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Control of the European rabbit in central Spain

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Abstract The European rabbit is a growing problem for agriculture in parts of its natural range. In this study, our aim was to use historical records over two periods within the last 50 years to analyze trends in the number of requests made for rabbit control in Central Spain. We gathered data on rabbit control applications made in 1967 from Rabbit and Hare Control Authorization Records (CARs) and corresponding information for 2005 from Technical Hunting Plans (THPs). THPs are currently the official mechanism to apply for rabbit control licenses in the country. We show that although only 4.2 % of municipalities requested to control rabbits in 1967, this proportion was 71 % in 2005. Given that there is no evidence of rabbit population increases in the study region, we suggest that other factors may explain the observed rise in control requests. We contend that sport hunting is the main reason for the higher numbers of control requests in 2005. Evidence for this is the fact that hunting has increased since the 1960s as a means of augmenting income for landowners, and that the most requested method for control was the shotgun. Based on these results, we recommend that in order to adequately assess the real negative impacts of rabbits on human interests in Spain there is a need to implement a more robust data-gathering mechanism when control requests are made. We suggest the development of a more detailed control application form, similar to that used in Spain in the 1960s, in which the reason(s) for a rabbit control request can be clearly described.

Keywords Wildlife conflict · Keystone species · Crop damage · *Oryctolagus cuniculus* · Hunting

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Introduction

The European rabbit (*Oryctolagus cuniculus*) is native to the Iberian Peninsula (Monnerot et al. 1994). The species is considered to be a keystone species in Mediterranean ecosystems (Delibes-Mateos et al. 2007) since it is a significant prey item for more than 40 species in these environments (reviewed in Delibes-Mateos et al. 2008). Rabbits are also viewed as ecosystem engineers (e.g., Gálvez-Bravo et al. 2009) and are one of the most important game species in the Iberian Peninsula (e.g., Angulo and Villafuerte 2003).

Rabbits have been introduced to many regions of the world (Flux and Fullagar 1992), and have rapidly posed major threats to biodiversity and agriculture (e.g., Mills 1986; Thompson and King 1994). Although most Iberian

rabbit populations have declined dramatically in recent decades (Villafuerte and Delibes-Mateos 2008; Delibes-Mateos et al. 2009a), the species still causes damage to agricultural interests in some regions (Barrio et al. 2010).

Herbivores can significantly threaten agricultural interests by browsing foliage, debarking trees, overgrazing pastures and eating crops. Although there are many examples of invasive species becoming pests (i.e., Chapman 2003; Elliott 1989; Engeman 2004), species which play a major role in an ecosystem are rarely regarded as pests in their native ranges. Examples of keystone species that affect farming activities include pikas (*Ochotona curzoniae*) on the Tibetan plateau (Smith and Foggin 1999) and prairie dogs (*Cynomys* spp.) in the North American prairies (Kotliar 2000). In the Iberian Peninsula, rabbits may parallel prairie dogs and plateau pikas because of the damage they cause to crops and the associated socioeconomic impacts (Delibes-Mateos et al. 2011).

Recent research on the control of rabbit populations has emerged from countries where the species has been introduced. Information on the ecological and economic effects of rabbits, as well as mechanisms for their control (e.g., poisoning, gassing and destruction of burrows, release of predators, erection of wire fences, myxoma and rabbit hemorrhagic disease viruses as biological control agents) are available for Australia (Cooke 2008). However, data of the impact of rabbits in Iberia are relatively scarce (however, see Barrio et al. 2010).

Research on rabbits in the Iberian Peninsula, which mainly commenced in the 1970s, has focused primarily on the causes and consequences of population declines (Delibes-Mateos et al. 2009a; Ferreira 2012). However, quantification of crop damage caused by rabbits has been little studied (i.e., Barrio et al. 2010). As a consequence, there is little information on the damage caused by the species and control methods that have been employed in their original range. Given the high ecological prominence of rabbits in the Iberian Peninsula, understanding situations in which the species is at conflict with human interests is important for rabbit management.

The ability to detect the effects of short- and long-term processes on landscapes may be clouded by collective "amnesia," or ignorance of past human events and their residual effects (Dovers 2000). To facilitate effective management, scientists and managers must explore the natural dynamics of ecosystems also from an environmental history perspective (Swetnam et al. 1999).

In Spain, to the best of our knowledge, there is only one historical data source on rabbit control: the Rabbit and Hare Control Authorization Records (CARs). As early as the 1960s, these records resulted from applications made by landowners seeking to protect agricultural crops and areas of reforestation from rabbit damage. These documents were requested by the Central Government throughout the 1960s, but no records were kept after 1970. Subsequently, Spanish legislation dictated that hunters were responsible for any agricultural damage caused by game species, and during the 1990s, all requests for rabbit control would have to feature within a hunting estate's management plan, known as Technical Hunting Plans (THPs). These documents have been mandatory since 1990 (Gálvez 2004) and periodically submitted to the appropriate Regional Government (depending on the region, every 4 to 5 years). The main aim of this documentation is to regulate the protection, and foster game variety. To this end, the intention to carry out management practices (including rabbit control) and the expected hunting bag sizes in the hunting estate must be reported in the document (Vargas et al. 2006). In summary, information on rabbit control over two distinct periods is available.

In the present study, our principal objectives were: (1) to compare the number of rabbit control requests made in the 1960s and during 2005; (2) to describe the principal rabbit control methods currently employed in Central Spain (the Castilla-La Mancha region); (3) to explore whether municipalities that requested rabbit control during the 1960s currently report high levels of rabbit abundance; (4) to analyze the principal land types for which rabbit control was requested during the 1960s and recently; and (5) to analyze whether current rabbit control is performed principally in regions of high rabbit abundance.

Materials and methods

Regulation and management of European rabbits causing crop damage in Spain

In Central Spain (Castilla-La Mancha), agricultural areas are highly favorable for rabbits and red-legged partridges (*Alectoris rufa*); here, both species have the highest recorded densities in Spain (e.g., Villafuerte and Delibes-Mateos 2008) (Fig. 1). Because of this high game abundance, farmers take advantage of hunting as an additional economic resource. Hunting is only allowed in "hunting estates", thus farmers may either create a hunting estate, or grant permission (e.g., by renting out the land) to a game manager or hunting association to hunt on their land (see below). Currently, there are around 6,000 hunting estates in Castilla-La Mancha, covering about 84 % of all land (Ríos-Saldaña 2010).

In Spain, some Regional Governments have recently approved special guidelines for the control of rabbits in response to concerns about excessive crop damage. Valencia (E Spain) issued a relevant Order on June 11, 2009 and Andalucía (in S Spain) promulgated a Resolution on June 30, 2011. However, the control of rabbits is not regulated by Pest Laws in Spain (e.g., see the Royal Order of April 19 of 1929; the Order of April 20 of 1932; and the Law of 20 December 1952, all of which seek to protect forests from pests). This is because Hunting Laws regulate the control and management of damage

Fig. 1 The Castilla-La Mancha region of central Spain showing the positions of the La Mancha Plain and the main mountain ranges and the boundaries of the five provinces

caused by game species. The Laws are based on the Hunting Act of May 16 1902, which states (article 9): "any farm owner can legally hunt on that farm, but will be directly responsible under the Civil Code for damage caused by such hunting to the property of adjacent property owners". This principle currently remains in force, and is included in all Laws dealing with damage caused by game species. For example, the Hunting Act of April 4 of 1970 includes a section (Title V) devoted to liability for damage. Article 33 states that "holders of hunts will be responsible for damage caused by game to neighboring lands; the owner of the land is the person who will be held to account". The current laws of most Regional Governments contain essentially identical text (i.e., that of Castilla-la Mancha, Central Spain; Article 17 of Law 2; 15 July 1993).

The THPs of some regions (including Castilla-la Mancha) contain specific sections detailing how rabbits are to be controlled when they damage crops. Managers must lodge their intent to control the species, and must also declare the proposed control period, as well as the preferred control method. A permit is usually granted after the extent of crop damage has been formally assessed. "Control" refers to practices used to reduce rabbit numbers to reduce agricultural damage.

As the rabbit is a game species, shooting is considered an important control method in Spain. Rabbit hunting periods, as regulated by the Spanish government, have not changed since at least 1902. Shooting of rabbits is permitted from October to December inclusive (Angulo and Villafuerte 2003). However, when control is required, shooting outside this time period may also be allowed. In addition, ferrets (Cowan 1984) and corral trapping (also termed the drive corral approach, which employs a wire-fenced trap resembling a gill net; see Shepherd and Williams 1976) are also used to control rabbits. The trap-and-snare method, which was the exclusive method of rabbit control 40 years ago, is currently prohibited.

Data sources and analysis

We collected and analyzed rabbit control applications based on CARs and THPs. The CARs are historical records collected from the early 1960s; the principal goal of the CAR system was to protect agricultural crops and areas of reforestation from rabbit damage. An estate manager requesting rabbit control would detail the geographical location of the farm and the crop type damaged in the CAR. We used CARs for 1967 since prior to this year no property application form was required and most CARs after 1967 were not available. We obtained 110 CARs for this year (>99 % of all CARs for that year).

For 2005, a total of 5,357 THPs (100 %) were available for analyses. We employed a chi-square test to determine whether numbers of municipalities in each province requesting rabbit control were significantly different between 1967 and 2005.

Because managers recorded the specific control methods planned for use in the game estates in THPs, we could determine which control method was preferred. Managers would typically request more than one control method, thus combinations of the control methods requested were also analyzed.

To explore whether municipalities that requested rabbit control in 1967 had high rabbit numbers in 2005, we used the average hunting yield (HYs) as an estimate of rabbit abundance. HY realistically identify areas rich or poor in Iberian small game species at a macro-geographical scale (Vargas et al. 2006; Farfán et al. 2008). Average HYs were estimated from THP data reported by the game estates. Digital maps of the estates were not available, so we assigned each estate to the appropriate municipality.

We estimated the average HY of rabbits in each municipality as:

$$HY = \frac{Total\ number\ of\ rabbits\ captured\ in\ the\ game\ estates\ in\ the\ previous\ hunting\ season}{Total\ area\ of\ the\ game\ estates\ (ha)} \times 100,$$

where HY is the hunting yield per municipality, expressed as the number of rabbits captured per 100 ha (1 km^2) of game estate (e.g., Delibes-Mateos et al. 2009b).

The THP data for 2005 were compared, using one-way ANOVA, with rabbit abundance in municipalities that requested control during 1967 (n=36) and hunting estates within municipalities where such management was not performed (n=883). We also determined whether 2005 rabbit abundance levels differed significantly among hunting estates. Each dependent variable was normalized using the log (x+1) transformation (Zar 1999).

Finally, we used information from the CARs and THPs to determine the type of crop and forest resource in which rabbits caused damage during 1967 and 2005. Land use was evaluated according to six main categories: cereal crops, olive groves, vineyards, grasslands, forests (including scrublands, native forest, and reforestation), and "other" (including cotton, garden crops, vegetables, legumes and unspecified crops). We determined land types affected by rabbit damage within each municipality during 1967 from data contained in the CARs. As land type damaged by rabbits in hunting estates was not specified in THPs we calculated the total surface area of each land use category within hunting estates that had requested rabbit control, assigned a predominant land use type to each municipality, and assumed that this was the land type affected by rabbits. We used a chi-square test to compare differences in the number of rabbit control requests per land use type between 1967 and 2005.

To explore whether any relationship existed between the control method requested and rabbit abundance (measured as HY), we performed a binary logistic regression on data derived for each control method used (shotgun, ferret control, and corral trap). To assess whether rabbit control type used was related to local rabbit abundance and/or current land use status, we used logistic regression to analyze the HY data in the THPs. We calculated the accuracy of prediction revealed by the area under the receiver operating characteristic (ROC) curve in a goodness-of-fit model (AUC; Fielding and Bell 1997; Manel et al. 2001; Brown and Davis 2006). In all statistical testing, we used SPSS for Windows (version 12, SPSS Inc.).

Results

The distribution of rabbit control requests in central Spain has changed during the past 50 years. The proportion of municipalities in each province requesting rabbit control during 1967 and 2005 differed significantly [$\chi^2(df=4)=45.81$, $p<0.001$]. Rabbit control was requested by only 4.2 % of municipalities in 1967, but approximately 72 % (of the 919 municipalities in our study area) of hunting estates in 2005 (Fig. 2).

In 2005, rabbit abundance was higher in those hunting estates within municipalities that had requested rabbit control in 1967 compared with those hunting estates from which no such requests had been received ($F_{1,\ 3,981}=72.27$, $p<0.001$).

Rabbit control requests per land use type varied between 1967 and 2005 [$\chi^2(df=3)=160.33$, $p<0.001$; Table 1]. Compared to 1967, a greater proportion of control requests made in 2005 involved cereal crops and forest areas. There was a lower proportion covering olive groves, vineyards, and other land types. Moreover, the types of agricultural and forest resources present in any area were found to be associated with the number of requests for rabbit control, as shown by chi-square tests. The data were statistically significant ($p<0.001$) and logistic regression was therefore able to predict if rabbit control was or not requested within a given area (Table 2).

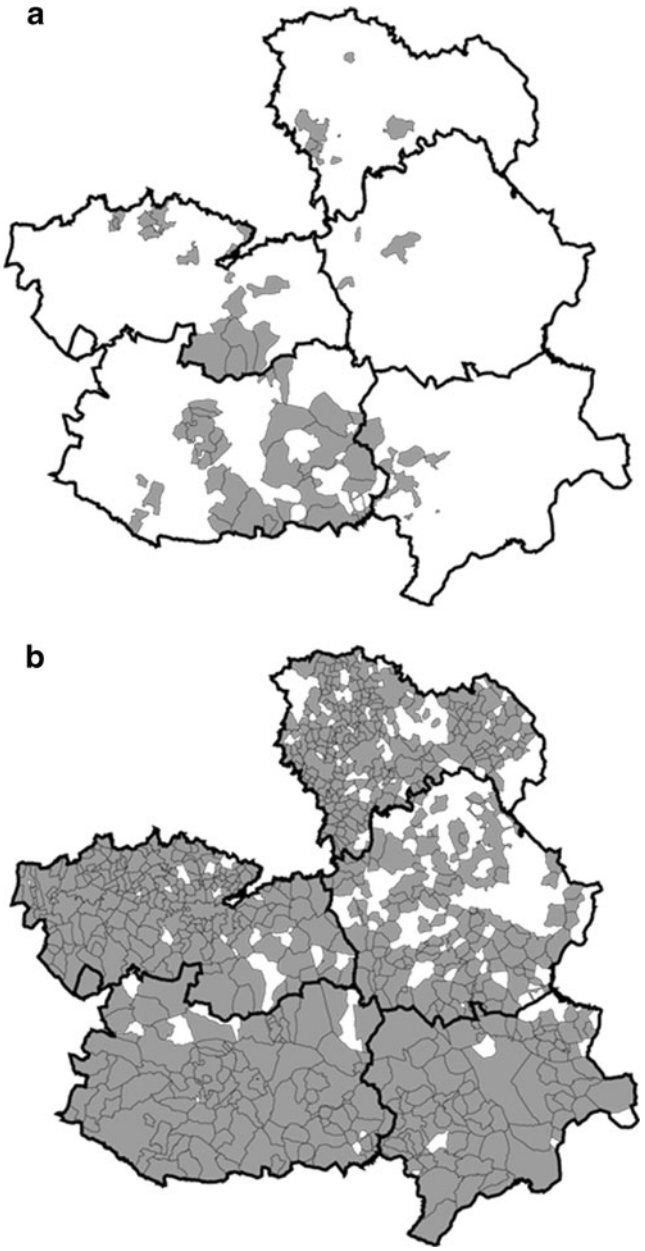

Fig. 2 Municipalities (*shaded*) within the five provinces of the Castilla-La Mancha region that requested rabbit control in 1967 (**a**) and 2005 (**b**) because of crop damage

The principal rabbit control method requested in THPs was the shotgun; this was true of >95 % of the game estates. Use of ferrets was applied for by approximately 44.5 % of hunting estates. Corral trapping by only 9.7 % of estates.

We found no significant difference between the numbers of requests for use of shotgun control [likelihood ratio test, χ^2 (df=1)=2.3, p=0.12] and ferrets [χ^2(df=1)=0.02, p=0.88] in game estates varying in rabbit abundance in 2005. However, requests for the corral trap method were more frequently made in game estates on which rabbits were abundant [χ^2(df=1)= 71.1, p<0.001] (Fig. 3).

Table 1 Numbers (with percentages) of rabbit control requests for six types of agricultural and forest resources

Type of agricultural and/or forest resource	1967 *n* (%)	2005 *n* (%)
Cereal crops	17 (15.5)	970 (45.9)
Forests	36 (32.7)	913 (43.2)
Olive groves	1 (0.9)	38 (1.8)
Vineyards	24 (21.8)	55 (2.6)
Other land uses	32 (29.1)	138 (6.5)
Total rabbit control requests	110	2,114

Discussion

The present study, for Central Spain, is arguably the first to provide direct evidence that the rabbit is increasingly considered a threat to human interests in the Iberian Peninsula. Specifically, rabbit control was requested by 51 % of game estates and 71 % of municipalities in 2005 but only 4.2 % of municipalities in 1967. One possible explanation for the change over time may be that rabbit numbers were very low in Spain during the late 1960s because of widespread mortality caused by myxomatosis (Muñoz 1960). Although few reliable data are available, it is known that rabbit numbers recovered in Spain when resistance to myxomatosis developed, as was the case in Australia (e.g., Saunders et al. 2010). However, rabbit populations in Spain declined markedly from the 1970s to the 1990s (Villafuerte and Delibes-Mateos 2008; Delibes-Mateos et al. 2009a). Indeed, most rabbit population numbers are still declining, and recoveries have been documented in only a few instances (Delibes-Mateos et al. 2009a). It is therefore unlikely that rabbit numbers were higher in 2005 than during the 1960s.

Other factors may have contributed to the increase in rabbit control requests. For example, farmers might currently seek to

Table 2 Logistic regression exploring whether rabbit control requests in 2005 were associated with local rabbit abundance (estimated as hunting yields) and/or land use at that time

Variable	Coefficient
Hunting yield	0.012
Olive groves	0.374
Grasslands	0.333
Cereals	0.579
Vineyards	0.311
Number of observations	3,975
χ^2 Wald	158.399*
AUC	0.70

*p<0.001

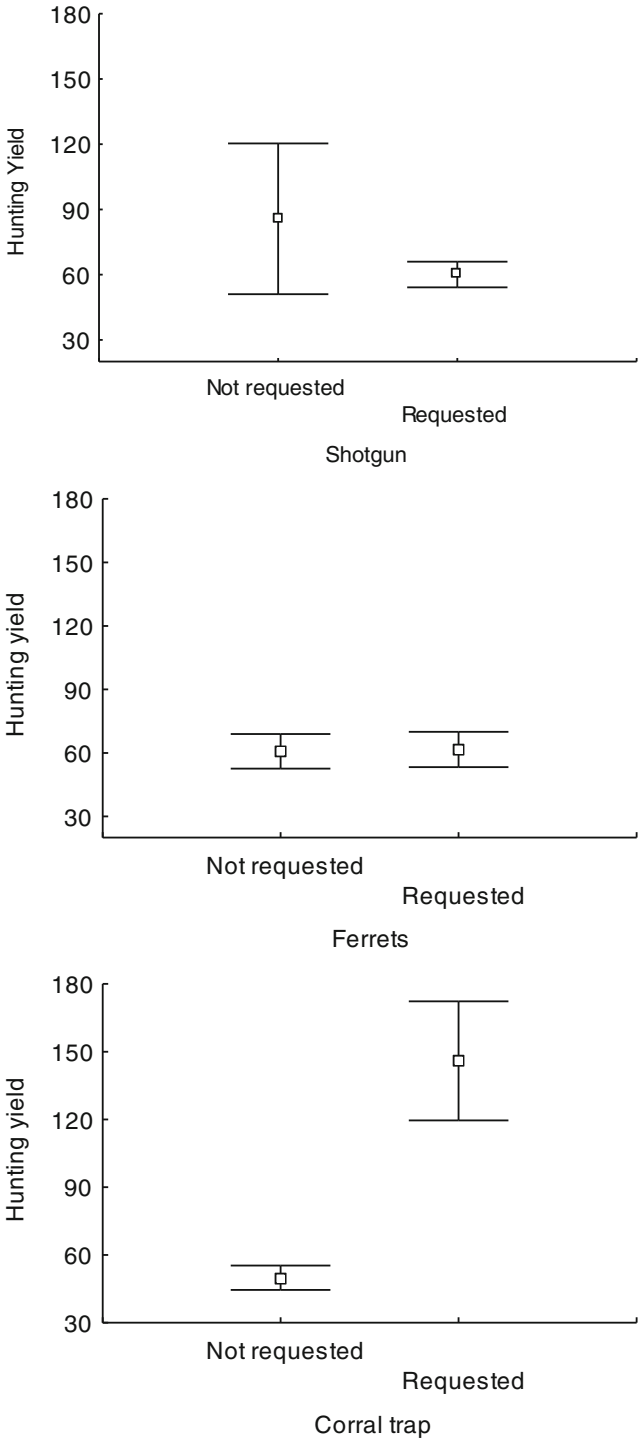

Fig. 3 Rabbit control methods and hunting yield in 2005 (average number of rabbits captured per 100 ha of hunting estate). Error bars represent the 95 % confidence interval

extract greater economic benefit from their land than was the case in the past. Farmers may now be more sensitive when viewing rabbit damage to crops, resulting in an increase in rabbit control requests. Farmer sensitivity may be currently higher than in the sixties because they are accustomed to receiving subsidies via a number of different financial mechanisms (i.e., Common Agricultural Policy of the EU). It is also true that the loss of weeds and the impoverishment of plant communities caused by agricultural intensification may have had significant effects on rabbit food availability, consequently forcing the animals to browse crops (Barrio et al. 2010, 2013). Another explanations could be that hunters would request to control rabbits in order to extend the hunting season (and therefore increase rabbit hunter bags) independent of the amount of crop damage actually caused by the species. The fact that the most commonly requested rabbit control method was the shotgun may support this hypothesis. Administratively, such a situation may be promoted, or at least tolerated, because the terms "hunting methods" and "control methods" are used synonymously in THPs.

Differences between the data sources from the two study periods could also explain our results. Thus, whereas CARs expressly addressed mitigation of crop damage caused by rabbits and hares, THPs were developed as part of an effort to protect game species (FUNGESMA 2001). The focus of the two initiatives is therefore completely different. Furthermore, the obligation to complete a THP for rabbit control a priori, may encourage some game estates to request a THP as a preventative measure, despite the absence of any real need to control rabbits. If damages occur while the THP is in force, the farmer/hunter should only have to request an additional authorization to control rabbits.

A significant finding was that in 2005, the use of corral traps was common in areas of high rabbit density, where large numbers of animals are hunted annually. Corral trapping is a traditional hunting method whereby a group of hunters flushes rabbits into a large fenced plot, after which the animals are captured (Palmer 1896). This method requires substantial effort (Henke and Demarais 1990) and can allow the capture of multiple numbers of animals (Powell and Proulx 2003). However, the approach is appropriate only where rabbits are very abundant. In contrast, shotguns are usually employed within low rabbit density sites though shotgun use may also reflect a desire to hunt outside the designated hunting season (see above). The use of ferrets (described as early as Strabo; see García y Bellido 1983) originated in Spain but has subsequently been employed in many countries (Cowan 1984). In Spain, this method is normally prohibited, although ferret use may be authorized under exceptional circumstances (e.g., Castilla-La Mancha Hunting Law, Decree 141/1996). Our results showed that this control method is frequently requested in central Spain, usually in areas where rabbits do not attain high numbers (Fig. 3).

In 2005, rabbit hunting yields were higher in municipalities where rabbits were controlled during the 1960s. One such region, Montes de Toledo, in the north of our study area has been considered a good hunting area since the 16th

century (López-Ontiveros 1991). The high HYs (104 rabbits/100 ha; Ríos-Saldaña 2010) in this area reflect the large numbers of rabbits present (Villafuerte et al. 1998). Such rabbit densities explains why several endangered predators that depend on rabbits, including the Spanish imperial eagle (*Aquila adalberti*), are found in many game estates in this region (Delibes-Mateos et al. 2007). These data are consistent with studies on rabbit population dynamics suggesting that areas in which had high rabbit densities in the past recovered more quickly from the effects of rabbit hemorrhagic disease than those areas where rabbit densities were low (Blanco and Villafuerte 1993; Cotilla et al. 2010).

Our model reveals a strong link between the type of agricultural or forest resource and the number of requests for rabbit control. An AUC value can be interpreted as the probability that the model will correctly distinguish between two distinct possibilities. In the present example, the AUC data suggest that our model (which includes data on land type) can accurately distinguish between the presence or absence of rabbit control requests for a particular land use type with an accuracy of 0.7 (Table 2). AUC values of 0.5 −0.6 indicate low accuracy, 0.7−0.9 indicate intermediate but useful accuracy, and >0.9 indicate high accuracy (Swets 1988).

Agricultural and forest resources supposedly damaged by rabbits differed between 1967 and 2005. During the late 1960s, the principal resource type damaged was “forests”. This was unexpected, as rabbits are usually associated with agriculture and typically are not abundant in woodlands (Farfán et al. 2004). A significant reforestation campaign was conducted in Spain between 1940 and 1970 (Gómez and Mata 2002), which may explain why damage to forest resources was significant during this period. In contrast, the main land use types for which requests for rabbit control were made in 2005 were cereal crops, followed by forests. Unfortunately, information on resources subject to rabbit damage is not collected in THPs, and, consequently, the damage recorded in localities with a significant proportion of forest may have been influenced by damage to adjacent agricultural land.

In summary, we have provided the first direct evidence that the rabbit is broadly considered to be harmful to agriculture in Central Spain and this is potentially a recurrent situation in other parts of the species’ natural range. We also demonstrated that the perception of rabbits as a threat to human interests has increased significantly over the last 50 years. This could have important management consequences. For example, conservation biologists may find it difficult to accept that a keystone species currently labeled as “vulnerable” should be controlled in a manner appropriate for a pest (Delibes-Mateos et al. 2011). A possible means for targeting management solutions appropriate to whether the rabbit is a pest or a keystone species is to encourage administrators to devise a simpler system for estate managers to request measures for rabbit control. However, this is not easy. Hunters may exploit the current system to increase hunting activity even in circumstances where crop damage is not really a problem. Therefore, we recommend the implementation of a more specific application form, similar to the one employed in the 1960s, that allows an applicant to ask for rabbit control measures whenever the clear evidence of damage to crops, and after being assessed by competent authorities. The management authorities may even allow further methods to control rabbits on assessment of the actual problem. The area damaged by rabbits should be described in more detail, as was the case in the CARs. Such a form, perhaps not necessarily to be completed by hunters, would help researchers and managers develop a more realistic understanding of rabbits as threats to human interests. Finally, further research on methods of rabbit control in Spain should be encouraged, such as the quantification of extent of damage to agriculture, the efficacy of rabbit control, and the development of new methods to reduce impacts or numbers.

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