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REVIEW

Habitat management as a generalized tool to boost European rabbit *Oryctolagus cuniculus* populations in the Iberian Peninsula: a cost-effectiveness analysis

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ABSTRACT

1. The European rabbit *Oryctolagus cuniculus* was designated as a protected species in Spain and Portugal following sharp declines in many populations. The ongoing decline highlights the need to implement cost-effective management strategies for this staple prey and important small game species of Iberian Mediterranean ecosystems.
2. Habitat management is one strategy in general use, though little is known about its true influence on rabbit populations. The main goal of this study was to assess the frequency of use and cost-effectiveness of habitat management techniques for European rabbit populations in the Iberian Peninsula. We conducted a thorough literature review and used this information to: (i) estimate the frequency of use of habitat management techniques; (ii) evaluate the relative and absolute effectiveness of habitat management; and (iii) assess the economic implications of its application.
3. At least one habitat management technique was used on over 60% of hunting estates. The relative effectiveness (measured as the % population change before

and after management) of habitat management techniques is high, although we found no relationship between high relative effectiveness and rabbit densities considered biologically and/or economically meaningful (e.g. densities able to support a breeding population of endangered predators or medium to high rabbit harvest yields). We did not find any clear relationship between the cost and the effectiveness of the habitat management techniques applied, as the most costly techniques were not the most successful ones.

4. We conclude that rabbit management strategies in the Iberian Peninsula should include improved and upscaled protocols for habitat management, in order to mitigate threats and promote the recovery of rabbit populations.

INTRODUCTION

The western part of the Mediterranean Basin is considered a global biodiversity hotspot (Myers et al. 2000). This region is made up of a mosaic of different terrestrial habitats, containing a diverse range of species, about half of which are endemic (Blondel & Aronson 1999). Loss and degradation of habitats caused by changes in land-use patterns are primary causes of species depletion and represent the most important threats for Mediterranean species (Hoekstra et al. 2005, Cuttelod et al. 2008). Therefore, mitigating the effects of habitat degradation through habitat management is one of the most commonly recommended actions for the recovery of declining species, not only in the Mediterranean Basin, but also in other ecosystems worldwide (see, e.g. Anonymous 1998).

One of these declining species is the European rabbit *Oryctolagus cuniculus*, which is native to the Iberian Peninsula (Monnerot et al. 1994). Among the many factors involved in rabbit decline, the gradual degradation of habitat favourable for this species is held as one of the most important (Delibes-Mateos et al. 2010). Decline in rabbit populations has had important negative consequences in the Iberian Peninsula, both ecologically and economically; e.g. it has contributed to declines in populations of predators specialized in consuming rabbits, such as the Iberian lynx *Lynx pardinus*, and it has caused a drastic decline in the number of rabbits killed by human hunters. This has resulted in a general rise in management actions aimed at increasing numbers of rabbits (e.g. restocking, vaccination campaigns; Angulo 2003, Piorno 2006, Delibes-Mateos et al. 2008a). Habitat management is one of the main management tools used to increase Iberian rabbit density, either for conservation purposes or for hunting, so that this species is a suitable model for the study of the effectiveness of this management strategy.

Habitat management is one of the oldest forms of wildlife management (Leopold 1949) and comprises a variety of techniques. In general, the main goal of habitat management is to increase carrying capacity, by fulfilling a species' basic requirements and allowing it to increase its abundance and expand its range into surrounding areas. In the case of European rabbits, interventions are intended to reproduce traditional landscapes, i.e. mosaics of agricultural areas and natural vegetation (Fernández-Alés et al. 1992). These landscapes provide suitable food and cover (Moreno & Villafuerte 1995). Thus, current habitat management consists generally of (i) creating feeding habitats (by providing crops or pastures – generally mixtures of Leguminosae and Graminae – or by providing supplementary feeders in dense scrubland areas); and (ii) providing shelter through scrubland management and/or the construction of artificial warrens where refuge for rabbits is scarce (e.g. Cabezas & Moreno 2007, Fernández-Olalla et al. 2010, Rouco et al. 2011).

On the whole, habitat management techniques used to aid the recovery of European rabbit populations are considered effective in Mediterranean ecosystems (Moreno & Villafuerte 1995, Cabezas & Moreno 2007, Catalán et al. 2008, Ferreira & Alves 2009). However, to date, their success has been systematically tested only by assessing changes in rabbit abundance at a local scale in plots with and without habitat management. Therefore, the questions arise whether these changes are important at the rabbit population level and how effective various combinations of habitat management techniques are. For example, changes in rabbit abundance following the implementation of habitat management may have been magnified because these interventions were applied to low density populations in most need of intervention. In such cases, although apparently effective, habitat management would not, by itself, allow rabbit densities to reach the minimum levels necessary, e.g. to sustain rabbit-specialist predator populations (Palomares 2001), or even levels necessary for optimal harvest yields (Farfán et al. 2004). Moreover, with a few exceptions (e.g. Ferreira & Alves 2009), recommendations are not given about how often habitat management needs to be carried out in order to ensure its success over time (Litvaitis & Villafuerte 1996).

The importance of evaluating the performance of alternative conservation programmes, by comparing their effectiveness in achieving pre-established biological aims while taking into account programme costs, is increasingly recognized (e.g. Murdoch et al. 2007, Busch & Cullen 2009, Moran et al. 2010), as financial investment in these projects also increases. For example, in Spain, a few species have been the target of conservation projects in Doñana National Park that, from 2004 to 2006 alone, attracted funding of nearly €7.9 million from the Spanish Government and European LIFE+ Funds (Martín-López et al. 2009). Regionally, part of this funding was allocated exclusively to the conservation of the European rabbit, as the primary prey of top predators from Mediterranean ecosystems (Delibes-Mateos et al. 2008b). Simón et al. (2012) estimated that nearly €91 million (mainly from European Union funds) has been spent in Spain on Iberian lynx conservation projects, which included habitat and prey (European rabbit) management. Likewise, but with smaller budgets, hunting estates frequently apply similar management strategies to try to boost rabbit numbers (Angulo 2003). Analysis of cost-effectiveness is one tool that allows alternative programmes to be compared, and a small but growing body of literature on this method has been applied to biodiversity conservation (e.g. Cullen et al. 2001, 2005, Engeman et al. 2002, Shwiff et al. 2005, Laycock et al. 2009, Murdoch et al. 2010, Laycock et al. 2011). Cost-effectiveness analysis is particularly useful for evaluating conservation projects when the costs are measured in monetary units, but the expected benefits are measured using ecological information to assess the effect of the project. In this context, a project is said to be cost-effective if it achieves the policy objective at the lowest possible cost.

In this review, we combine ecological information (rabbit abundance measures) and economic information (costs) to assess and compare the effectiveness and cost-effectiveness of several habitat management techniques for the recovery of European rabbit populations, by using empirical case studies. More specifically, firstly, we estimate the frequency of use of several habitat management techniques; secondly, we evaluate their relative and absolute effectiveness; and thirdly, we assess their cost-effectiveness.

METHODS

Search strategy used to identify relevant published case studies

We conducted an in-depth review of published case studies about habitat management techniques aimed at boosting European rabbit populations in the Iberian Peninsula. Relevant studies were identified by conducting a Web of Knowledge search. We searched for terms that stemmed from the following words, in the following combinations: rabbit or *Oryctolagus* and habitat management or habitat improvement and Iberian Peninsula or Spain or Portugal. Searches were conducted until December 2011.

We also searched for data about this topic in technical reports, unpublished manuals, game and publicity magazines, and descriptive book chapters aimed at the general public. Taking into account the goals of this study, we only considered those works in which either the frequency of use of habitat management techniques was described, or their effectiveness was evaluated by means of robust experimental designs. None of these works met our standards, and so they were excluded from the review.

Frequency of use of habitat management techniques

We evaluated the frequency with which habitat management is employed in the Iberian Peninsula using the information reported in three studies, which were carried out in different areas at different spatial scales (Table 1; Fig. 1a). Two were performed in the central-southern region (Angulo 2003, Delibes-Mateos et al. 2008c), the main hunting area in the Iberian Peninsula (e.g. >80% of land in central Spain is made up of hunting estates; Ríos-Saldaña 2010), where rabbits reach their highest densities (Villafuerte et al. 1998). The third study (Piorno 2006) was carried out in the whole of Spain, and hence included information from areas where rabbit abundance is very variable (Table 1).

Hunters, landowners and game or conservation managers were personally interviewed for two of the studies; they were asked whether at least one habitat management technique was employed in their hunting estates (Angulo 2003, Delibes-Mateos et al. 2008c). In Andalusia (southern Spain), 307 survey points were selected using a step-random design based on altitude and topography (Angulo 2003). Delibes-Mateos et al. (2008c) selected 60 hunting estates that were apparently favourable for rabbits in central-southern Spain, which included Andalusia, Madrid and Castilla-La Mancha (Fig. 1). We also used the information gathered by Delibes-Mateos et al. (2008c) to investigate whether hunting managers considered habitat management techniques successful or not, and whether they thought that some habitat management techniques were more effective than other management strategies implemented in their hunting estates (e.g. predator control, rabbit restocking, etc.). Finally, in the only large-scale case study, questionnaires were sent by post to the technical personnel (working for regional governments) responsible for the supervision of hunting management in each of the Spanish provinces. Respondents were asked to classify the frequency with which each management strategy was applied in their provinces as: very rarely, rarely, intermediate, frequently or very frequently (Piorno 2006).

Table 1. Summary of the frequency of use of habitat management techniques for rabbits *Oryctolagus cuniculus* throughout the Iberian Peninsula, according to the literature included in this review

Reference	Study area	Study sites (*n*)	Data type	% of sites where at least one habitat management technique is employed	Creating pastures and/or planting crops (% of sites)	Scrub management (% of sites)	Supplementary feeding (% of sites)	Supplying water (% of sites)	Artificial warrens (% of sites)
Angulo 2003	Southern Spain	307 survey plots	Personal interviews with managers	64	42*	30	18	26	4
Delibes-Mateos et al. 2008c	Central-southern Spain	60 hunting estates	Personal interviews with hunting managers	88	65†	28	39‡	51	29
Piorno 2006	Spain	47 Spanish provinces	Questionnaires sent by post to technical personnel from regional governments	Data not provided	20–43§	Data not provided	Data not provided	Data not provided	23–54¶

*Creating pastures.

†Planting crops.

‡Specific supplementary feeding for rabbits.

§Includes both scrub management and planting crops. The minimum value includes only provinces in which the use of this management technique was intermediate, frequent or very frequent. The maximum value (more conservative) also includes provinces in which the use of this management technique was rare (see Methods for details).

¶Includes creating artificial warrens and protecting natural warrens. The minimum value includes only provinces in which the use of this management technique was intermediate, frequent or very frequent. The maximum value (more conservative) also includes provinces in which the use of this management technique was rare (see Methods for details).

Effectiveness of habitat management techniques

In five scientific field case studies undertaken between 1991 and 2007, the impact of different habitat management techniques on several aspects of the biology of the European rabbit was evaluated (Moreno & Villafuerte 1995, Palomares et al. 1996, Cabezas & Moreno 2007, Catalán et al. 2008, Ferreira & Alves 2009). All five were conducted in the south of the Iberian Peninsula, and both hunting and non-hunting areas of conservation concern were included (Fig. 1b). For that purpose, the original authors measured differences in rabbit abundance, either temporal or spatial, or between controls (as defined by the authors) and treatments (Table 2). In all case studies, the same methodology was used to assess relative rabbit abundance (pellet counts in sample plots of known size; Fernandez-de-Simon et al. 2011), and studies were carried out during comparable seasons (summer and/or monthly counts).

The habitat management techniques implemented in the case studies included: (i) scrub management, either by using fire in two distinct scrubland types (Moreno & Villafuerte 1995) or by means of heavy machinery, usually over a continuous dense scrubland area (Palomares et al. 1996, Ferreira & Alves 2009); (ii) constructing artificial warrens, either plastic (Mayoral, Marbella, Spain; Cabezas & Moreno 2007), or made from natural materials (Cabezas & Moreno 2007, Catalán et al. 2008); (iii) crop planting and/or creating pastures (to provide feeding areas; Palomares et al. 1996, Cabezas & Moreno 2007, Ferreira & Alves 2009); (iv) supplying water (usually using artificial drinking sources); and (v) fencing (Catalán et al. 2008; see Table 2). Although these techniques are common among case studies (e.g. crops, artificial warrens), they vary substantially in terms of cost and exact methods used (e.g. the crop species sown, the material employed to build artificial warrens, etc.).

We used two different parameters to assess and compare the effectiveness of the different sets of habitat management techniques used in the five case studies. Whenever deemed necessary for our estimates, we requested raw data from the authors of the original publications. Firstly, we determined relative effectiveness (RE): the percentage change between the pre-management and post-management rabbit abundance reported in each case study. Secondly, we estimated absolute effectiveness (AE): the difference in rabbit density between habitat management plots and control plots. These estimates were then compared with known relevant ecological thresholds of rabbit density, such as those necessary for the reproduction of top predators, and with known density levels of economic importance, such as those found in highly profitable small-game hunting estates. This approach allowed us to investigate and compare the magnitude of

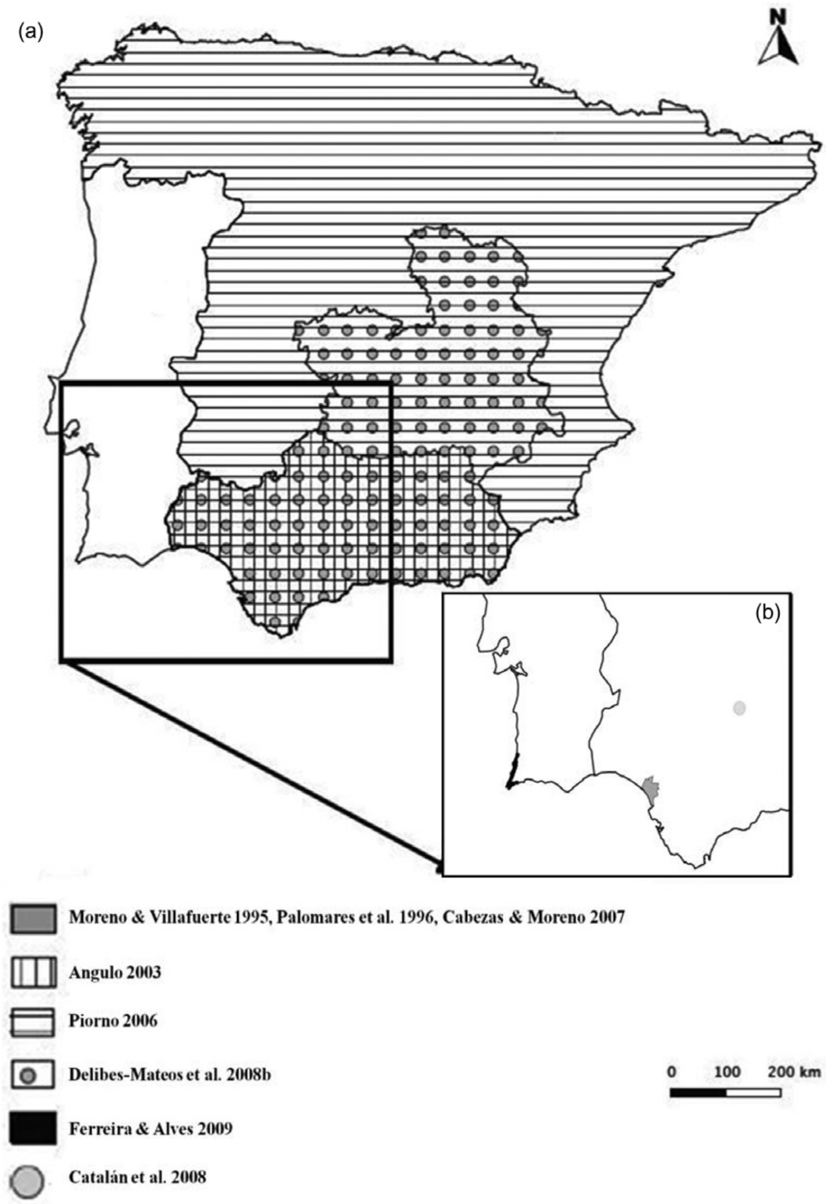

Fig. 1. Geographic distribution within the Iberian Peninsula of the case studies reviewed in the literature regarding (a) frequency of use (Table 1; Angulo 2003, Piorno 2006, Delibes-Mateos et al. 2008b) and (b) effectiveness (Table 2; Moreno & Villafuerte 1995, Palomares et al. 1996, Cabezas & Moreno 2007, Catalán et al. 2008, Ferreira & Alves 2009) of habitat management targeted at European rabbit *Oryctolagus cuniculus* populations. This map was built using Quantum GIS software (Anonymous 2012) .

changes in rabbit density caused by habitat management techniques.

RELATIVE EFFECTIVENESS

The baseline rabbit abundance prior to habitat management considered in this work was that quantified in what the original authors defined as 'controls'. Despite these not being true controls (because there was no replicated monitoring before and after the implementation of habitat management in plots with and without treatment), for the purpose of this study, we call these data CONTROL. In most of the original publications, the comparison between rabbit abundance before and after habitat management was done in relative (%) terms, so we estimated a similar RE rate using European rabbit abundance before ($CONTROL_i$) and after habitat management (HM_i), for each set of habitat management techniques used in the case studies, as follows:

$$RE_i = \frac{HM_i - CONTROL_i}{CONTROL_i} \times 100 \qquad \text{(Equation 1)}$$

This equation measures the relative magnitude (%) of change in rabbit abundance (pellets $day^{-1}\,m^{-2}$) induced by habitat management. In some of the case studies, different habitat management techniques within the same study were

Table 2. Summary of the case studies reviewed in the literature about the effects of habitat management on European rabbit *Oryctolagus cuniculus* abundance in different populations of the central-southern Iberian Peninsula

											CONTROL	HM	RE
Reference	Case study	Location	Goal	Study period	Habitat management technique employed	Original rabbit abundance units	Season during which counts were made	Study plots (n)	Total managed area (ha)	Feature	Overall rabbit abundance (pellets day^{-1} m^{-2})	Overall rabbit abundance (pellets day^{-1} m^{-2})	Overall %
Moreno & Villafuerte 1995	1	Doñana National Park, Spain	Con	1991–92	Scrub management using fire	Pellets m^{-2}	Summer counts 1989; monthly counts 1991 and 1992	16–40	120	1A: Wet scrubland	0.070	0.050	–28.0
										1B: Dry scrubland	0.020	0.050	263.5
Palomares et al. 1996	2	Doñana National Park, Spain	Con	1994	Scrub management using heavy machinery; creating pastures	Pellets m^{-2}	Monthly from July to September 1994	2	300	2	5.060	3.260	–35.6
Cabezas & Moreno 2007*	3	Doñana National Park, Spain	Con	1999–2002	Planting crops; plastic warrens; artificial warrens†	Pellets m^{-2}	Bimonthly from September 1999 to November 2002	8	24	3A: S, F	0.040	0.070	97.6
										3B: F	0.040	0.126	236.8
										3C: S	0.040	0.090	142.4
Catalán et al. 2008	4	Central Sierra Morena, Spain	Game	2005–07	Artificial warrens†; supplying water; fencing	Pellets day^{-1} m^{-2}	Monthly from March 2005 to March 2007	2	2	4A: SEV 1st year	0.020	0.330	1550
										4B: SEV 2nd year	0.030	1.080	3500
Ferreira & Alves 2009	5	South Portugal	Game	2000–02	Scrub management using heavy machinery; planting crops	Pellets m^{-2}	Spring 2000; monthly from May 2001 to October 2002	4	600	5A: SC 1st year	0.030	0.020	–40.6
										5B: SC 2nd year	0.040	0.050	36.2
										5C: SC 3rd year	0.010	0.060	292.3
										5D: SC, F 1st year	0.060	0.050	–15.9
										5E: SC, F 2nd year	0.070	0.120	66.9
										5F: SC, F 3rd year	0.030	0.060	79.6

Goal: Con – conservationist only; Game – game management. Feature (codes as in Fig. 2): S, shelter; F, food; SEV, several techniques applied; SC, scrub clearance; HM, plots in which habitat was managed; RE, relative effectiveness. To standardize results, the original method used in case studies 1, 2 and 5 (pellets m^{-2}) was converted into pellets day^{-1} m^{-2} (corrected by 30 days), and the original method used in case study 3 (pellets m^{-2}) was converted into pellets day^{-1} m^{-2} (corrected by 60 days).

*In this case study, only data from plots without translocation were used.

†Made of natural materials.

independently tested, so that more than one RE_i per case study is presented. Spearman correlations were used to assess if the rate of change in rabbit abundance was associated with a referential initial local abundance (i.e. if RE_i was correlated with $CONTROL_i$).

ABSOLUTE EFFECTIVENESS

To quantify the real magnitude of the changes induced in rabbit populations by habitat management, we converted rabbit abundance indices provided in the literature into rabbit densities. We used a regression formula, provided by Fernandez-de-Simon et al. (2011), between rabbit density (i.e. rabbits ha^{-1}) and pellet counts in cleared sampling plots as measured in the existing habitat management case studies. After conversion to rabbit densities, absolute effectiveness (AE_i) for each management technique was estimated as

$$AE_i = HM_i \text{ density} - CONTROL_i \text{ density} \quad \text{(Equation 2)}$$

where HM_i density is rabbit density (rabbits ha^{-1}) on habitat management plots and $CONTROL_i$ density is rabbit density on control plots in the case studies. The resulting densities after habitat management were then compared with threshold rabbit densities described in the general literature in order to investigate their relevance.

The cost-effectiveness of habitat management

Cost-effectiveness analysis was used to compare the costs of habitat management with rabbit abundance gains. First, we estimated the initial cost and annual costs of implementing the habitat management techniques presented in each of the case studies: scrub management, creating pastures, planting crops, constructing artificial warrens (from plastic or natural materials), supplying water and fencing (Table 3). To determine the initial cost of each technique, we used the data provided by Guil and Moreno-Opo (2007), who proposed guidelines for traditional land management to conserve Mediterranean forests in the Iberian Peninsula. Secondly, we estimated the effectiveness measure and the cost-effectiveness of European rabbit recovery for each set of habitat management techniques used in the case studies. As a measure of effectiveness, we used the concept of Conservation Output Protection Years (COPY), from the cost-effectiveness literature (Cullen et al. 1999, Fairburn et al. 2004, Laycock et al. 2011). This concept was developed to evaluate the success of programmes aimed to improve the conservation status of threatened species. COPY was used to quantify the level of improvement in the recovery of European rabbits achieved by each of the management techniques, according to the following formula:

$$COPY_i = \sum_{T=0}^{T} \frac{HM_{it} - CONTROL_{it}}{(1+d)^t} \quad \text{(Equation 3)}$$

where T is the elapsed time between the moment habitat management techniques were implemented and the moment the monitoring of their effects ceased, i.e. the number of years for which the effect of habitat management was measured; HM_{it} and $CONTROL_{it}$ are European rabbit abundance for habitat management i at year t in plots with management measures, and in those used as controls, respectively; and d is the discount rate: the alternative rate of return that could be accomplished with the same funds. For all case studies reviewed, T equals 2 years, except for Ferreira and Alves (2009; 1.5 years). The study by Palomares et al. (1996) was excluded from this analysis because T was notably higher (24 years) potentially biasing our results. The

Table 3. Descriptions of habitat management techniques for rabbits *Oryctolagus cuniculus* and initial cost (€, Euros) according to Guil and Moreno-Opo (2007)

Habitat management technique	Description	Average cost
Fencing	Game fence: 2-m high mesh.	(€12.87/m) €5.148/ha
Plastic warrens	Each warren consists of several independent modules made of polypropylene. The modules are assembled in a circle of approximately 3 m total diameter, providing radial entrances, tunnels and breeding chambers.	€464/warren
Scrub management	Mechanized clearing of woody shrubs that were present in 70% of the area. The debris were removed from the site, or piled in tiers where the slope was <20%.	€284.83/ha
Creating pastures/planting crops	Implementation of permanent pasture or rain-fed crops, including preparatory work and planting.	€281.33/ha
Artificial warrens (made of natural materials)	Earth and vegetation warrens, 2 × 2 m or 4 × 5 m in size, built from tree branches buried under 1 m of soil and including galleries with five entrances made of plastic tubes and covered by vegetation (leaves, scrub, etc.).	€272.30/warren
Supplying water	Constant volume automatic water supplier, total capacity 100 L (€80/unit)	€4/ha*

*For the purpose of comparison with other management techniques, we considered the use of an average of five water suppliers per 100 ha.

cost-effectiveness formula was estimated as the present value (PV) average cost (€ m^{-2}) per COPY, i.e. per unit discounted increase in rabbit abundance (pellets $day^{-1} m^{-2}$) associated with the habitat management technique, as follows:

$$\text{Cost–COPY ratio} = \frac{\sum_{t=0}^{T} C_{it}(1+d)^t}{COPY_i} \qquad \text{(Equation 4)}$$

where C_{it} is the cost per m^2 of habitat management i in year t. The discounting process, when d takes positive values in Equation 3, allows the expression of benefits (rabbit abundance) recorded in different years in PV equivalent terms, thus capturing that conservation status gains are preferred sooner rather than later (Cullen et al. 2001). This analysis would show that the management techniques that produced recovery more quickly are more cost-effective than those following which conservation gains took longer to occur. In addition, the initial and annual costs were discounted to the same common year equivalent value (Equation 4). Most expenditures were incurred at the time when habitat management techniques were implemented, so this was taken as the reference time for discounting of benefits and costs. For consistency with the cost-effectiveness conservation literature, the discount rate chosen was $d = 3.5\%$, and a sensitivity analysis was conducted by applying a lower level of $d = 0\%$, i.e. no discounting (and consequently no time preferences assumed for costs and rabbit conservation gains) and a higher level of $d = 6\%$ (e.g. Laycock et al. 2009, 2011).

In terms of evaluating the cost-effectiveness of the techniques, higher COPY measures imply higher conservation gains and a more effective habitat management technique; a smaller cost–COPY ratio means more cost-effective techniques in terms of recovery of rabbit population achieved per € invested.

RESULTS

Frequency of use of habitat management techniques

Habitat management was employed very frequently in the Iberian Peninsula (Table 1). More effort was put into habitat management in hunting estates apparently favourable for rabbits (at least one habitat management technique was used in 88% of hunting estates; Delibes-Mateos et al. 2008c; Table 1) than in randomly selected areas (64%; Angulo 2003; Table 1). This was true for all techniques except scrub management, as shown in Table 1.

Creating pastures and planting crops was the most commonly employed habitat management technique (Table 1). Supplementary feeding and supplying water were also very common in hunting estates apparently favourable for rabbits (Delibes-Mateos et al. 2008c); however, these were not so common when Andalusian areas alone were considered (Table 1; see also Angulo 2003). Other habitat management techniques, such as scrub management and the management of rabbit warrens, were employed less frequently (Table 1).

Most hunters and game managers considered habitat management techniques to be successful to boost rabbit numbers (Delibes-Mateos et al. 2008c). Creating pastures and/or planting crops and supplying water were considered the most successful strategies (78.9%, $n = 38$ and 75%, $n = 36$, respectively). Although supplementary feeding, scrub management and constructing artificial warrens were also considered generally effective (61.3%, $n = 31$; 60.6%, $n = 33$; 60.6%, $n = 33$, respectively), the number of interviewees perceiving these techniques as effective was lower. Nearly half of the hunters and game managers considered that the most effective management strategy was a habitat-oriented one (42%, $n = 60$). Among these, supplementary feeding and planting crops were considered by most interviewees to be the most effective techniques used (18% and 12%, respectively; $n = 60$), whereas scrub management, supplying water and constructing artificial warrens were rarely considered to be the most effective management strategy (4% in all cases; $n = 60$). Nevertheless, most hunters interviewed (58%; $n = 60$) considered that other management strategies (e.g. restocking, predator control, etc.) were the most effective of all strategies implemented in their hunting estates.

Effectiveness of habitat management techniques

RELATIVE EFFECTIVENESS

Overall, variation in rabbit abundance between pre- and post-management assessments (RE) was positive in most cases ($n = 10$); it was negative on only four occasions (Table 2). The highest RE was registered during the second year of the study by Catalán et al. (2008), when rabbit abundance in the managed area was nearly 35-fold greater than in the control. No significant correlation in rabbit abundance was found between RE and CONTROL (Spearman's $R = -0.5187$; $P > 0.05$), which suggests that the relative change in abundance is not related to the referential initial abundance in any of the case studies.

ABSOLUTE EFFECTIVENESS

With the exception of those estimated by Palomares et al. (1996), all estimated rabbit densities were well below 0.5 rabbits ha^{-1}, even after habitat management (Fig. 2). In fact, differences found in rabbit densities between control and habitat management treatments in some of the case studies were hardly perceptible (Fig. 2). Even after habitat manage-

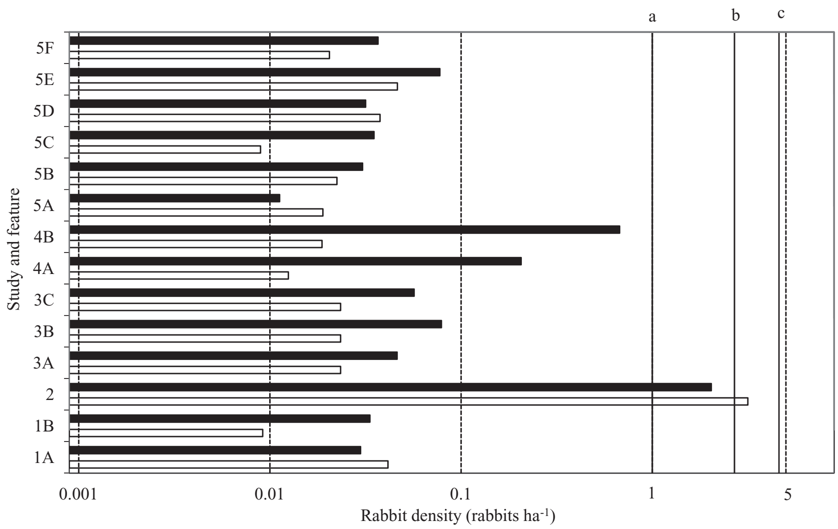

Fig. 2. Rabbit *Oryctolagus cuniculus* density (rabbits ha^{-1}) in control areas (C, as defined by the original authors; white bars) and in areas where the habitat was managed (HM; black bars) in each case study reviewed in the literature (see 'Feature' column in Table 2 for the codes on the vertical axis), after conversion using the pooled regression equation given by Fernandez-de-Simon et al. (2011). Vertical lines indicate reference rabbit densities for conservation and hunting purposes, as follows: (a) mean rabbit density necessary for Iberian lynx residence (Palomares 2001), below which areas are considered of low habitat quality for the Iberian imperial eagle *Aquila adalberti* (=1 rabbit ha^{-1}; González et al. 2008); (b) maximum rabbit density (=2.69 rabbits ha^{-1}) in areas where rabbits are controlled to prevent damage to crops (Fernandez-de-Simon et al. 2011); (c) mean rabbit density for Iberian lynx reproduction (=4.6 rabbits ha^{-1}; Palomares 2001).

ment, densities are far from reference rabbit densities considered necessary to sustain predator communities and hunting activity (Palomares 2001, Farfán et al. 2004; Fig. 2).

The cost-effectiveness of habitat management

The initial cost of implementing each habitat management technique reported in the literature is presented in Table 3. The most expensive techniques to apply are, in decreasing order: fencing; constructing artificial warrens (plastic), creating pastures/planting crops/scrub management; and constructing artificial warrens using natural materials. Supplying water is the cheapest technique to implement. Annual maintenance costs were determined only for those studies in which periodic renewal or checking of the habitat management techniques implemented was performed (Cabezas & Moreno 2007, Catalán et al. 2008).

The cost-effectiveness of the set of habitat management techniques used to aid the recovery of European rabbit populations in the case studies reviewed is shown in Table 4. Results are shown using only the 0% and the 3.5% discount rate, because sensitivity analysis on the discount rate chosen ($d = 0\%$, 3.5% or 6%) showed that this had little effect on the values of the cost-effectiveness analysis: the relative order of the habitat techniques evaluated did not change. The PV of the average costs subjacent to the implementation of habitat management techniques when $d = 3.5\%$ varied from €0.02 to €0.63 m^{-2} with a mean value (±standard error) of €0.12 ± 0.07 m^{-2} and a median value of €0.03 m^{-2}.

The conservation gains (COPY) achieved by all case studies were positive, with the exception of wet scrubland management applied by Moreno and Villafuerte (1995). The mean COPY achieved (±standard error) was 0.25 ± 0.15 with a range of −0.03 to 1.28 when $d = 3.5\%$. The maximum COPY was achieved by the set of habitat management techniques used by Catalán et al. (2008) that combined providing artificial warrens, supplying water and fencing. However, there was no significant correlation between the PV average costs and the PV COPY measure (Spearman's $R = 0.44$, $P = 0.27$), the RE index (Spearman's $R = 0.09$, $P = 0.82$), or the AE index (Spearman's $R = 0.02$, $P = 0.95$). Therefore, the most expensive habitat management techniques are not necessarily those that provide the best conservation gains for European rabbits.

The PV cost-effectiveness ratio (PV cost–COPY ratio) varied from €–0.81 to €0.99 per COPY achieved ($d = 3.5\%$). The mean value (±standard error) was €0.36 ±0.19 and the median was equal to €0.51 per discounted change in rabbit abundance. The ranking of the set of techniques described in the literature, based on their effectiveness in allowing the recovery of rabbit populations (PV COPY) was not correlated with their ranking based on conservation gains per € invested (PV cost–COPY ratio; Spearman's $R = -0.01$, $P = 0.98$). Although the combination of

Table 4. Costs, present value (PV) costs, COPY, PV COPY, cost–COPY ratio and PV cost–COPY ratio of the habitat management techniques described in the case studies reviewed in the literature

Reference	Feature	COSTS* *d* = 0%	PV COSTS* *d* = 3.5%	COPY *d* = 0%	PV COPY *d* = 3.5%	Cost–COPY ratio *d* = 0%	PV cost–COPY ratio *d* = 3.5%
Moreno & Villafuerte 1995	1A: Wet scrubland	0.028	0.028	0.077	0.071	0.368	0.400
	1B: Dry scrubland	0.028	0.028	–0.037	–0.035	–0.765	–0.806
Cabezas & Moreno 2007	3C: S	0.074	0.074	0.152	0.141	0.483	0.523
	3B: F	0.021	0.020	0.327	0.303	0.065	0.067
	3A: S, F	0.095	0.094	0.152	0.142	0.625	0.662
Catalán et al. 2008	4: SEV	0.636	0.634	1.360	1.280	0.468	0.495
Ferreira & Alves 2009	5: SC	0.028	0.028	0.030	0.029	0.949	0.995
	5: SC, F	0.038	0.038	0.074	0.071	0.509	0.531

Feature: S, shelter; F, food; SEV, several techniques applied; SC, scrub clearance; *d*, discount rate. All values are expressed in Euros (€).
*Average cost per m^2, including both initial and annual costs. In Catalán et al. (2008), for the estimation of annual costs, we assumed maintenance of water suppliers to be performed twice a week, for half a day, during spring and summer only, by one person with an intermediate professional minimum wage.

management techniques applied by Catalán et al. (2008) offered the best COPY index, these techniques are relatively costly to implement (Table 3), which is why they are not the most cost-effective. The most cost-effective technique, according to our analyses, was creating pastures/planting crops, as described by Cabezas and Moreno (2007; feature 3b: F in Table 2). This technique obtained reasonably high conservation outputs (it ranked second in the COPY index) and was also the cheapest to implement. Some habitat management techniques applied in other case studies ranked similarly when evaluated on the basis of their effectiveness, but their position changed when analysed in terms of their cost-effectiveness (e.g. Ferreira & Alves 2009).

DISCUSSION

To our knowledge, we are the first to attempt to estimate the absolute effectiveness of habitat management for European rabbit populations and to perform a cost-effectiveness analysis on habitat management techniques. For this reason, it is possible that our approach is biased towards the scarce information available, and our use of original calculations could have produced debatable estimates. For example, the initial costs used in this study (Table 3) could be considered underestimations, as prices can vary considerably both within regions (e.g. the construction of an artificial warren using natural materials may cost as much as €500–600, depending on the builder; R. Villafuerte, pers. obs.), and inter-regionally (e.g. in Portugal and Spain). Also, the RE of a technique may depend on the local ecological context where it is implemented (type of soil, vegetation composition, etc.), so that similar management techniques may have different outcomes. It is also difficult to assess whether differences in cost-effectiveness between studies reflect actual changes in the breeding population size or just shifts in the home range of individuals (it is possible that habitat management attracts neighbouring individuals). Management outcomes may also be affected by the total area in which habitat management is implemented, which varied among the studies reviewed in this paper. This is why the cost–COPY ratio results reported here are site specific: they refer to, e.g. particular habitat features and/or background rabbit densities. Moreover, in the case studies reviewed here, effects of habitat management were assessed within a relatively short temporal scale, so the estimates from our cost-effectiveness analysis may also apply to a short temporal window. Therefore, it would be very useful to perform a large-scale analysis, both temporally and spatially, especially taking into account the fact that investment in habitat management needs to be maintained (or increased) over time (Litvaitis & Villafuerte 1996, Ferreira & Alves 2009). We believe that our results are precise, reliable and generally representative and that they may contribute to discussions on maximizing the effect of human and economic resources on European rabbit recovery in the Mediterranean region. Our results highlight the importance of departing from accurate baseline information when performing impact assessment analysis (e.g. using rabbit abundances assessed prior to any intervention as well as replicated control treatments). Our study also reveals the lack of validated scientific information, based on carefully designed experiments, concerning the application of habitat management in the Iberian Peninsula and, hence, the lack of information on the true consequences of its implementation.

Our results suggest that habitat management techniques (especially creating pastures, planting crops and supplying water) are widely used in Iberia by game managers, hunters and conservationists, who consider them extremely successful in aiding the recovery of rabbit populations. Interestingly, most hunters still consider other strategies, such as restocking and predator control, to be more effective for allowing the recovery of this species in the wild. This perception raises concern among conservationists because these strategies are frequently implemented without regard for scientific recommendations and because their ecological effects are not clear (Delibes-Mateos et al. 2008a, 2013). The widespread creation of pastures, planting of crops and water supply is probably related to their low cost (Table 3). Perhaps the fact that other habitat management techniques (fencing, provision of artificial warrens) are too costly to implement does not favour their application, even if in the long term they provide better results as ascertained by our cost-effectiveness analysis.

The relative magnitude of changes in rabbit abundance produced by habitat management is high. However, effects take place on a small scale, both temporally and spatially, and effects in the medium or long term and at larger spatial scales were not investigated in any of the case studies reviewed. Indeed, the fact that Palomares et al. (1996) found that, 24 years after habitat management was implemented, rabbit abundance in control plots was actually higher than in managed plots suggests that the effects of habitat management decrease over time if it is not properly maintained (Litvaitis & Villafuerte 1996). Ongoing habitat management is particularly important in patches where rabbit abundance is low, which may act as population 'sinks' (Battin 2004), and where local habitat management may not be effective enough to reverse the negative demographic trend. This state is probably perpetuated by the implementation of inadequate management protocols in which the few scientific habitat management guidelines available are disregarded (e.g. guideline distances from shrubs to artificial warrens, warren sizes, shape of pastures; Moreno & Villafuerte 1995, Rouco et al. 2011). Variable outcomes result from the disparity of ways and variable frequency with which these techniques are implemented, as represented by the diverse sets of techniques used in the literature we reviewed (Table 2).

In absolute terms, the changes in rabbit density were insignificant (Fig. 2); the highest densities obtained from the literature even after habitat management were <1 rabbit ha^{-1} (with the exception of Palomares et al. 1996, who actually departed from higher initial rabbit abundance). Though generally effective in increasing rabbit abundance (RE), habitat management alone, at least following current protocols, may actually be inefficient in reverting rabbit density in certain areas to levels of biological significance for predators (Fig. 2; Delibes-Mateos et al. 2008b) or in obtaining densities capable of producing high yields for hunters, such as those described for Andalusia (>0.4 rabbits ha^{-1}; Farfán et al. 2004) even after habitat management (Fig. 2; except during the second year of the study of Catalán et al. 2008). This implies that there is probably a threshold density that needs to be achieved before management is abandoned, to ensure that investment is worthwhile (Rouco 2008).

We also evaluated the effectiveness of habitat management techniques using the COPY index, previously used in the evaluation of UK and New Zealand threatened species conservation programmes (Cullen et al. 2001, Laycock et al. 2011). The mean COPY level found for rabbit conservation measures reviewed in our study (0.25 when $d = 3.5\%$) was lower than the mean value found for UK individual Species Action Plans and New Zealand threatened species programmes with mean values of 0.47 (with $d = 3.5\%$) and 0.53 (with $d = 6\%$), respectively (Cullen et al. 2001, Laycock et al. 2011). Bearing in mind that differences in these conservation outcomes clearly depend on the particularities of the population level of each particular species, the temporal and spatial scale of the techniques applied, and how the programmes are implemented, several additional factors could explain this discrepancy. The techniques evaluated here were drawn from the scientific literature, and so they may have objectives other than mere efficiency in terms of conservation gains per € invested in the application of habitat management techniques, e.g. improving knowledge of the performance of certain techniques. On the other hand, the fact that we were unable to find a correlation between RE and the CONTROL rabbit abundances suggests that these case studies were actually performed in areas with very low and very similar rabbit abundances, which means that increasing numbers of rabbits in these areas is difficult (Moreno & Villafuerte 1995).

Our results also showed that cost-effectiveness varies according to the combination of habitat management techniques applied. For those evaluated here, the most cost-effective was that used by Cabezas and Moreno (2007) that provided an increase in food supply through planting crops, using relatively cheap techniques and materials. The next most cost-effective techniques were those carried out by Moreno and Villafuerte (1995) in dry habitats (which included scrub clearance), closely followed by those of Catalán et al. (2008): supplying water, fencing and increasing available shelter (no extra food was supplied). However, because fencing increased considerably the overall cost of the habitat management in this study, the conservation gains obtained (which were the highest) in relation to costs were less. Management techniques described by Ferreira and Alves (2009; scrub management and planting crops) were among the least cost-effective, probably due to the large area of intervention (600 ha, Table 2). This suggests that high investments do not ensure success, as the PV costs of implementing the management techniques were not correlated with the effectiveness (COPY index) of these techniques. Thus, there may be scope for improving economic efficiency in resource allocation, by investing more in those techniques that provide the greatest European rabbit recovery returns from a set budget (clearly, these would include planting crops, supplying water and/or establishing rabbit warrens). Nevertheless, the lack of relationship between investment and success in meeting conservation aims could be due to a multitude of other factors affecting the dynamics, and hence the recovery, of rabbit populations in the wild (e.g. locality, habitat features, timing, initial abundance, diseases, hunting and predation pressure, etc.; Angulo 2003) and so more experimental research is needed. Additionally, the same habitat management technique may be implemented differently by managers, either due to the lack of information about the correct protocol or because of local traditions in managing the land. None of these factors could be controlled for in our approach, although they are likely to affect the success of habitat management techniques.

Rabbits' needs are probably best met at a local scale (as suggested by the small scale of the most cost-effective studies), so management interventions need to be multiplied over a large area as opposed to being applied as continuous large-scale management (as represented by Ferreira & Alves 2009). However, these habitat management techniques are usually implemented in isolated patches, making them consequently difficult to coordinate and to scale up to the ecosystem level. This is particularly relevant when prey management is targeted at top predator conservation or rabbit harvesting, as both predators and human hunters usually occupy and explore large areas (e.g. Jachowski et al. 2011). Therefore, management sites should be considered elements of a network rather than stand-alone projects (Cleary 2006, Ferreira & Delibes-Mateos 2010), at least if regional level effects are expected. Also, different levels of intensity of habitat management can be planned at a large scale, depending on the local specific needs of rabbits and on the species' gradient of abundance. For example, more intensive efforts can be centred in local patches (e.g. high density nuclei; Rouco 2008), whereas connectivity between them can be promoted by using less expensive techniques (e.g. scrub management; Sarmento et al. 2012). In sum, a macroscale (ecosystem level) approach is recommended for the strategic planning of intervention in large areas (e.g. Miller et al. 2002, Loveland & Merchant 2004, Laycock et al. 2011), as this approach will ultimately provide higher rabbit conservation gains at a lower cost.

CONCLUSIONS

After habitat management, rabbit densities show mostly negligible increases lacking biological or economic relevance at a large scale. Still, there are areas within the Iberian Peninsula where rabbit densities are naturally very high. These typically comprise optimal habitats for the species, or areas where strong management efforts are made to integrate several management strategies (not only habitat management), such as soft releases (restocking) and predator control (Delibes-Mateos et al. 2009). However, these management strategies are very expensive (Simón et al. 2012), and sufficient investment is seldom available. Thus, maximizing the economic resources subjacent to the application of habitat management techniques is of interest but requires improving protocol designs in order to increase temporal and spatial gains. For example, continuous supervision and maintenance of habitat management is likely to increase its success, highlighting the need for minimal follow-up (Litvaitis & Villafuerte 1996, Ferreira & Alves 2009). Therefore, there is an urgent need for scientists to provide clear and scientifically driven guidelines for habitat management to all sectors involved in rabbit management. This way, it will be easier to plan habitat management interventions at larger scales that will produce more effective and widespread results. We call attention to the lack of information on the amount of investment made in habitat management techniques and on the assessment of the results of the measures implemented to aid the recovery of rabbit populations, despite significant funding made available over the past years by many public and private entities. Accessing this information would allow a much more precise analysis and facilitate the optimization of resources invested in rabbit management and conservation.

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