to the rabbit population decline across the Iberian Peninsula (Moreno and Villafuerte 1995; Fa et al. 1999).

Nowadays, it is known that RHD does not affect all rabbit populations similarly. Although many studies related to RHD have been conducted in Spain (Villafuerte et al. 1994, 1995; Fa et al. 1999; Calvete and Estrada 2000) and in other countries (Marchandeanu et al. 2000; Cooke and Fenner 2002), there is scarce information about how populations are responding to recurrent annual disease outbreaks of both RHD and myxomatosis (Villafuerte et al. 1995). Furthermore, most studies of rabbit population change in the Iberian Peninsula have been done at a local scale and very little information exists at a regional scale (Villafuerte et al. 1995, 1998).

Two of the main factors likely to influence the speed of rabbit population recovery are optimal habitat conditions and a reduction in hunting pressure. Villafuerte et al. (1995) suggested that rabbit population recovery after the appearance of RHD is higher in those areas with initially high rabbit densities. Therefore, increases after the crash would be expected to be larger in those areas with optimum conditions and smaller in places where,

for example, the habitat is less suitable for rabbits. High hunting pressure has already been cited as a negative factor for the recovery of rabbit populations in the Iberian Peninsula (Angulo and Villafuerte 2003; Williams et al. 2007). Other less studied factors related to management to increase game such as habitat improvement, predator removal, disease prevention treatments and supplementary feeding could also be influencing local rabbit abundance and population changes, especially when such techniques are applied more frequently since rabbits declined (Angulo and Villafuerte 2003).

The drastic decrease in rabbit numbers has affected the reproductive success of some predators (Villafuerte et al. 1996) and in some occasions, it has led to some increases in the level of their illegal control (Villafuerte et al. 1998). The Iberian Lynx, considered the most threatened cat of the world (Nowell and Jackson 1996), has suffered a great decline in recent decades at least in part due to rabbit population decreases (Palma et al. 1999; Palomares et al. 2001; Moreno et al. 2004). In addition it has been suggested that one of the main causes of the decline in red-legged partridge (*Alectoris rufa*) populations was the switch by rabbit hunters and predators towards this alternative prey species as rabbits declined (Gortázar et al. 2002). Therefore, because of the ecological and economic importance of rabbits, it is necessary to study in depth those factors which are determining the change in rabbit populations at a regional scale across the Iberian Peninsula.

As it is now 15 years after the arrival of RHD, and a decade after the most extensive rabbit censuses carried out in Spain (Blanco and Villafuerte 1993), the first objective of this paper was to evaluate whether or not rabbit populations are showing signs of recovery. Our second objective was to determine which factors were correlated with different levels of recovery of these populations. Factors related to habitat characteristics and hunting management activities were taken into account in order to explain rabbit population change.

Materials and methods

Rabbit population change

To determine recent rabbit population changes, in 2002 we repeated 60 surveys previously carried out in central-southern Spain during 1993 (Fig. 1). One rabbit survey was performed in each 1:100,000 map (Army Cartographic Service) within the study area, except in the distribution areas of the Iberian lynx and the imperial eagle, where two surveys were carried out per map. It is remarkable that our study area included almost all of the distribution areas of the Iberian lynx and the imperial eagle. From each 1:100,000 map, we selected a zone for the survey that was apparently favourable for rabbits (Blanco and Villafuerte 1993; Villafuerte et al. 1995, 1998). This criterion has been applied recently in studies concerning the relative abundance of mammals (Acevedo et al. 2005). To avoid seasonal differences in rabbit abundances, all the field work was again performed during June and July when rabbits reach their maximum densities in Spain (Blanco and Villafuerte 1993).

Each survey consisted of a 4-km walked transect. When possible, two observers walked together in a straight line crossing homogeneous environments. One of them counted rabbits while the other recorded signs: numbers of rabbit scrapes, numbers of warren entrances and numbers of rabbit latrines. A latrine was defined as a group of at least 20 pellets within an area of $200 \times 300 \text{ mm}^2$ (Virgós et al. 2003). Both rabbits and signs were recorded within a 6-m wide band along the transect.

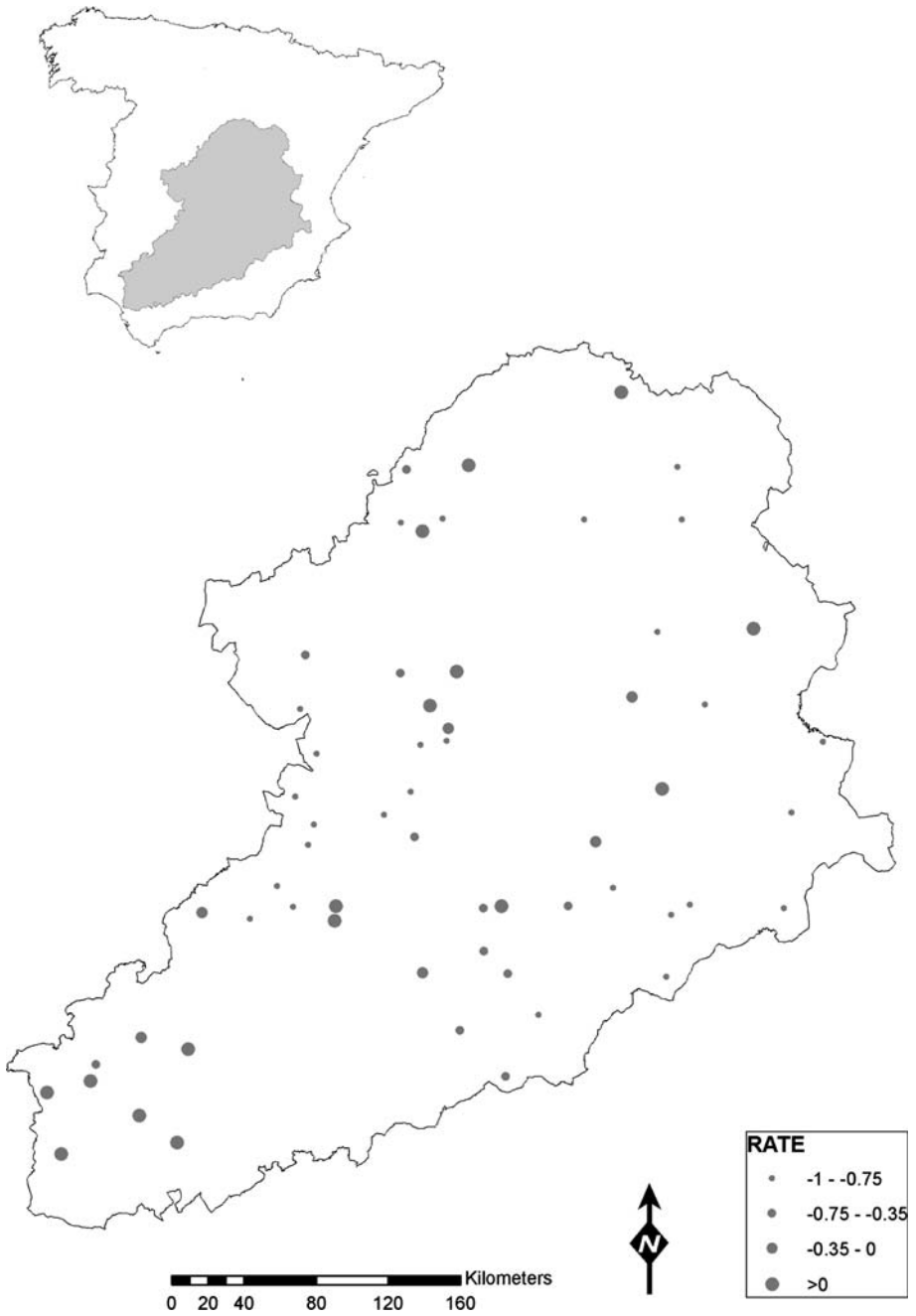


Fig. 1 Location of the sampling points. The size of the circles is proportional to the value of rabbit population change (RATE) in each locality

Habitat variables (vegetation cover and hardness of soil)

During the transects performed in 2002, we visually estimated the percentage of cover of trees or bushes, scrubland, pastures and bare ground within 100 m radius every 400 m (Virgós et al. 2003). We calculated average cover for each vegetation class using the 10 values obtained along the transect.

At the end of each transect performed in 2002, we visually estimated the percentage of different soil types within the 6-m wide band along the whole transect. We distinguished visually five kinds of soils: sandy soils like beaches or dunes where warrens could collapse; soft soils where building of permanent warrens is easy; hard soils where building of permanent warrens is difficult; stony soils where building of permanent warrens is very difficult and rock outcrops where building of warrens is impossible.

Variables related to hunting management activities

To document game management practices that were performed in surveyed areas and the intensity of their use during the intervening 10 years, we interviewed either a hunting manager, a hunter or a gamekeeper in each locality during 2003 and 2004 (Villafuerte et al. 1995). Overall, in about 90% of the interviews we met these people personally while for the rest we obtained information by fax, post or e-mail.

Game management activities were grouped into four types (Table 1). Questions about habitat management, predator removal, rabbit translocation, disease prevention treatments and creation of refuges were asked. According to the answers, we scored the intensity of these management activities on a scale of 1–5 (5: very frequent, 4: frequent, 3: sporadic, 2: few times, 1: never).

We asked which game species were considered most important in each hunting area and then grouped hunting areas into four categories (GAME): (1) big game hunting areas; (2) areas where at least two other small game species like red-legged partridge, Iberian hare *Lepus granatensis*, European turtle-dove *Streptopelia turtur*, common wood pigeon

Table 1 Game management activities about which hunters, gamekeepers or hunting managers were interviewed

1. Habitat management	Supplementary feeding for rabbits Supplementary feeding for partridges Supplementary feeding for other species Water supplies Crops for game species Scrub management
2. Predator removal	Fox removal Dog and cat removal Corvid removal Rodent removal
3. Restocking	Rabbit restocking
4. Disease prevention treatments and creation of refuges	Rabbit vaccination Warren deparasitisation Medicine supply Artificial warrens

Columba palumbus or thrushes *Turdus* sp. were more important than rabbits; (3) localities where rabbits were considered the second important game species and (4) hunting areas where rabbits were the main game species.

Finally, we also obtained other general information about hunting areas like the type of hunting (public, private or non-hunting estates; HUNTY) and the size of hunting areas.

Statistical analyses

The number of rabbits seen, the number of latrines, the number of warren entrances and the number of scrapes were highly correlated. To assess rabbit abundance a Principal Component Analysis (Zar 1984) was performed to express the four correlated variables using a single rabbit abundance index (the Relative Density Index, RDI, Villafuerte et al. 1998). In order to estimate the rabbit population change we employed the following formula

$$RATE = \frac{RDI2002 - RDI1993}{RDI1993}$$

In order to avoid multicollinearity we discarded a number of variables related to game management activities by using the Spearman rank correlations (Zar 1984). First, the most representative variables of each block of hunting management activities were chosen (see Results; Table 2). Second, we tested the correlations among variables of different blocks of hunting management activities (Table 3). After this reduction of variables, a total of 16 predictors were used to explain rabbit population change (see Results; Table 4).

We performed an exploratory analysis to evaluate the individual effect of each single variable on rabbit population change. We used Kruskal–Wallis test (Zar 1984) to explore the influence of the categorical variables HUNTY and GAME on the dependent variable. Spearman rank correlations were used to test the individual relationships between the

Table 2 Results of Spearman rank correlation between game management activities ($n = 60$ in all the cases; only pairs with at least one variable selected to explain rabbit population change are shown)

	<i>r</i>	<i>P</i> -value
<i>Habitat management</i>		
Supplementary feeding for rabbits & Supplementary feeding for partridges	0.68	<0.001
Supplementary feeding for rabbits & Supplementary feeding for other species	0.48	<0.001
Supplementary feeding for rabbits & water suppliers	0.45	<0.001
Supplementary feeding for rabbits & Crops	0.12	0.354
Supplementary feeding for rabbits & Scrub management	0.06	0.612
Crops & Scrub management	0.29	0.020
<i>Predator removal</i>		
Fox removal & Dog and cat removal	0.74	<0.001
Fox removal & Corvid removal	0.65	<0.001
Fox removal & Rodent removal	0.32	0.010
<i>Medical treatment and creation of refuges</i>		
Rabbit vaccination & Warren deparasitisation	0.49	<0.001
Rabbit vaccination & Medicine supply	0.34	0.007
Rabbit vaccination & Artificial warrens	0.44	<0.001

Table 3 Results of Spearman rank correlations among variables of different blocks of game management activities

	Crops	Fox removal	Rabbit restocking	Rabbit vaccination
Supplementary feeding for rabbits	$r = 0.14$ $P = 0.28$	$r = 0.39$ $P < 0.01$	$r = -0.11$ $P = 0.38$	$r = 0.23$ $P = 0.07$
Crops	–	$r = 0.28$ $P = 0.02$	$r = -0.09$ $P = 0.47$	$r = 0.14$ $P = 0.26$
Fox removal	–	–	$r = 0.29$ $P = 0.10$	$r = 0.23$ $P = 0.07$
Rabbit restocking	–	–	–	$r = 0.60$ $P < 0.01$

Table 4 Independent variables used to explain rabbit population change

	<i>r</i>	<i>P</i> -value
Initial rabbit density (1993RDI)	0.06	0.610
Vegetation structure		
% of trees and bushes	0.04	0.726
% of scrubland	-0.12	0.356
% of pastures	0.07	0.574
% of bare ground	0.07	0.571
Soil type		
% of sandy soils	-0.05	0.695
% of soft soils	0.37	0.003 ^b
% of hard soils	0.12	0.331
% of stony soils	-0.21	0.106
% of rocks	-0.35	0.004 ^b
Game management		
More important game species (GAME)	–	–
Type of Hunting (HUNTY)	–	–
Size of hunting areas	0.10	0.415
Fox removal	0.30	0.018 ^b
Rabbit vaccination	0.24	0.057 ^a

Results of Spearman rank correlation between rabbit population change (RATE) and the continuous independent variables considered are shown ($n = 60$ in all the cases; ^a $P < 0.1$; ^b $P < 0.05$)

dependent variable RATE and the continuous independent variables. After this exploratory analysis, factors that yielded $P < 0.1$ were used in the model building procedure (Acevedo et al. 2005; Sergio et al. 2005). We employed General Regression Models by following a backward stepwise procedure (Sen and Srivastava 1990). The most parsimonious model was selected using the Mallow’s Cp coefficient (Sen and Srivastava 1990; Mac Nally 2000).

Results

Rabbit population change

Average RDI decreased from 1.07 in 1993 (SE = 0.14; range 0.02–5.25) to 0.62 in 2002 (SE = 0.10; range 0–3.02). Rabbits increased only in 26.6% ($n = 16$) of the analysed

localities while in the other 73.4% localities ($n = 44$), they declined (Fig. 2). Rabbit population change (RATE) showed a maximum value of 3.26 and a minimum of -1 while its average was -0.23 .

Rabbit Density Index (RDI) explained 60% of the variance of the single rabbit variables. The eigenvalue of the PCA-factor extracted was 2.41. The most meaningful variables were number of warren entrances and number of latrines (factor loadings were 0.81 in both cases), although two other variables, number of scrapes and number of rabbits seen, were also highly correlated with RDI (factor loadings 0.75 and 0.70 respectively).

Variables related to hunting management activities

The results of Spearman rank correlations among variables explaining the four blocks of defined game management types are shown in Table 2. In the group called “Habitat management”, supplementary feeding for rabbits was strongly correlated with supplementary feeding for partridges, for other species and with the provision of water (Table 2). The establishment of crops was strongly correlated with scrub management and these two activities were not correlated with supplementary feeding for rabbits (Table 2). In the “Predator removal” group there was a strong correlation between fox removal and the other activities (Table 2). Finally, in the block called “Disease prevention treatment and creation of refuges”, vaccination showed a strong correlation with the other three activities within the group (Table 2). On the other hand, the results of Spearman rank correlations among variables of different blocks of game management activities are shown in Table 3. Both crops and supplementary feeding for rabbits were strongly correlated with fox removal and rabbit restocking was highly associated with vaccination (Table 3). On the basis of these results, we selected fox removal and rabbit vaccination as predictors to explain rabbit population change (Table 4).

Relation between dependent variable and independent variables

We did not find any significant correlation between RATE and the four classes of vegetation estimated in this study (Table 4). For the analysis of soils, rocky soil was negatively and significantly correlated with RATE, while soft soil showed positive and significant correlation with RATE (Table 4; Fig. 3). Because soft soil and rocky soil were highly correlated ($P = 0.01$) and the first one is more suitable for rabbits, we selected this variable for our final model.

Fig. 2 Rabbit abundance index (RDI) of 2002 in relation to those of 1993. The black line represents stable populations. Under this line populations decreased while those above increased

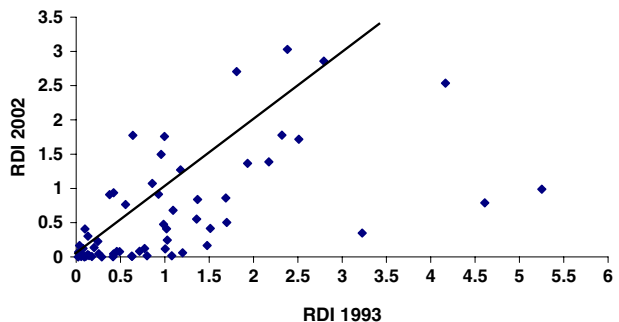
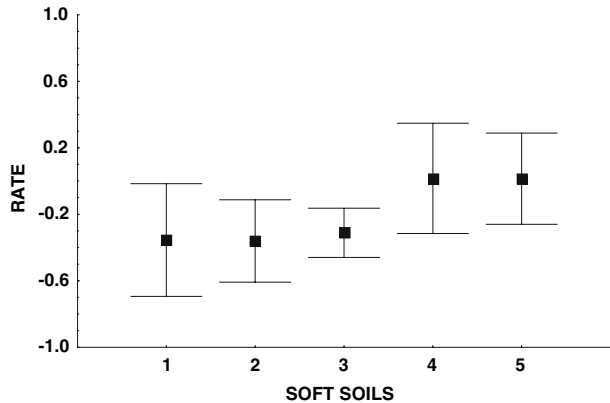


Fig. 3 Rabbit population change (mean and SE of variable RATE) in relation to percentage of soft soil (1 = 0%; 2 = 0–20%; 3 = 20–40%; 4 = 40–60%; 5 = >60%). See text for details



The rabbit rate of change (RATE) was significantly positively related to the importance of rabbit as game species (GAME; Kruskal–Wallis test $H = 16.84$; $P < 0.01$), but not with the type of hunting (HUNTY; Kruskal–Wallis test $H = 2.15$; $P = 0.54$). In fact, estates where rabbits were the most important game species, had largest RATE values, and estates concentrating on big game had smallest values (see Fig. 4a).

Among the variables related to hunting management activities, fox removal was significantly and positively correlated with RATE (Table 4; Fig. 4b). Rabbit vaccination was also positively correlated with RATE but was only marginally significant (Table 4).

According to these results we selected four variables for the model building procedure: (1) the importance of rabbits as game species (GAME); (2) soft soils where building of permanent warrens by rabbits is feasible; (3) fox removal and (4) rabbit vaccination. The final model retained two of the variables included in the initial models: fox removal and GAME. Fox removal was the main factor explaining rabbit population change ($df = 1$; $F = 4.99$; $P = 0.02$), while the importance of rabbit as game species (GAME) was marginally significant ($df = 3$; $F = 2.21$; $P = 0.09$).

In other words, rabbit recovery occurred most frequently in areas with soft soils, where rabbits were considered an important game species and some management activities such as habitat management and predator removal were carried out to increase rabbit numbers.

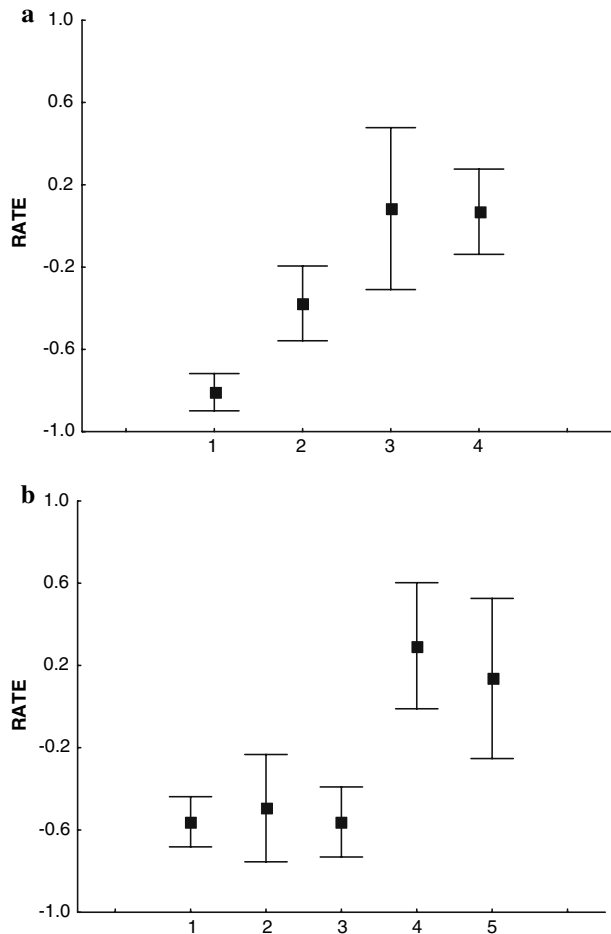
Discussion

Rabbit population change

Although some authors have suggested that rabbit populations are recovering in some areas of the Iberian Peninsula (Vicente Piorno, pers. comm.), we have only found an increase in little more than a quarter of our study plots (Figs. 1 and 2). Even though it has been suggested that rabbit recovery could be higher in those localities which have had high rabbit abundance in the past (Villafuerte et al. 1995), we did not find any evidence of this here (Table 4; Fig. 2).

The index used here (RDI) is known to have some biases associated with the variables from which it comes (Palomares 2001). However, it is considered a reliable way to estimate rabbit abundances at a large scale (Villafuerte et al. 1998). Our index is strongly correlated with other rabbit signs such as latrines, warren entrances (see Results) or pellet counts

Fig. 4 (a) Rabbit population change (mean and SE of variable RATE) in relation to its importance as game species (1 = big game hunting areas; 2 = rabbits are not considered between the most important game species; 3 = rabbits are considered the second most important game species; 4 = rabbits are the most important game species). (b) Rabbit population change in relation to fox removal (1 = never; 2 = few times; 3 = sporadic; 4 = frequent; 5 = very frequent)



(M. Delibes-Mateos, unpublished data), which have been commonly employed in other studies to estimate rabbit densities in the Mediterranean region (Palma et al. 1999; Palomares 2001; Lombardi et al. 2003; Fernández 2005). Moreover, we have compared rabbit abundance at the same localities on two different dates using the same techniques, so avoiding the problem of making comparison of rabbit abundance between different habitats.

Habitat

The distribution of rabbits is determined by variables related to habitat such as vegetation cover, soil fertility and hardness and water availability (Blanco and Villafuerte 1993; Wilson et al. 2002). Rabbits reach higher numbers in ecotones between open and shrub-covered areas, which allow them to feed and avoid predators by moving from one habitat to another at different times of the day (Rogers and Myers 1979; Moreno et al. 1996; Villafuerte and Moreno 1997; Fa et al. 1999; Lombardi et al. 2003; Virgós et al. 2003).

Despite using a similar methodology to others to characterize the cover of vegetation classes (Fa et al. 1999; Virgós et al. 2003), we did not find significant relationships between rabbit population change and different types of vegetation (Table 4). It has been suggested that habitat variables act as good predictors in areas of high rabbit densities while in localities where the species occurs in low numbers or where its distribution is fragmented, other stochastic factors (like disease) or deterministic factors (hunting management) may explain rabbit population change (Virgós et al. 2003). However, the variables we considered and the way that they were measured could be masking the importance of vegetation cover on rabbit population change. Furthermore, another important issue to consider in studies of the influence of vegetation cover is the role of scale (Orrock et al. 2000). Silva et al. (2005) suggested that microhabitat characteristics tend to influence small mammals at the population level while macrohabitat and landscape features are important determinants of small mammals especially at the community level.

Rabbit abundance and distribution seems to be strongly influenced by soil type (Parer and Libke 1985; Blanco and Villafuerte 1993; Wilson et al. 2002) because its hardness determines the possibility of warren digging. Although rabbits can live above ground when there is a dense scrub layer, they are usually dependent on warrens for breeding and for protection from predators and climatic extremes (Parer and Libke 1985). Blanco and Villafuerte (1993) found that, in study areas with high rabbit densities, most of the species signs (latrines, scrapes or warren entrances) were recorded in sandy soils. In studies conducted in southern England, Trout and Smith (1995) observed a strong correlation between the breeding success of rabbit populations and the type of soil where they appear. Soil type also modifies the warren microclimate and these environmental conditions in the rabbit burrows have a great influence on the development of fleas, considered important disease vectors in the European rabbit (Osacar-Jimenez et al. 2001). In our work, soil type was correlated with rabbit population change (Table 4). However, this variable did not appear as one of the main predictors of rabbit recovery in the final model (see Results). Despite this lack of significance in the final model, population recovery seems to be higher in areas with higher percentage of soft soils (Fig. 3) than in localities with soils in which warren building is more difficult. This has also been observed in a recent research in northern Spain (Williams et al. 2007).

Game management

We did not find any relation between rabbit population change and the type of hunting (HUNTY) on our study plots (Table 4), probably because the management carried out to improve rabbit populations is very similar in all types of hunting areas. On the other hand, the lower proportion of public estates in central Spain could be masking the differences between both types of hunting areas. The size of hunting area also showed no relationship with rabbit recovery (Table 4).

Despite the lack of significance in the final model, the rate of recovery was highest in those hunting areas where rabbits were considered one of the main game species (Fig. 4a). Hunters probably consider rabbits more important in those places where recovery was higher, but, as we discussed before, highest levels of rabbit recovery did not depend on highest rabbit numbers (Table 4; Fig. 2). Areas where rabbits were the main or the second most important species showed similar average rates of population recovery (Fig. 4a). However, there was great variance in rabbit recovery among localities where rabbits were not considered as the main game species, but still important (Fig. 4a). This is probably

because in such areas red-legged partridges were the most important small game species, and rabbits were secondary. Where rabbits were not an important game species, their populations decreased (Fig. 4a).

In the light of our results, rabbits seem to be recovering better in areas where several game management activities to improve their numbers were carried out simultaneously and regularly. Thus, we have observed a higher rabbit recovery in estates where predator control and several habitat management activities such as scrub management, crops for game species or supplementary feeding were frequent practices (see Results; Fig. 4). Conversely, other management activities such as rabbit restocking or rabbit vaccination were not related to rabbit population change (see Results).

Habitat management

Habitat management is a common practice in hunting areas in Spain. Several studies have discussed the benefit of this management activity. O'Donoghue and Krebs (1992), working with snowshoe hares *Lepus americanus* in Canada, did not observe any increase of reproduction after food addition, but Krebs et al. (1995) found that numbers were higher where food was provided and proved that cycles in snowshoe hares are a result of the interaction between food supplies and predation. However, it has been suggested that the availability of food in winter modifies the start of the breeding season in rabbit populations (Wallage-Drees 1983). Furthermore, Villafuerte et al. (1997) found that rabbit numbers in Doñana National Park depend on the availability of food of high quality. Similarly, traditional management of scrubland, mainly clearings, may trigger a rapid rise in rabbit numbers as a consequence of an increase in food availability (Moreno and Villafuerte 1995). According to our results, scrub management, crops for game species and supplementary feeding were frequent activities in areas where rabbit populations seem to be recovering (see Results).

Predator removal

The role of predators in regulating prey populations has been debated over many years (Erlinge et al. 1984). Trout and Tittensor (1989) concluded that predator pressure on rabbits can be a potential regulating factor, especially at low rabbit densities. After the outcome of the RHD in central-southern Spain some populations dropped dramatically, and some local extinctions were observed (Blanco and Villafuerte 1993). Therefore, below certain levels of rabbit numbers, predator pressure could be limiting rabbit population recovery—the “Predator-Pit” hypothesis (Trout and Tittensor 1989; Pech et al. 1992; Banks 2000). The model employed in our study suggested that rabbit recovery was higher in those areas where predator control, especially fox removal, was a common practice (Fig. 4b). Similar results have been found previously by other authors (Trout and Tittensor 1989; Trout et al. 2000). After the arrival of RHD, Spain may be experiencing a situation resembling that which occurred during the myxomatosis crash, when predator extermination campaigns were in operation (Villafuerte et al. 1998). Certain fast, cheap and non-selective methods of predator control, such as poison, could also affect “non-guilty” but vulnerable species (Villafuerte et al. 1998; Virgós and Travaini 2005), such as raptors or protected carnivores. While certain hunters continue to control predators (including rare

species) without any selective criterion, the supposed benefits for rabbits do not justify, in our opinion, the damage caused to protected species.

Restocking

Translocation is a common practice in conservation biology and wildlife management (Griffith et al. 1989; Letty et al. 2003). In Spain, rabbit restocking is frequently carried out for hunting purposes and for predator conservation, with thousands of individuals being released every year (Moreno et al. 2004). We did not find any relationship between rabbit restocking and population change (see Results). This finding is not surprising since there are many factors affecting the efficiency of such techniques. For example, Moreno et al. (2004) suggested that the highest restocking success occurred whenever rabbits were released in the richest quality habitat and out of the breeding season in sparse groups. These recommendations made by researchers are not usually taken into account in most of the rabbit releases carried out in Spain, because hunters try to achieve a significant increase in rabbit density in a relative short period of time (Calvete et al. 1997).

Disease prevention treatments

Disease prevention treatments are becoming frequent in hunting areas of Spain. Since both myxomatosis and RHD have had a substantial impact on rabbit populations, many efforts have been made to rescue these populations by vaccinating rabbits against these viral diseases. The effectiveness of these vaccination campaigns has been debated by hunters, conservationists and wildlife managers because the success of these procedures has been generally negligible (Calvete et al. 2004). According to our results, vaccination was marginally significant in the first exploratory analysis (Table 4) but it did not appear related to rabbit population change in our final model (see Results). This is probably because to be effective a large proportion of rabbit needs to be vaccinated every year; but owing to the low density of rabbit populations in many of the study areas rabbit capture is expensive and its effectiveness limited. Also, rabbit stressed through capture may be immunodepressed so vaccination may not be as effective as when used in domestic rabbits, for which it was initially designed (Calvete et al. 2004).

Implications for rabbit conservation

Although the wild rabbit is a very important species for both predator conservation and hunting activity on the Iberian Peninsula, and a great deal of effort is being applied to estimate trends in its abundance, there is no standard methodology to monitor populations. It is clearly necessary to establish a long-term program to monitor rabbit abundance on the Iberian Peninsula. The use of an index derived from several kinds of rabbit signs, such as the one used in this work, provides a relatively quick way of assessing abundance and could help to monitor rabbit population change at a large scale and should be encouraged at a national level.

Unfortunately, our study represents only a snapshot of the situation as it is based on two surveys separated by nearly 10 years and may be miss information from intra-annual variations. In spite of this we have clearly shown that rabbits in central-southern Spain

continue to decline slowly. The repetition (every 5 years) of this survey over the same transects would provide more valuable information of the changing status and conservation of rabbit populations.

It is likely that population recovery depends on the joint effect of several management activities. Although it is not possible to determine cause-effect from the relationships between rabbit population change and management activities, the species seems to be recovering better in those estates in which game management practices to improve its numbers are frequently carried out. However, experimental approaches are necessary to prove the specific role played by game management. Despite this lack of experimental evidence and because rabbits are so important for both conservation and hunting in Spain, it is of critical importance to maintain those game management activities that seem to be related to rabbit recovery. Moreover, those Authorities with responsibility in hunting management and/or conservation should encourage management practices focused on rabbit recovery especially where it is required for maintaining endangered predators, and provide detailed advice on the methodology that should be employed.

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