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Free housing for declining populations: Optimizing the provision of artificial breeding structures

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ABSTRACT

The improvement of habitat quality and reproductive success through the implementation of artificial breeding structures is one of the most widespread *in situ* conservation strategies applied to the recovery of declining wildlife populations. Several past studies have monitored the use of artificial breeding structures in the wild, but virtually none of them have investigated which demographic and environmental factors actually determine their effectiveness in facilitating reproductive success. Therefore, the aim of the present study was to identify those factors influencing breeding success in artificial structures. With this purpose we surveyed a declining population of a keystone species of Mediterranean ecosystems, namely the European wild rabbit. In Doñana National Park, we sampled during the course of two years the breeding success of wild rabbits from 47 artificial warrens, experimentally provided under different demographic and environmental conditions. In order to determine the relative importance of such factors, we applied an AIC model selection procedure to alternative biological hypothesis groups, postulating that breeding success in artificial structures would primarily depend on population density, food availability and/or predator limitation. We found that the efficiency of artificial warrens in facilitating rabbit reproductive success can vary, with an increase associated with greater pasture availability. Predator limitation by fencing also positively affected rabbit reproduction, but only in combination with high pasture availability. On their own, fencing treatment and population reinforcements had low and null effectiveness facilitating reproduction, respectively, as well as entailing significant economic and biological costs. The best way to improve breeding success in artificial structures, therefore, was through their strategic placement in potential high-quality habitats, *i.e.* with suitable pasture availability. We suggest that vegetation management can effectively increase carrying capacity and consequently the target species' reproductive success, especially in fast breeding species like the European wild rabbit. The provision of artificial breeding structures for conservation purposes may significantly benefit from the elaboration of concurrent experimental studies similar to the present research, which can help establish useful guidelines for optimizing future conservation efforts.

Introduction

Anthropogenic changes are negatively affecting all existing ecosystems as well as most animal species, including abundant ones (Vitousek et al. 1997; Gaston and Fuller 2008). In order to mitigate population declines, researchers and wildlife managers are working on the development and application of different *in situ* and *ex situ* conservation actions (Soulé et al. 1986; Balmford et al. 1995). Some of these strategies entail environmental modifications, with the aim of improving or restoring habitat quality for concerned species (*e.g.* vegetation management, supplementary provision of drinking troughs and resting sites: Smallidge and Leopold 1997; Epaphras et al. 2008; Polo-Cavia et al. 2010). In this context, one widespread measure has been the installation of artificial structures across natural areas to provide wild species with additional breeding and shelter sites (Bolton et al. 2004; Lindenmayer et al. 2009).

Artificial breeding structures have long been used with several different *taxa*, from the well-known bird nest-boxes to artificial burrows for reptiles or mammals (Stamp et al. 2002; Souter et al. 2004; Catalán et al. 2008). Their primary purpose is to compensate for the loss of natural shelters and the subsequent high offspring mortality suffered by target species (Møller 1989; Fargallo et al.

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2001). In some cases, these structures have successfully increased reproductive success and recruitment (Griffith et al. 2008; Libois et al. 2012); however their efficiency might highly depend on local demographic and environmental characteristics. Indeed, several factors such as population density, stress conditions, food availability and young predation are likely to modulate breeding success (Tapper et al. 1996; Siikamäki 1998; DeMaso et al. 2013), and consequently the effectiveness of artificial structures for reproduction. Therefore, in order to optimize habitat management and conservation efforts, the identification of suitable locations for the installation of artificial breeding structures is of paramount importance. Nevertheless, no previous research has examined this issue, and for this reason the main purpose of the present study is to investigate the demographic and environmental factors which determine reproductive success in artificial structures. More specifically we focus on the relative roles of site-specific population density, food availability and predation risk.

Given this objective, we used as a study model the provision of artificial warrens for the conservation of the European wild rabbit *Oryctolagus cuniculus* (Linnaeus, 1758) in southern Spain. This is a keystone species in Mediterranean ecosystems of south-western Europe, where it is the essential prey for the endangered Iberian lynx *Lynx pardinus* (Temminck, 1827) and Iberian imperial eagle *Aquila adalberti* Brehm, 1861 (Delibes-Mateos et al. 2007). The wild rabbit is an ecosystem engineer (Gómez-Sal et al. 1999; Gálvez-Bravo et al. 2009) and one of the most harvested game species within its original distribution range, where hunting has great socio-economic importance (Villafuerte et al. 1998; Letty et al. 2008). Indigenous rabbit populations have severely declined in the last 50 years, mainly due to new epizootics (myxomatosis and rabbit haemorrhagic disease; Virgós et al. 2007); although the modification of landscape use (Letty et al. 2008) and climate change (Tablado and Revilla 2012) are also contributing factors. Today, hunters and wildlife managers are working to reverse this decline, usually by trying to increase rabbit abundance, either directly *via* restockings (Calvete et al. 1997; Moreno et al. 2004) or indirectly through the improvement of survival and reproduction (Moreno and Villafuerte 1995; Ferreira et al. 2009). The provision of artificial warrens is the oldest and most commonly used practice which attempts to enhance rabbit breeding success and recruitment (Thompson and King 1994) through the increase of reproduction site availability and the limitation of kitten mortality (Fernández-Olalla et al. 2010; Rouco et al. 2011). Nevertheless, there are still no studies which try to identify the demographic and environmental variables affecting rabbit reproductive success in artificial warrens. Therefore, we applied a model selection procedure to alternative biological hypotheses, in order to verify the relative importance of the factors determining the efficiency of artificial warrens as breeding sites.

The first hypothesis incorporated only the month and year of the surveys (the null model) given that wild rabbit breeding success can present intrinsic temporal variation (Tablado et al. 2009). The second hypothesis suggests that reproductive success in artificial warrens will be positively related to the density of potential breeders, as is the case in natural burrows (Villafuerte et al. 1997; Moreno et al. 2004). Alternatively, a negative density-dependent effect corresponding to extremely high population abundance may also be possible (Myers and Poole 1962; Rödel et al. 2004). Moreover, wild rabbit restocking (independently or interacting with density) can negatively affect breeding success since the sudden intrusion of foreign potential breeders can disrupt the previously established social structure (Cowan and Garson 1985; Moreno et al. 2004).

According to the third hypothesis, reproduction success within artificial warrens will be primarily related to food availability, either alone or in combination with density and restocking. Pasture availability improves several rabbit reproductive parameters (Poole 1960; Tablado et al. 2009) and it can limit kitten malnutrition mortality (Stodart and Myers 1966; Rödel et al. 2009), and as a result the effectiveness of artificial warrens may strongly depend on their access to green pastures.

The fourth hypothesis postulates that wild rabbit breeding success in artificial warrens will mainly depend on predator pressure, again in combination with density and restocking. Predation is often managed by exclusion fencing (Calvete and Estrada 2004; Cabezas et al. 2011), which attempts to limit access to carnivore species actively feeding on breeders, newborns and juveniles. Furthermore, predator presence intrinsically increases breeder stress levels (Monclús et al. 2005, 2009), thus reducing their fecundity (von Holst 1998). Finally, we also included a group of models which test different combinations of the above hypotheses, including the full model.

The identification of the demographic and environmental factors affecting rabbit breeding success in artificial warrens would provide the information necessary to strategically place these structures in the wild, in order to optimize their use. Moreover, the present case study could also provide an example applicable to declining populations of other species, with the aim of improving a frequently implemented conservation practice: the provision of artificial breeding structures.

Materials and methods

Study area

This study was carried out within the Doñana Biological Reserve (DBR, south-western Spain: 36°59′ N, 6°26′ W), an area of approximately 7000 ha localized within the Doñana National Park (DNP; Fig. 1). Climate in the area is Mediterranean sub-humid with Atlantic influence.

Wild rabbits are present predominately in the Mediterranean scrubland ecosystem, positively related with pasture availability, which is greater close to wetlands (*i.e.* marshlands and lagoons; Palomares et al. 2001; Fig. 1). Within our study area there was a wide-scale management project with the aim of recovering the wild rabbit populations of the DBR (Román et al. 2006; Palomares et al. 2007). This project was focused on two experimental zones denominated *Vera* and *Lagunas* (each of them 600 ha; Fig. 1).

Warren building and experimental treatments

Within the *Vera* and *Lagunas* zones the above mentioned conservation project established 24 and 18 five-ha experimental sites, respectively (Román et al. 2006; Palomares et al. 2007; in the present study we only surveyed 8 experimental sites per zone, see below in *Data collection*). Every experimental site was provided with five artificial warrens, each consisting of a two-floor wooden structure (15 m × 3 m × 1 m) with 30 entrances and covered with a metallic net, ground cloth and sand (Román et al. 2006; Palomares et al. 2007).

Just prior to the present study, DBR wild rabbit populations had extremely low densities (0.01–0.03 individual per ha; Palomares 2004). Therefore, both experimental zones were restocked prior to the wild rabbit breeding season (*i.e.* mainly during the months of October and November; 2004 for *Vera* and 2005 for *Lagunas*; Appendix 1), with the aim of minimizing social structure disruptions (Moreno et al. 2004).

The wild rabbit sex ratio in natural populations tends to be balanced (*i.e.* 1:1; Villafuerte 1994; von Holst et al. 2002); nevertheless, this is a polygynous species and with the aim to optimize the probabilities of reproduction we released 2–3 females for each introduced male. The applied restocking density varied