Universidade de Aveiro Departamento de Biologia
2013

Verónica de Jesus Onofre Pinto

IMPLEMENTAÇÃO DE MEDIDAS COMPENSATÓRIAS PARA ÁGUIA-REAL

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia Aplicada, realizada sob a orientação científica do Doutor Carlos Fonseca, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro.

Aos meus pais,
porque um agradecimento não é suficiente.

o júri

presidente

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agradecimentos

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palavras-chave

Compensação ambiental; linhas elétricas; gestão de habitat; zero perdas líquidas; *Aquila chrysaetos*; *Oryctolagus cuniculus*.

resumo

A compensação ambiental, ramo relativamente recente da mitigação de impactes, tem vindo a ganhar destaque e importância em diversos contextos de conservação ambiental, incluindo os processos de Avaliação de Impactes Ambientais. Seguindo a lógica da hierarquia de mitigação, os programas de compensação ambiental têm por objetivo a compensação dos impactes residuais até ao ponto em que os seus efeitos negativos são neutralizados (‘no net loss’) ou suplantados (‘net gains’).

No presente trabalho é descrito e avaliado um programa de compensação direcionado à compensação de potenciais perdas sofridas por 2 casais de águia-real, cujos domínios vitais cobrem áreas muito próximas ou coincidentes com a área afetada pela construção de uma linha de muito alta tensão no Nordeste de Portugal. Atendendo à natureza da infraestrutura, os impactes expectáveis relacionam-se com colisão com a linha. O programa consistiu em gestão de habitat para uma importante espécie-presa, o coelho-bravo, em áreas localizadas estrategicamente de forma a melhorar a qualidade de habitat de caça e diminuir a probabilidade de colisão de rapinas com a linha. Através de diversos programas de monitorização, foi possível avaliar o efeito das medidas implementadas ao nível da espécie-alvo do programa e da espécie-presa, e também a eventual ocorrência de perdas associadas à linha.

A avaliação das perdas e ganhos foi realizada de forma abrangente, tendo sido possível demonstrar a adequação do programa à problemática e a ocorrência de ganhos em proporção superior às perdas, resultando num ganho líquido de biodiversidade.

Finalmente, tecem-se considerações sobre os resultados obtidos e são definidas algumas implicações para gestão, a considerar em futuros programas de compensação ambiental.

keywords

Biodiversity offsets; power line; habitat management; no net loss; *Aquila chrysaetos*; *Oryctolagus cuniculus.*

abstract

Biodiversity offsets, a relatively recent branch of impacts mitigation, have been gaining prominence and importance in several contexts of environmental conservation, including Environmental Impact Assessment procedures. Following the mitigation hierarchy, offset programs aim to compensate residual impacts to the point where their negative effects are neutralized ('no net loss') or supplanted ('net gains').

In this work, is described and evaluated an offset programme directed to benefit two pairs of Golden eagle, which home ranges are close or intersected by the construction of a Very-high Voltage Power Line in northeast of Portugal, due to potential losses related with the infrastructure. Attending to the type of infrastructure, the expectable impacts result from collision with the power line. The programme consisted of habitat management for an important prey species, the European Wild Rabbit, in areas strategically located in order to simultaneously improve the quality of hunting habitats and reduce the probability of collision with the power line. Through various monitoring programs it was possible to assess the effect of the measures both at target species and prey species level, as well as the occurrence of losses associated with the power line.

The assessment of losses and gains was conducted in a comprehensive way, being possible to demonstrate the adequancy of the programme and that biodiversity gains obtained supplanted losses, resulting in a net gain of biodiversity.

Finally, some considerations are made about the results obtained and some guidelines are defined, to consider in future offset programmes.

ÍNDICE

Introdução

O desenvolvimento industrial e económico que se verificou ao longo de todo o século XX, e que se continua a verificar hoje em dia, proporciona-nos melhorias ao nível da qualidade de vida completamente impensáveis há relativamente pouco tempo. Contudo, ao longo das últimas décadas verificou-se também uma tomada de consciência em relação à face mais preocupante do progresso alcançado: os efeitos negativos para a biodiversidade que muitos projetos de desenvolvimento acarretam.

É hoje reconhecido que muitas das alterações operadas em função das crescentes exigências da população humana, têm efeitos irreversíveis sobre a biodiversidade e os ecossistemas (MEA 2005). Assim, o desenvolvimento de estratégias que permitam a conciliação do desenvolvimento económico e a preservação da biodiversidade tornou-se incontornável (Rajvanshi 2008). As avaliações de impacte ambiental (AIA), proclamadas pela Declaração do Rio sobre Ambiente e Desenvolvimento (Rio de Janeiro, 1992) como ferramenta de decisão necessária à autorização de projetos passíveis de causar impactes negativos sobre a biodiversidade, são a principal estratégia de mitigação de efeitos adversos associados aos projetos de desenvolvimento.

Entende-se como mitigação, a redução dos impactes negativos até os seus efeitos adversos serem neutralizados. Este objetivo pode ser alcançado pela aplicação conjugada de diferentes estratégias, nomeadamente implementando medidas para (1) evitar impactes, (2) minimizar os impactes verificados, (3) reabilitar os valores de biodiversidade afetados e (4) compensar impactes residuais negativos que se verifiquem apesar da implementação das 3 etapas anteriores (BBOP, 2012b). Para que a mitigação de impactes seja adequada e eficiente, as diferentes estratégias têm necessariamente que ser adoptadas hierarquicamente, pela ordem em que são acima enunciadas. Assim, as medidas compensatórias surgem como última linha de defesa contra a perda de biodiversidade (EPA 2006), sendo também a componente mais recente e menos desenvolvida da mitigação de impactes.

Diversas políticas e programas de compensação têm surgido ao longo dos últimos anos, em vários pontos do globo (Madsen *et al.* 2011; McKenney & Kiesecker 2010), sendo que o levantamento de programas de compensação mais recentemente tornado público apontou a existência de 39 programas de compensação estabelecidos em todo o mundo e mais 25 em desenvolvimento ou sob investigação (Madsen *et al.* 2011). Existem diversos pontos-chave em comum entre as diferentes políticas estabelecidas, mas também pontos de divergência resultantes do distanciamento físico e cultural entre os vários países e entidades sob estudo. A abordagem adotada com o objetivo de compensar os impactes causados é uma das diferenças evidenciadas pelo estudo. Na América do Norte e Oceânia, onde os programas estão mais desenvolvidos e devidamente estabelecidos, a compensação ambiental está sobretudo ligada à aquisição de créditos através de mercados de compensação ou mitigação, tal como se verifica com os mercados de carbono; noutros pontos do globo, incluindo a Europa, os programas estabelecidos são mais escassos e mais recentes, sendo muitas vezes impostos por AIA (ten Kate *et al.* 2011; Madsen *et al.* 2011).

Os mercados de compensação ou mitigação têm vantagens, nomeadamente no que diz respeito à simplicidade do processo de aquisição de créditos e à redução de custos, uma vez que esta abordagem não implica a contratação de entidades responsáveis por planear e implementar programas de compensação (Peterson *et al.* 2011). Contudo, através dos mercados de compensação perde-se a especificidade possível com a compensação nascida no seio de uma AIA, especificidade essa essencial para a conservação de importantes valores de biodiversidade. A implementação de medidas compensatórias associadas a processos de AIA tem-se tornado cada vez mais frequente e, apesar da compensação ambiental ser considerada independente destas avaliações (EC 2007), pode e deve ser parte integrante dos respetivos planos de mitigação sempre que se identifiquem impactes residuais significativos (BBOP, 2012a).

Na União Europeia existem vários instrumentos legais que preveem a implementação de medidas compensatórias como parte da mitigação de impactes, nomeadamente as Diretivas Habitats (Diretiva 92/43/CEE), Aves (Diretiva 79/409/CEE) e AIA (Diretiva 85/337/CEE). Adicionalmente, a Diretiva de Responsabilidade Ambiental (Diretiva 2004/35/CE) impõe a implementação de medidas compensatórias quando há risco de dano para os habitats (Rajvanshi 2008). No contexto jurídico e administrativo nacional, a aplicação de medidas compensatórias tem como principal base legal o decreto-lei 140-99, que transpõe as Diretivas Habitats e Aves, de acordo com o qual, só podem ser aprovados projetos que não interfiram com a manutenção da integridade da Rede Natura 2000 (ICNB 2010). Contudo, quando é inevitável provocar impactes em áreas classificadas, e a situação está devidamente enquadrada no previsto no artigo 6(4) da Diretiva Habitats, as medidas de compensação a aplicar devem ser:

- Completamente direcionadas para compensar o dano causado;
- Eficazes em termos ecológicos e legais;

- Suficientes para alcançar as exigências ecológicas das espécies afetadas;
- Bem localizadas, de preferência o mais próximo possível do local impactado;
- Calendarizadas e implementadas de forma a estarem funcionais na altura da ocorrência do impacte (BLI 2010).

Apesar da implementação de compensação ambiental de acordo com as regulamentações associadas a processos de AIA contribuir para verificar a necessidade e adequação deste tipo de programas (BBOP 2009b), existe também o risco das medidas compensatórias serem indevidamente utilizadas para viabilizar projetos cujos impactes residuais são demasiado significativos para poderem ser compensados (ten Kate *et al.* 2011) e o risco de ocorrência de perdas a nível ecológico devido à falta de capacidade dos agentes envolvidos para implementarem programas de compensação eficientes (Hill 2005). Para ultrapassar estas dificuldades, é essencial a definição clara do que pode ser considerado como compensação e das respetivas normas de implementação (Bull *et al.* 2013), de forma a que os programas de compensação sejam claros nos seus objetivos e capazes de demonstrar que estes foram alcançados.

O Business and Biodiversity Offsets Programme (BBOP), através da promoção de um esforço conjunto de diversas entidades, produziu as primeiras normas para a implementação de medidas compensatórias. De acordo com este programa, são considerados como compensação ambiental (do inglês biodiversity offsets) os ganhos ao nível da conservação resultantes de ações definidas para compensar impactes residuais negativos e significativos, associados a projetos de desenvolvimento, que ocorrem apesar da implementação adequada das três primeiras etapas da hierarquia de mitigação. O objetivo deste tipo de compensação é neutralizar as perdas líquidas de biodiversidade ou, se possível, criar ganhos líquidos no que diz respeito a composição específica, estrutura dos habitats, funções dos ecossistemas, ao uso humano e aos valores culturais associados à biodiversidade (BBOP 2013).

Foram enunciados 10 princípios utilizáveis como diretrizes para a correta implementação das medidas e a avaliação do respetivo sucesso (BBOP 2012c), relacionados com as seguintes temáticas:

1. Adesão à hierarquia de mitigação;

2. Limites da compensação ambiental;
3. Planeamento à escala da paisagem;
4. Demonstração da inexistência de perdas líquidas de biodiversidade;
5. Criação de ganhos de biodiversidade adicionais;
6. Integração das partes interessadas no planeamento e implementação do programa;
7. Equidade entre os intervenientes;
8. Criação de resultados a longo-prazo;
9. Transparência;
10. Aplicação de conhecimentos científicos sólidos.

O conceito de “perdas líquidas de biodiversidade nulas” surgiu nos EUA nos anos 70 (Gardner *et al.* 2013) e é hoje o ponto central da compensação ambiental, sendo a necessidade de demonstrar que este nível de conservação foi alcançado uma das características que mais diferencia esta de outras abordagens à compensação (BBOP 2009a). A avaliação do sucesso de um programa de compensação implica a quantificação das perdas e ganhos decorrentes do projeto. Este passo é frequentemente apontado como uma das principais dificuldades sentidas pelos agentes implementadores dos programas de compensação, visto que a valoração da biodiversidade é altamente subjetiva e complexa (Hayes & Morrison-Saunders 2007; Overton *et al.* 2013).

Com o objetivo de avaliar de forma precisa as perdas e os ganhos resultantes das medidas compensatórias, têm vindo a ser desenvolvidas metodologias de análise de equivalência de biodiversidade, integrando conhecimentos ecológicos, matemáticos e económicos. Entre as abordagens aplicadas até à data encontramos (1) índices da alteração da biodiversidade; (2) modelação da relação entre a área de habitat afetado e o tamanho populacional das espécies consideradas mais relevantes; (3) métricas económicas que estimam a evolução em relação aos objetivos definidos para o programa e (4) métricas multidimensionais que incorporam dados relativos às preferências das partes interessadas, à gestão implementada e aos diferentes componentes da biodiversidade (Overton *et al.* 2013). A metodologia a adotar deve ser escolhida de acordo com as características e condicionantes do projeto, sendo que a avaliação de perdas e ganhos deve ser feita de forma o mais abrangente possível (Bull *et al.* 2013).

Apesar da enorme importância inerente à capacidade de atribuir valores aos elementos dos ecossistemas abrangidos por programas de compensação, tanto para o planeamento e definição das medidas necessárias, como para a avaliação do cumprimento dos objetivos do programa, é importante frisar que existem muitos outros fatores que contribuem decisivamente para o sucesso do programa. Entre estes encontramos o acesso e recurso a dados e conhecimento técnico adequados, a definição de medidas compensatórias cuja eficiência na conservação dos grupos afetados seja reconhecida, a existência de meios económicos que permitam sustentar o programa, a implementação de programas de monitorização adequados e rigorosos e a gestão adaptativa do programa de acordo com os resultados verificados (BBOP 2012c; Gardner *et al.* 2013).

Atualmente, e apesar da publicação de diretrizes por parte do BBOP, continua a verificar-se a ocorrência de falhas nos programas de compensação publicados, nomeadamente ao nível da demostração da neutralização de perdas líquidas de biodiversidade (Bull *et al.* 2013). Os programas de compensação ambiental estão ainda na sua infância, e continuarão a ser alvo de controvérsia durante muito tempo (Gardner *et al.* 2013); é necessário um trabalho constante e rigoroso para que esta abordagem à conservação se estabeleça como uma defesa sólida e real contra a perda de biodiversidade. Gardner *et al.* (2013) realçam a importância e necessidade de mais e melhores casos de estudo publicados, que contribuirão para que a discussão sobre as melhores práticas de compensação deixe de ser apenas teórica, passando a integrar conhecimento teórico e casos reais de sucesso e insucesso. De facto, a exposição do trabalho desenvolvido à opinião de especialistas e a comparação de casos é fundamental para o crescimento e o estabelecimento de normas mais adequadas e eficientes (BLI 2010).

Enquadramento do projeto

Em seguida apresenta-se um caso prático de implementação de um programa de compensação a nível nacional, decorrente de um processo de AIA. Trata-se de um programa definido com o objetivo de compensar potenciais perdas ao nível da comunidade de rapinas, relacionadas com colisão com uma linha de muito alta tensão. Deu-se especial enfoque à evolução de dois casais de águia-real (*Aquila chrysaetos*), espécie ameaçada (EN), cujo habitat de caça foi potencialmente melhorado através do fomento das populações de coelho-bravo (*Oryctolagus cuniculus*), importante espécie-presa. De facto, a devolução dos habitats ou espécies afetados à situação pré-intervenção humana ou o seu beneficiamento, através de ações de gestão estão entre as práticas a adotar como medidas de compensação, nomeadamente pela recuperação ou reintrodução de espécies nativas, fomento de espécies-presa, remoção ou controlo de espécies invasoras, entre outros (Gardner *et al.* 2013; ICNB 2010).

Todo o programa de compensação foi definido de acordo com a legislação aplicável à área em questão. Foi realizada gestão de habitat de acordo com as exigências ecológicas da espécie-presa e todo o programa de compensação foi monitorizado ao nível dos seus vários componentes durante toda a sua duração, de forma a realizar uma avaliação realista das perdas e ganhos resultantes das medidas implementadas.

Objetivos

Os objetivos deste trabalho passam por:

- Avaliar a adequação das medidas de gestão implementadas enquanto parte de um programa de compensação.
- Avaliar o balanço obtido entre perdas e ganhos ao nível das espécies abrangidas pelo programa.
- Estipular implicações de gestão para futuros programas de compensação.

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BIODIVERSITY OFFSETS MADE REAL: THE ROLE OF HABITAT MANAGEMENT FOR THE ENDANGERED GOLDEN EAGLE *AQUILA CHRYSAETOS*

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Abstract

The construction of infrastructure may cause negative impacts on wildlife. Whenever early mitigation steps are incapable to reduce or neutralize those impacts, an offset program should be defined and implemented.

We settled an offset program in the northeast of Portugal from 2007 to 2010 to compensate the potential residual impacts of a Very-high Voltage Power Line on two Golden Eagle *Aquila chrysaetos* pairs. The eagles' hunting areas, far from the Power Line, were improved through habitat management that aimed the recovery of one of the most important prey species in the Mediterranean ecosystem: the European Wild Rabbit *Oryctolagus cuniculus*.

Several monitoring programs were defined to assess (1) net gains, both in prey and Golden Eagle populations, and (2) net losses, namely the occurrence of fatalities in the raptor community due to collisions with the Power Line. We verified a significant increase in the relative abundance of the European Rabbit population in the managed areas compared to control areas. A similar trend was recorded in terms of utilization of management units by rabbits. Simultaneously, we confirmed the use of the managed areas by Golden Eagles. Usage of the Power Line corridor by this species was low and there was no record of Golden Eagle fatalities.

The positive effects of the offset program were confirmed, as well as the efficiency of the measures implemented. The evaluation of losses and gains revealed a biodiversity net gain. We conclude with some detailed guidelines for future offset programs.

The positive effects of the offset program were confirmed, as well as the efficiency of the measures implemented. The evaluation of losses and gains revealed a net gain for biodiversity. We conclude with some detailed guidelines for future offset programs.

Keywords

Biodiversity offsets; power line; habitat management; no net loss; *Aquila chrysaetos*; *Oryctolagus cuniculus*.

INTRODUCTION

Over recent decades, human actions have caused more changes in ecosystems than ever before, and ecosystem services have seemed to decline as interventions over natural resources increased (Raudsepp-Hearne *et al.* 2010). Finding a balance between biodiversity and economic development has been highlighted as one of the major challenges faced by humanity in the 21st century, but there are few mechanisms capable of achieving this (Bull *et al.* 2013). Environmental impact assessments (EIA) can be a valuable tool in this context (McKenney & Kiesecker 2010). By identifying and evaluating the impacts on biodiversity resulting from development projects, EIAs can facilitate decision-making in terms of the need for mitigation. When needed, EIAs can also establish related strategies aimed to reduce the negative impacts of such projects to the point where they have no adverse effects (BBOP 2009). Mitigation measures are hierarchically categorized according to their goals: (a) avoidance, (b) minimization, (c) rehabilitation and (d) offsets (BBOP 2012a). Impacts that cannot be avoided, minimized or repaired (i.e. residual impacts) must be addressed through biodiversity offsets (PricewaterhouseCoopers LLP 2010). Offsets are a recent field in biodiversity conservation and have introduced some completely new concepts in this arena, such as the need to prove that the final balance between biodiversity losses and gains is neutral ('no net loss') or positive ('net gains') (Bull *et al.* 2013).

The success of an offset program depends on the reliability and adequacy of the procedures followed (Hayes & Morrison-Saunders 2007). The Business and Biodiversity Offsets Program (BBOP) developed and introduced the first Standards on Biodiversity Offsets. The principles of which, though not mandatory, provide a framework for designing and implementing biodiversity offsets and, further, verifying their success (BBOP 2012b). The first principle of these Standards is respect for the mitigation hierarchy. Moreover, the Standards highlight that the measures implemented must produce additional conservation gains, i.e. 'no net loss' or 'net gains'. The remaining principles of these Standards refer to limits and scales for offsetting and encourage the participation of local communities and other stakeholders.

To date, there are few available results on offset programs (Bull *et al.* 2013) and, to our knowledge, most of the published work is merely theoretical. Worldwide, offset programs targeted to species are rare (e.g. Pickett *et al.* 2013; Bull *et al.* 2013b), and much of the published work concerns the creation of new habitats to replace similar habitats lost due to development projects (Madsen *et al.* 2011; McKenney & Kiesecker 2010). Offsets planned to compensate direct mortality are even scarcer and quite often predictive and theoretical (e.g. Cole & Dahl 2013; Pascoe *et al.* 2011). To our knowledge, there are no published studies on offset programs to compensate mortality of endangered species in Southern Europe.

Back in 2006, a project to construct a Very-high Voltage Power Line in northeastern Portugal was subjected to an EIA process, since power lines (PL) are considered potential sources of negative impacts on biodiversity (PSCW 2009). Several important ecological values where identified in the selected area for the construction of the PL, including an important raptor community. PL may negatively affect several bird species, either through electrocution, collision or habitat alteration (ICNB 2010; Flynn & Nairn 2012) and raptors are among their common victims (BLI 2007; Jenkins *et al.* 2010). The likelihood and nature of problems relates to many variables, such as PL conformation (Manville 2005; Ferrer 2012) and voltage (Rollan *et al.* 2010; ICNB 2010). Electrocution is only common on PL with voltages below 45 kV (Cole & Dahl 2013; Ferrer 2012; APLIC 2006) and High or Very-high Voltage PL have less significant impacts, with fatalities mainly being caused by collisions (Jenkins *et al.* 2010; ICNB 2010). The characteristics of individual bird species are also decisive in the occurrence of fatalities, particularly in terms of body size and flight behavior (Jenkins *et al.* 2010; Ferrer 2012; APLIC 2006).

Following the mitigation hierarchy, the corridor for the implementation of the PL was defined to avoid, as much as possible, traversing special conservation areas. However, it was not possible to fully achieve this aim and, despite choosing the least harmful alternative, some species were exposed to negative impacts. One impact of high concern was related to the presence of Golden Eagle *Aquila chrysaetos* in the area, an "Endangered" species in Portugal (Cabral *et al.* 2006). Due to its low density and to the natural threats that affect small populations (Watson 2010), potential losses of this species related with PL collisions were considered significant impacts and prompted the definition of a mitigation strategy. As a result, the project was approved by the Portuguese Environment Agency, which issued a favorable Environmental Impact Statement on condition that minimization and offset measures were implemented to mitigate the non-avoidable impacts for Golden Eagle. Construction of the PL was finished in late 2008. Bird Flight Diverters were implemented as an efficient strategy to minimize deaths by collision (Jenkins *et al*. 2010). The offset program was planned in order to improve ecological conditions for Golden Eagle and started prior to PL construction.

Recovery of prey species to offset impacts on endangered predator species is among the strategies recommended in the EU, in line with the Habitats Directive (ICNB 2010). Accordingly, and as Golden Eagle breeding success is related to prey abundance and its availability (Whitfield *et al.* 2009; McIntyre & Schmidt 2012), the offset program targeted the European Wild Rabbit, *Oryctolagus cuniculus*. The European Rabbit is a keystone species in Mediterranean ecosystems and is one of the main prey species of Golden Eagle (Sánchez-Zapata *et al*. 2010), as well as of other raptor species (Delibes-Mateos *et al.* 2007) that also occur in our study area. This lagomorph is native of the Iberian Peninsula and its populations have been decreasing dramatically in Iberia since the middle of the past century (Calvete *et al.* 2004; Delibes-Mateos *et al.* 2009) and is now classified as "Near Threatened" in Portugal (Cabral *et al.* 2006). The offset program was implemented between late 2007 and 2010 and consisted in habitat management measures to improve habitat suitability in terms of food and shelter availability for the prey species, thereby promoting an increase of food resources for Golden Eagle.

Here, we discuss the adequacy of the offset program and its effectiveness in limiting losses in the targeted raptor species. Moreover, we examine how habitat management actions influenced prey availability for raptors and we highlight some management guidelines that can be drawn from this study.

MATERIALS AND METHODS

Study area

Our study area is located in Bragança district, northeastern Portugal (41 25'19'' N and 6 44'58'' W) (Fig. 1). The area includes three Natura 2000 areas: two sites of community importance (Council Directive 92/43/EEC) and one special protection zone also classified as an Important Bird Area (Costa *et al.* 2003). The area is part of the Mediterranean biogeographic zone and the climate is temperate with warm and dry summers. Mean precipitation varies from 600 to 800 mm/year and mean temperatures are approximately 15-16 ºC (APA (2010), available from http://sniamb.apambiente.pt/webatlas/).

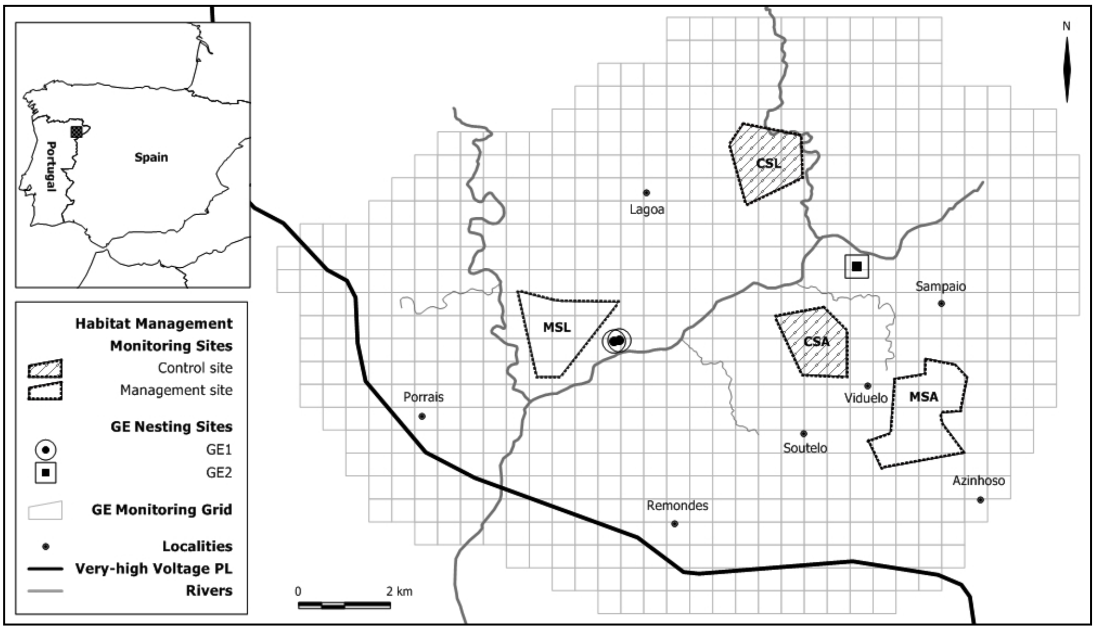

Fig. 1 Location of the study area delimited by the Golden Eagle monitoring grid and location of the habitat management monitoring sites.

The prevailing soil types are leptosols and anthrosols (Hoelzer 2003). Landscape structure is dominated by typical Mediterranean vegetation composed mainly of scrubland areas (*Cistus ladanifer*, *Retama sphaerocarpa*, *Lavandula* sp.), woodland (*Quercus rotundifolia*, *Quercus suber*, *Juniperus oxycedrus* var. *Lagunae*, *Quercus faginea*) and agricultural use (especially olive and almond cultures). The landscape is heavily contoured by the Sabor river valley, with heights ranging from 200 m to 700 m. Cliffs are abundant along the river catchment, providing good nesting places for cliff-nesting birds, including two pairs of Golden Eagle (GE1 and GE2). Human occupation of the region is limited and activities are deeply linked to rural and forestry land use. The study area is used by several hunting clubs and hunting activity is common among the local community.

Offset program

The offset program was based on habitat management measures that are known to greatly improve habitat suitability for the European Rabbit (Catalán *et al.* 2008; Ferreira & Alves 2005; Sarmento *et al.* 2011) and involved adjusting the habitat conditions in accordance with the ecological requirements of the species (Cooke 1974; Rogers & Myers 1979). The implemented measures were: (1) creation of small patches inside continuous scrubland vegetation that were periodically sown with cereal and leguminosae ('pastures') (Delibes-Mateos *et al.* 2008; Ferreira & Alves 2009; Sarmento *et al.* 2011) to improve ecotone areas and increase the nutritional quality of available food; (2) construction of artificial warrens (Catalán *et al.* 2008; Ferreira 2003; Sarmento *et al.* 2011); and (3) installation of supplemental food and water units ('feeders and waterers') (Delibes-Mateos *et al.* 2008; Weidman & Litvaitis 2011) during the summer.

These habitat management measures were implemented inside two independent management sites, located near Lagoa and Azinhoso localities (MSL and MSA, respectively) (**Erro! A origem da referência não foi encontrada.**). These sites were strategically chosen to be within Golden Eagles home ranges, near their nesting sites and also sufficiently distant from the PL to avoid the promotion of PL crossing. The interventions were performed in sites with initially low/median population densities of European Rabbit and with landscape features that could be improved to enhance habitat quality for this species. To assess the effect of habitat management in rabbit populations control sites (CSL and CSA), with similar habitat conditions, were defined for each management site.

During project execution, stakeholders and in particular local hunting associations were involved to assist in the implementation of management actions, contributing to the efficiency and acceptance of the program (BBOP 2012c). The offset also included several monitoring programs to guarantee that every component of the offset was followed-up, to verify its success and the adequacy of the measures and to determine if 'no net loss' or 'net gains' had been achieved.

Monitoring programs

To assess biodiversity losses and gains, several monitoring programs were defined, both for prey and raptor species.

Gains in prey populations

Indirect census techniques based on latrine counts along transects were used to assess the evolution and trends in the European Rabbit population (*e.g.* Beja *et al.* 2007; Delibes-Mateos *et al.* 2008; Sarmento *et al.* 2011) both in managed and control areas. One linear transect of 150 m length was defined in each cell of a 250 x 250 m grid, according to the species mean home range (Lombardi *et al.* 2007). Prior to the implementation of management actions (in February 2008) the first field surveys were conducted to assess the initial relative abundance of the species. Afterwards, pellet counts were conducted periodically, three times per year (February, June and October), from June 2008 to October 2010.

European Rabbit usage of habitat management units was monitored on a regular basis from the outset when management actions were first implemented. Each pasture and artificial warren was checked for signs of rabbit presence every two months. All feeders and waterers were monitored monthly during summer season. The existence of latrines, pellets, footprints, dens or digging attempts was registered as an indicator of rabbit presence.

Gains and losses in the Golden Eagle population

Golden Eagle activity and spatial use was monitored using two techniques. The first one was satellite telemetry - a method also used by other authors on this and other bird species (e.g. Sandgren 2012; Soutullo et al. 2013). Both adult eagles of the GE1 pair (which nests closer to the PL) were tagged with solar-powered Argos GPS Platform Transmitter Terminals (PTT), using appropriate transmitters for the species size. Male GE1 was followed from November 2008 to February 2009 and female GE1 was followed from November 2009 to the end of the study in December 2010. The second sampling technique was direct observation. Both eagle pairs were surveyed from seven vantage points, distributed across the study area according to orography, landscape characteristics and visibility (e.g. Gregory et al. 2004; Bibby et al. 2000). Each vantage point was surveyed for two hours every month, from October 2007 to December 2010. After the first management measures were implemented, one of the seven initially-defined vantage points was relocated in order to optimize monitoring of Golden Eagles activity in managed areas by ensuring that those areas where properly sampled. For each observation of the target species, the number of individuals and behavior were registered. All Golden Eagles movements were mapped and analyzed at a spatial level.

To assess breeding success, all known and potential breeding sites of GE1 and GE2 pairs were monitored. Nest surveys were performed monthly during the breeding season, from 2008 to 2010, in terms of nest-building and occupation period (January/February), egg laying and incubation (March/April), hatching and chick care (mid-April/mid-June) and first flights of chicks (from mid-July) (BWPi 2004; Eaton et al. 2007). Observation points were strategically defined to simultaneously ensure good visibility of nesting sites and to avoid disturbance.

Regarding the feeding ecology of the eagles, a dietary analysis was undertaken to confirm the intake of prey species by pairs GE1 and GE2 and their relative importance. Food remains and pellets were collected directly from the nests at the end of the breeding seasons of 2008 and 2009.

To assess the negative impact of PL on Golden Eagle (mortality due to collisions), carcass searches were conducted along the PL corridor in order to estimate the number of fatalities. This procedure started in January 2009, after the PL became operational and was conducted until the end of the study. Searches were undertaken along transects located under the PL cables (total length: 16.2 km, approximately 53% of the total extent of the PL). Carcass searches were conducted periodically throughout the year in winter, spring, summer and autumn (Buehler & Piersma 2008). For each season, searches were conducted weekly, for four continuous weeks (surveys in January-February; April-May; July-August; and November). Since not all carcasses are detected by searchers and some can be removed between searches (by scavengers or decay) (e.g. Morrison 2002; Erickson 2004), detection and removal trials were also conducted under the PL corridor and at different times of the year.

Data analysis

Gains in prey populations

The initial relative abundance of rabbit population, recorded on the survey of February 2008, was compared for each set of managed and control sites with a Mann-Whitney-Wilcoxon test (Mann & Whitney 1947). The number of latrines found in transects from June 2008 to the end of the monitoring period allowed rabbit relative abundance in the monitored sites to be estimated using the Kilometric Abundance Index (KAI). This index is considered an effective method for detecting trends and oscillations in the abundance of populations (Barrio *et al*. 2010). Differences between KAI in managed and control areas were also assessed with the Mann-Whitney-Wilcoxon test.

The influence of habitat management actions and other environmental conditions on rabbit presence and abundance was then analyzed with Generalized Linear Mixed Models (GLMMs) (Zuur *et al.* 2007), a flexible approach for analyzing non-normal data (Zuur *et al.* 2007; Bolker, 2008), allowing correlations between observations by taking spatially- or temporality-correlated counts as random effects (Zuur *et al.* 2009). The variable "Transect" (TRS) was used as a random effect to avoid pseudoreplication (Bolker *et al.* 2008), related to the repetition of European Rabbit surveys in the same transects. "Number of latrines" (NLT) was considered the response variable, which consisted of overdispersed count data with excess zeros. The response variable was not log-transformed, as recommended for O'Hara and Kotze (2010) for count data. The GLMM was fitted with an extension for Hurdle models (Cragg 1971; Mullahy 1986), which consists of two distinct component models: the first part produces a "presence/absence" outcome and the second part corresponds to an "abundance" analysis (e.g. Zuur *et al.* 2009; Zeileis *et al.* 2008). A binomial error distribution with a logit link function was employed for the Hurdle component (presence/absence) and a negative binomial distribution with a log link function was employed for the truncated count component (abundance).

To fit the Hurdle GLMM to the response data, a set of 17 explanatory variables (fixed effects) was considered (Table 1). The significance of each covariate was initially assessed using univariate models; subsequent multivariate models included the predictor variables whose p-values for the Wald test were less than 0.25 in the univariate models (Hosmer & Lemeshow 2000). To measure colinearity between explanatory variables, the Spearman's rank correlation coefficient (Spearman 1907) was calculated to ensure that covariates were not highly correlated. Selection of the final model was based on the Akaike Information Criterion (AIC) (Akaike 1974) through a backward stepwise procedure. Finally, goodness-of-fit measures were estimated through Likelihood Ratio Tests and the residuals for the final fitted model were analyzed. This statistical analysis was performed with R 2.15.3 software, using the "glmmADMB" package (Fournier *et al*. 2012). Confidence level was set at 95% ($\alpha = 0.05$).

Table 1 - Explanatory variables used in the GLMM analysis of habitat management effects on the European Rabbit population.

Category	Code	Type	Description
Habitat management	TRT	Categorical (2 factors)	Area type: *management; control*
	NMU	Continuous	Total number of management units (pastures, artificial warrens and feeders/waterers) in a 200 m *buffer* around transects
Location	AREA	Categorical (2 factors)	Offset implementation areas: *Azinhoso; Lagoa*
	ARTR	Categorical (4 factors)	Type of treatment at each area: *MSA; MSL; CSA; CSL*
Time	YEAR	Categorical (3 factors)	Year: *2008, 2009, 2010*
	SSN	Categorical (8 factors)	Season of each monitoring action in each year
Landscape	ALT	Continuous	Altimetry (m)
	TPE	Continuous	Topographic exposure (degrees)
	SLP	Continuous	Slope (degrees)
Meteorological *	PRS	Continuous	Precipitation sum (mm)
	AVT	Continuous	Average temperature (ºC)
Habitat	AC	Continuous	Annual cultures (percentage)
	PC	Continuous	Permanent cultures (percentage)
	HF	Continuous	Hardwood forest (percentage)
	SC	Continuous	Scrubland cover (percentage)
	RF	Continuous	Reforestation areas (percentage)
	OT	Continuous	Other: shrub hedges, riparian vegetation and artificial areas (percentage)

* Obtained from FOODSEC Meteodata Distribution Page (URL: http://marswiki.jrc.ec.europa.eu/datadownload/index.php).

For each type of management plot, we analyzed the frequency of occurrence of the prey species in management units. Differences across the years in pasture plots and artificial warrens were assessed with a *t*-test. For feeders/waterers, the statistical significance of differences was assessed with the Friedman Test (Friedman 1937), with the critical value defined at 4.667 (Bagui & Bagui 2005).

Gains and losses in the Golden Eagle population

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RESULTS

Gains in prey populations

Prior to the implementation of management measures, no significant differences were found for rabbit abundance between each set of managed and control sites (MSL-CSL: W = 72, P = 0.451; MSA-CSA: W = 69, P = 0.897).

The KAI for the two area types showed a trend for increasing numbers of latrines throughout the monitoring period, with this result significantly higher in the managed areas (W = 9, P = 0.0148). The lowest values were registered at the beginning of the program. The highest values of abundance (51 latrines detected per kilometer) were registered in the managed areas, in the last monitoring season of 2010 (Fig. 2**Erro! A origem da referência não foi encontrada.**).

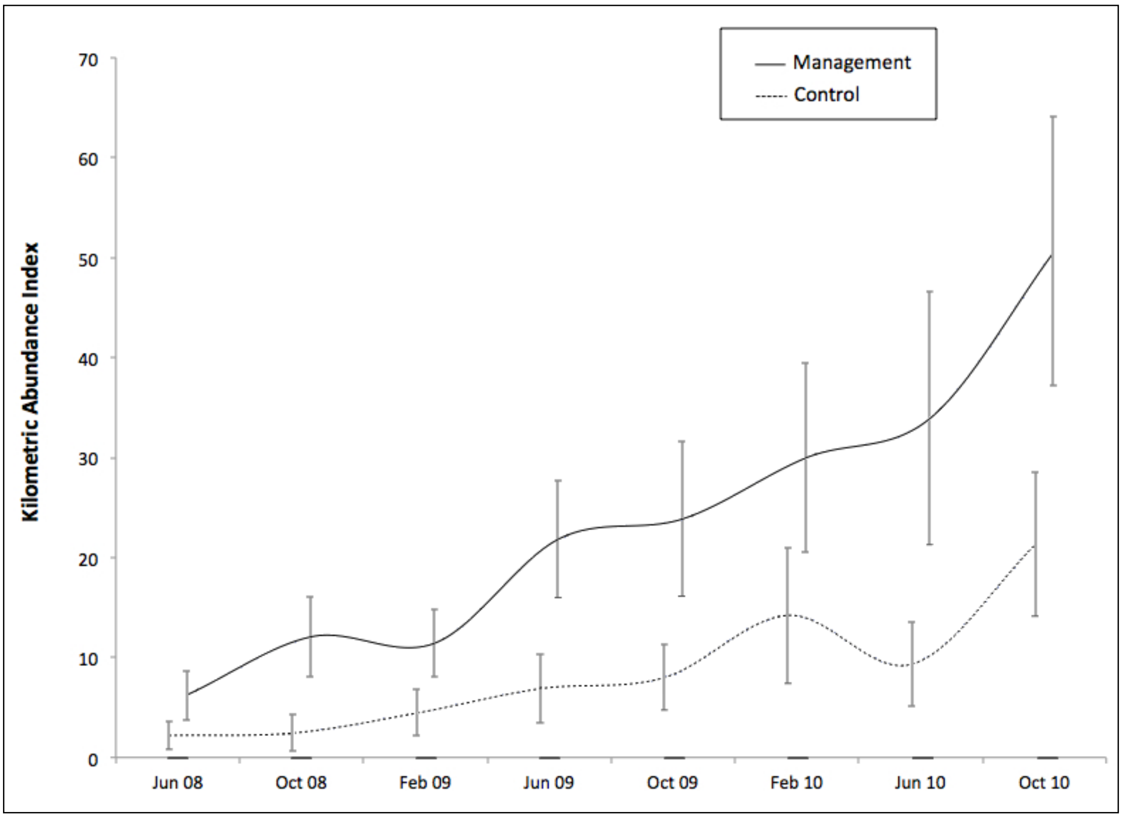

Fig. 2 – Evolution of ER relative abundance in control and managed sites throughout the monitoring period.

The Hurdle model output presents two distinct components: the first models the presence (binary outcome) of European Rabbit in fixed sampling sites and the second models the abundance (given that presence is positive). The final model included a total of six explanatory variables (Table 2).

Results from the binary outcome showed that the variables with a significant influence on European Rabbit presence in sampling sites were TRT, YEAR, AC and PC. The probability of having rabbit presence was significantly higher in management sites compared to control sites. Significant differences were also found between years, being higher in 2009 and 2010 when compared to the beginning of the project in 2008. At the vegetation cover level, our results showed a negative influence of AC and PC habitats.

The truncated count component analysis revealed that European Rabbit abundance was also significantly influenced by TRT and YEAR variables. Results showed that the probability of achieving a greater abundance was significantly higher in managed than in control sites, and the results obtained in 2009 and 2010 were higher than those obtained in 2008 (the differences were marginally significant for 2009 and significant for 2010). The explanatory variable AREA was also included in the final model, revealing that differences occurred between both intervention areas. The variable PRS was also part of the model. This indicated that precipitation was negatively related to the abundance of rabbit signs. OT habitat had also a significantly negative influence on rabbit abundance.

Table 2 – Final model obtained through the Hurdle GLMM analysis for European Rabbit population dynamics (presence and abundance) during the study (significance level: * p<0,05).

Component	Variable		Estimate	Std. Error	Z value	Pr(>|z|)
Hurdle Component (Presence)	(Intercept)		-1.9786	0.7482	-2.64	0.00818 *
	TRT	Management	1.6024	0.7931	2.02	0.04332 *
	YEAR	2009	2.2029	0.4503	4.89	1,00E-06 *
		2010	2.3287	0.4544	5.12	3,00e-07 *
	AC		-0.0877	0.0309	-2.83	0.00461 *
	PC		-0.1169	0.0353	-3.31	0.00092 *
Truncated count component (Abundance)	(Intercept)		0.8258	0.3434	2.40	0.0162 *
	TRT	Management	0.8122	0.3368	2.41	0.0159 *
	YEAR	2009	0.2720	0.1579	1.72	0.0849
		2010	0.9572	0.1482	6.46	1,00e-10 *
	AREA	Lagoa	-0.8607	0.3211	-2.68	0.0074 *
	PRS		-0.0132	0.0044	-3.02	0.0025 *
	OT		-0.0808	0.0363	-2.23	0.0259 *

The frequency of occurrence of European Rabbit on pastures showed a marked tendency to increase, with significantly higher values in 2010 (t = -2.632, P = 0.046), reaching 84% of occupation in the last survey of the program. In terms of artificial warrens and feeders/waterers, occupancies also increased gradually during the monitoring period, achieving 91% and 45% respectively in the last survey of 2010. Differences registered across the monitoring period were significant in the case of artificial warrens (t = -3.460, P = 0.019), but for feeders/waterers the differences were not significant between years (*Friedman chi-squared* = 3.714, P = 0.156).

Gains and losses in the Golden Eagle population

Through satellite tracking between November 2008 and February 2009, the PTT attached to the male GE1 emitted 740 independent GPS locations. Between November 2009 and December 2010, the PTT attached to the female GE1 provided 3813 locations of a similar nature. The estimated home range for the male GE1 totaled 5912 ha, with a core area of 374 ha. For the female GE1, the estimated home range was 7132 ha, with a core area of 1142 ha. For both animals, home ranges overlapped the known breeding sites and the management site located nearest to their breeding area (MSL) (Fig. 3). The estimated home range of female GE1 resulted from a much larger dataset, which included data collected during the breeding period. Nearly 77% of the MSL was included inside one of the two core areas of this female. The nesting sites of the GE1 pair were also included in this core area. Only 3.8% of female GE1's home range was located south of the PL; for the male, there were no records of activity in that area.

During the monitoring, it was possible to complete near 525 hours of observation from vantage points, corresponding to almost 22 days of observation. These efforts resulted in a total of 51 observations of Golden Eagle. During the initial monitoring period after PL activation, *i.e.* until October 2008, the activity index summed 1.38 ± 0.42 observations/vantage point/day; after October 2008, the activity index rose to 2.71 ± 1.20 observations/vantage point/day. Differences between the two periods were significant (*Kruskal-Wallis* = 51.87, P < 0.001).

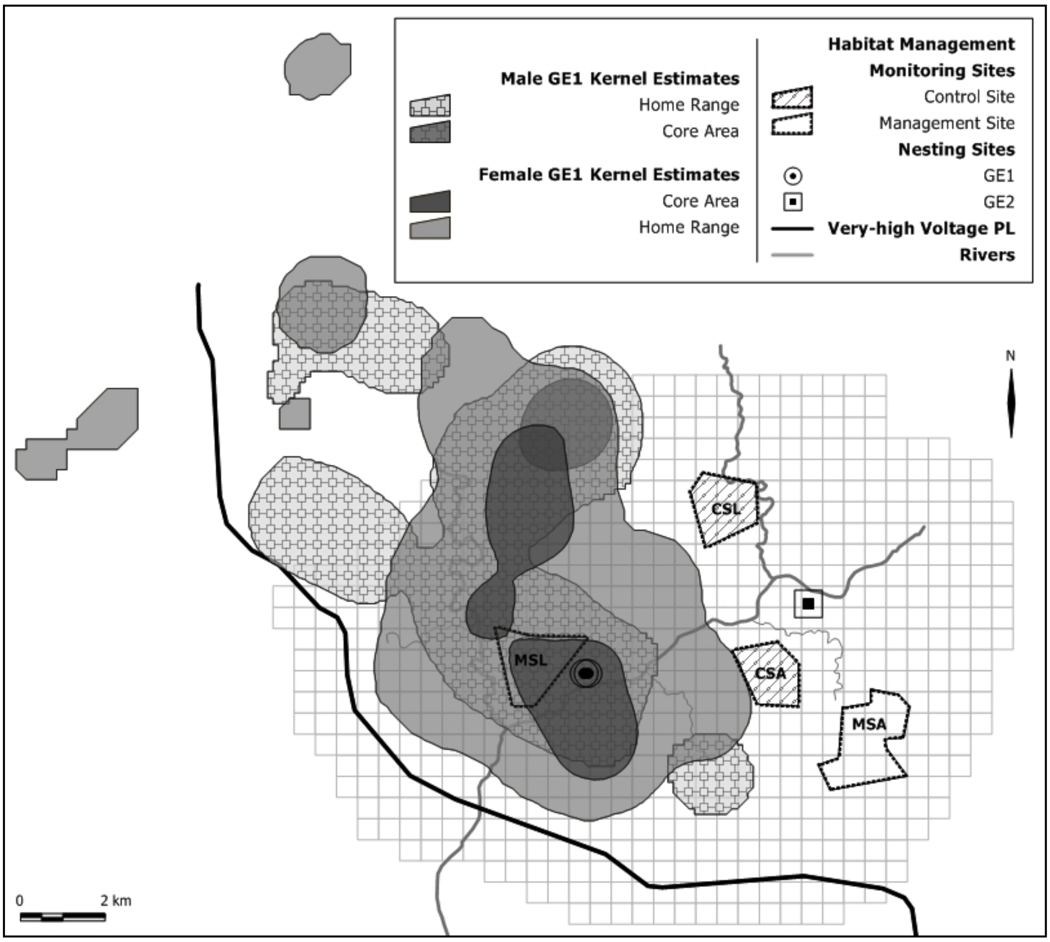

Fig. 3 Home range and core areas estimated through the Fixed Kernel Method for both individuals of the GE1 pair using the GPS locations provided by PTT devices. The figure also includes the known locations of GE nesting sites and habitat management monitoring sites.

At the spatial analysis level, we verified that, in the second period, after October 2008, flight records were concentrated in the vicinity of the breeding areas of each pair. That result was not so obvious in the first monitoring period. After October 2008, observations surrounding the GE1 nesting area overlapped almost every grid cell associated with the MSL. A similar, though less marked, result was recorded in the MSA. No records of PL crossing were registered and records near the line were rare, with GE typically located at a safe distance (greater than 500-700 m) from the PL.

Breeding success was confirmed for both pairs in two years. The GE1 pair reproduced successfully in 2008 and 2009, producing two fledglings each year. In 2010, there were no signs of breeding attempts for this pair. Average productivity during the monitored period equaled 1.3 ± 0.67 fledglings/year. The GE2 pair reproduced successfully in 2009 and 2010, also with an annual productivity of two fledglings. In 2008, the location of this pair's nests was unknown, so it was not possible to assess breeding success. As reproduction in 2008 was undetermined, average productivity for this pair was calculated as a function of the two years of effective nest surveys, *i.e.* 2 fledglings/year. For the study area and with a weighting for the results of both pairs, the overall productivity reached 1.6 ± 0.4 fledglings/year.

Concerning the dietary analysis, in 2008 it was only possible to collect dietary remains for the GE1 pair; in 2009 the analysis was undertaken for both pairs. The number of pellets collected totaled 21, being mainly composed of bones, hair, feathers, scales and plant material. Considering the total number of remains collected for both pairs in 2008 and 2009, rabbits comprised 15.4% of the preys consumed. In addition to European Rabbit, the prey species with greatest incidence in the diet of the two Golden Eagle pairs were: Rock Pigeon/other pigeons *Columba livia*/*Columba* sp. (17.9%); Red Fox *Vulpes vulpes* (15.4%); Iberian Hare *Lepus granatensis* (10.3%); and Red-legged Partridge *Alectoris rufa* (7.7%).

To assess the PL impact on Golden Eagle (direct mortality) in the study area, 28 carcass searches were undertaken. Although a total of 67 carcasses and other remains of birds were found during the sample period, no signs of Golden Eagle mortality due to PL collisions were registered, nor were they for other raptor species. Given that we found no evidence of mortality of Golden Eagles in the study area, no fatality estimations were undertaken.

DISCUSSION

Despite the fact that the habitat management measures that we implemented have already been used in several European Rabbit conservation programs aimed at the recovery of endangered predators (*e.g.* Sarmento *et al*. 2011; Ferreira & Delibes-Mateos 2010), our study is a pioneer in the context of biodiversity offsets and in trying to assess losses and gains through the integration of predator-prey relationships. Most conservation programs do not attempt such analysis because the valuation of biodiversity is complex (Hayes & Morrison-Saunders 2007) and often not mandatory, and since the need to express 'no net loss' or a 'net gain' is a specific characteristic of offset programs (BBOP 2012c).

Gains in prey populations

At the prey population level, gains related to the implemented habitat management measures were assessed through periodic population surveys. Before offset implementation, control and monitoring areas were proved to be similar respecting to European Rabbit abundance. After offset implementation, however, we verified that the presence and abundance of the species were significantly different in this same areas, suggesting that the measures implemented contributed to improved habitat suitability for the species.

The verified increase in European Rabbit usage of management plots was gradual and, by the end of 2010, this parameter reached significantly higher values both for pastures and artificial warrens. The positive results of the management measures can mainly be explained by the fact that the species shows a high preference for areas with vegetation heterogeneity and ecotone conditions that have a good balance between food availability and cover from predators (Delibes-Mateos *et al.* 2008). Furthermore, the creation of artificial warrens in regions with hard-to-dig soils, like the leptosoils of the study area, greatly benefits European Rabbit by counteracting the limitations of burrow construction (Catalán *et al.* 2008).

As for other factors that significantly affected the presence and abundance of the prey species, like habitats and weather conditions, our results are in accordance with other ecological studies on European Rabbit that have already been widely discussed by several authors (e.g. Beja *et al*. 2007; Calvete *et al*. 2004; Delibes-Mateos *et al*. 2009).

Considering that Golden Eagle shows a preference for hunting habitats that correspond to the habitat requirements of its main prey (Watson 2010), the registered recovery of the European Rabbit population probably increased habitat suitability for this predator. Furthermore, as several other raptor species that feed on European Rabbit (Delibes-Mateos *et al*. 2007) occur in the study area, it would be expected that they also benefitted from our offset program. The European Rabbit is a keystone species for landscape structure and one of the most important small game species in the Iberian Peninsula (Delibes-Mateos *et al*. 2007). Additionally, the habitat mosaics we created are important as hunting areas for raptors and other predators and act as sources of food and shelter for many other animal species (Law & Dickman 1998; Sánchez-Zapata & Calvo 1999). Taking into account the ecological and social importance of European Rabbit in Mediterranean ecosystems, the registered population “gain” certainly had contributed to the health of the ecosystem that had been affected by the construction of the PL. These results could be seen as additional conservation outcomes in terms of ecosystem services and functions, which is a desirable result for any offset program (Bull et al. 2013).

While the negative impacts on biodiversity arising from development projects are often immediate, it takes time to achieve conservation outcomes from offset programs (McKenney & Kiesecker 2010). Considering that expected trend, we began our offset program before the activation of the PL (as recommended by several authors, BLI 2010; López-López *et al.* 2011), in an attempt to reduce the period without offset benefits. Our results on European Rabbit populations confirmed the importance of the timeframe, as the results in 2010 were significantly higher than those in previous years. Sarmento *et al*. (2011) also pointed the existence of a time lag between the implementation of management techniques and the early recovery of rabbit populations.

Gains and losses in the Golden Eagle population

Gains in Golden Eagle populations are more difficult to assess since there are other important factors besides prey availability, external to the project that may influence their dynamics. Intra- and inter-specific competition, expansion of potentially dangerous infrastructure for raptors, human persecution, human disturbance during the breeding season and habitat fragmentation are among the main factors that can negatively affect the species (Cabral *et al.* 2006; Watson 2010).

Furthermore, predator-prey relations are intrinsically complex due to (1) natural fluctuations in population dynamics, (2) interspecific interactions and (3) specificities inherent to the food chain itself (Boyce & Byrne 2007). Typically, these relations are assessed through dietary analysis (e.g. Moleón *et al.* 2012; Ontiveros *et al.* 2005) or evaluations of productivity in relation to prey abundance/availability (e.g. Ontiveros & Pleguezuelos 2000; 2003). The dietary analysis performed as part of this study allowed us to confirm the importance of the European Rabbit in the Golden Eagle diet, but the sample size was not robust enough for further inferences such as assessment of predator’s response to changes in prey populations (Ontiveros *et al.* 2005).

Golden Eagle productivity was incorporated into our gains analysis. Both pairs evidenced a good breeding performance and the lack of reproduction in 2010 by the GE1 pair may reflect the normal fluctuations in the breeding patterns of the species (Eaton *et al*. 2007). It is worth mentioning that productivity in our study area was higher than results recorded from elsewhere in the Iberian Peninsula (e.g. Quadrado 2010; Sánchez-Zapata *et al.* 2000). However these comparisons should be made with caution, as those studies encompassed broader time scales and, quite often, larger populations that included sub-adults, which would lower global productivity (Sánchez-Zapata *et al.* 2000).

The influence of prey availability on the breeding success of the species is widely recognized (Whitfield *et al.* 2009; McIntyre & Schmidt 2012), and although Golden Eagle is not a European Rabbit specialist predator (Watson 2010), any measure that allowed prey enhancement can potentially contribute to its demographic success. Accordingly, the implementation of management measures that benefitted rabbit populations and, potentially, other prey species (Bro *et al*. 2004; Ayanz & Igualada 2006) may have contributed to the success of the eagle population. In the context of potential negative impacts due to PL collisions, achieving and maintaining high productivities in Golden Eagle population is particularly important to ensure population stability and this could potentially compensate losses caused by PL collisions or other causes.

Regarding the spatial analysis of Golden Eagle movements in the study area, the GPS locations obtained through PTT confirmed the use of the MSL by the GE1 pair and its importance, given that the management site was included in the core area of female GE1. Habitat use by this species is related to the existence of food resources (Watson 2010) and hunting accessibility linked to vegetation structure (Tapia *et al*. 2008). Hence, the recovery of rabbit populations in the managed areas most likely increased the suitability of those areas for Golden Eagle, which is consistent with the results obtained. The simultaneous promotion of measures capable of shaping the vegetative cover and increasing food availability was probably determinant in creating areas highly attractive to the raptor species. We note that in cases where habitat management measures for Golden Eagle were based only on the creation of more adequate habitat structure and lacked measures to increase prey species populations (e.g. Walker *et al.* 2005), success seemed lower than in our study.

Furthermore, field observations from vantage points revealed that both pairs were detected ranging inside the management sites and in their immediate vicinity and the Golden Eagle activity index showed a significant increase in the period after PL activation, when habitat management measures were being implemented and producing results

According to Cole (2010), infrastructural impacts on raptors can arise both directly (losses caused by death through collisions) and indirectly (reduction in productivity or offspring mortality due to the loss of reproductive birds). During the studied period, none of those impacts seemed to have affected Golden Eagle population in our study area, as there was no record of mortality due to collisions with the PL or evidence of a productivity decrease or loss of chicks. The number of recorded PL crossings by the species was also very low, representing only a small proportion of the data collected from the PTT attached to the GE1 female. Furthermore, most of the records were located relatively far from the PL corridor and were concentrated around the breeding areas. Additionally, the results concerning the activity index reinforce the low probability of PL negative impacts on GE populations and the positive influence of the measures implemented, as the breeding areas were successfully preserved and the use of the study area by the raptor species increased.

In recognizing the importance of involving the local communities and stakeholders in the offset process (BBOP 2012c), we redoubled efforts to keep them up-to-date on the goals and evolution of the offset program. Hunting associations were actively involved in the implementation of the habitat management measures and attended periodic meetings, thereby complying with the transparency principle of BBOP (BBOP 2012b). Those meetings were also opportunities to raise awareness about the importance of conserving emblematic species, with particular attention on the Golden Eagle. Results, such as the dietary analysis, were used to illustrate the importance of this top predator in predating on older, sick or weakened animals, and by controlling generalist predators such as the Red Fox *Vulpes vulpes*. By involving the community, we hope to have achieved more long-term results, as some hunting associations continued the implementation of the habitat management measures after the program ended and will probably expand habitat management measures to areas not treated before.

Management guidelines

The research associated with the planning and implementation of this offset program and the results obtained have allowed us to draw some management guidelines that may be used in similar projects to compensate for impacts on raptor populations.

1. Time and expertise are crucial factors: an offset program must be properly planned and designed prior to implementation of the infrastructural project and should be based on sound science (BBOP 2012c). Implementing recognized efficient measures to conserve target species such as the habitat management techniques that we implemented, grants some degree of predictability for the outcomes of the program and reduces risks (Gardner *et al*. 2013).

2. Location of management areas should be defined according to (1) the constraints of project development; (2) ecological requirements of the target species; and (3) landscape characteristics.

3. The success of the offset may be conditioned by the acceptance of local communities and other stakeholders, so they should be included in offset planning and implementation (BBOP 2012c). We recommend the hosting of periodic meetings to clarify to stakeholders the offset objectives, to present results achieved and to demonstrate the socioeconomic benefits that it can produce. Simultaneously, such meetings should be used to raise awareness of the importance of biodiversity conservation.

4. To assess offset success and demonstrate 'no net loss' or 'net gains', rigorous and appropriate monitoring programs have to be defined and implemented (BBOP 2012c; Bull *et al.* 2013). Whenever possible, the monitoring program can and should start before offset implementation (allowing BACI procedures to be implemented) and be extended after its conclusion so as to provide solid baselines and confirm the occurrence of long-term outcomes.

5. We recommend going further in the evaluation of losses and gains and accounting for ecosystem functions and services, enabling a more realistic and accurate evaluation of the program. Though the BBOP considers that in cases similar to ours, the evaluation of gains and losses focused on a particular species can be an adequate solution, it also promotes the use of complex accounting models, including multiple metrics and surrogates (BBOP 2012d). As each

biodiversity component can only be included in the equivalency analysis if its value is measurable (Gardner *et al*. 2013), development and validation of more comprehensive approaches is needed.

6. As the present case study was planned to benefit high-conservation status raptors, there is evidence that our approach can be used, or adapted, to benefit other raptor species due to similarities in several behavioral, feeding and breeding parameters (Ontiveros & Pleguezuelos 2000; Delibes-Mateos *et al.* 2007). Likewise, as the nature of the impacts is quite similar (Drewitt & Langston 2006), this kind of offset program could also be deemed suitable to offset impacts related to raptor collisions at wind farms.

CONCLUSIONS

Our results confirm the efficiency of the defined offset program in achieving additional gains of biodiversity that would not occur without the habitat interventions, thereby eliciting a net gain of biodiversity. Hence, we confirmed the efficiency of habitat management to offset potential negative impacts of PL on endangered raptor species. Given the importance of finding efficient tools to reconcile biodiversity conservation and economic development, this approach could be of broad benefit to other projects with similar impacts.

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Considerações finais

Pretendeu-se com este estudo demonstrar a adequação do programa de compensação em causa e a sua capacidade enquanto ferramenta de defesa ativa contra a perda de valores ecológicos afetados pela extensão de uma linha de muito alta tensão. De uma forma geral, considera-se que os objetivos estipulados foram atingidos.

Ao nível das populações de coelho-bravo, confirmou-se a eficácia da gestão de habitat, posta em prática através da criação de zonas de ecótono e do aumento da disponibilidade de alimento e abrigo, tendo-se verificado melhorias significativas nas áreas geridas relativamente às áreas controlo, quer a nível da presença quer a nível da abundância da espécie-presa. Os aumentos registados foram graduais e mais significativos no terceiro ano de monitorização, evidenciando-se assim a importância do fator tempo para o sucesso dos programas de compensação.

Quanto aos casais de Águia-real presentes na área de estudo, foi possível confirmar a boa performance reprodutiva dos indivíduos, bem como a utilização das áreas geridas e a reduzida utilização do corredor ocupado pela linha elétrica. Através de diversos estudos levados a cabo por outros autores, foi já possível demonstrar a influência positiva da disponibilidade de alimento sobre o sucesso reprodutivo e a utilização do espaço pela espécie, pelo que o fomento das populações de coelho-bravo terá potencialmente contribuído para a estabilidade destas populações e para assegurar a existência de condições favoráveis à sua manutenção na área de estudo, resultado particularmente importante tendo em conta o estatuto de conservação da espécie e o reduzido número de núcleos populacionais em território nacional.

Provou-se que, para além do planeamento cuidado e apoiado em conhecimento científico sólido, a monitorização regular dos diversos elementos intervenientes no programa é uma etapa fundamental e determinante para a demonstração de objetivos. Atendendo à fragilidade de muitos dos valores ecológicos afetados por impactes negativos associados a projetos de desenvolvimento, é imperativo acompanhar a sua evolução durante todo o processo e assegurar a neutralização de perdas líquidas de biodiversidade ou a ocorrência de ganhos.

Verificou-se assim, com este estudo, que a gestão de habitat com o objetivo de aumentar a disponibilidade de alimento para um predador ameaçado pode permitir alcançar ganhos que ultrapassam largamente as perdas. Esta abordagem à compensação ambiental não tem sido integrada nos programas implementados no passado recente, mas pelo seu elevado potencial enquanto potenciadora de ganhos de biodiversidade deve ser adotada em programas futuros.

Conclui-se que o programa de compensação implementado foi bem sucedido e permitiu alcançar ganhos líquidos de biodiversidade. Não obstante, e atendendo ao recente aparecimento da compensação ambiental, considera-se que existe ainda muito a aprender e a explorar neste campo da conservação, pelo que é necessário dar continuidade à investigação e publicação de resultados, com vista à otimização dos procedimentos e metodologias e a assegurar a existência de ferramentas eficazes para travar a perda de biodiversidade.

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