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The contribution of non-protected areas to the conservation of Eurasian Eagle-owls in Mediterranean ecosystems

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Citation: León-Ortega, M., J. E. Martínez, E. Pérez, J. A. Lacalle, and J. F. Calvo. 2017. The contribution of non-protected areas to the conservation of Eurasian Eagle-owls in Mediterranean ecosystems. Ecosphere 8(9):e01952. 10.1002/ecs2.1952

Abstract. Land-use management, human impacts, and wildlife population processes taking place outside protected areas may affect the conservation of species within protected areas. While many studies have evaluated the effectiveness of protected areas for conserving biodiversity, the contribution of non-protected areas in this respect has seldom been assessed. Here, we assess the suitability of non-protected areas for a Eurasian Eagle-owl population using long-term monitoring data of 127 territories, together with survival and home range data from 30 radio-tracked individuals, in order to investigate whether the demographic parameters estimated and home range size differed inside and outside protected areas. The results showed that the number of breeding territories was higher inside the protected areas and that the average home range was significantly smaller for individuals nesting inside the protected areas. However, no significant differences in survival or in the breeding performance were observed between individuals nesting in territories inside and outside the protected areas. We conclude that although protected areas are effective for maintaining breeding populations of Eurasian Eagle-owls and their size can be considered sufficient to offer suitable protection of the foraging habitat, non-protected areas also deliver positive outcomes for these populations.

Key words: breeding success; *Bubo bubo;* home range; Mediterranean ecosystem; productivity; protected area; survival.

Received 22 June 2017; revised 1 August 2017; accepted 24 August 2017. Corresponding Editor: Alice W. Boyle.

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Introduction

The designation of protected areas is one of the most commonly used tools for the conservation and management of biodiversity worldwide (Chape et al. 2008, Gray et al. 2016), and numerous studies (e.g., gap analysis) have assessed the extent to which they fulfill this role at different scales (Rodrigues et al. 2004, Abellán et al. 2011, Orlikowska et al. 2016). However, many authors have found that the coverage of populations and communities by existing networks of protected areas is insufficient for the long-term preservation of biodiversity (Araújo et al. 2007, Albuquerque et al. 2013, Abellán and Sánchez-Fernández 2015).

Effective management of protected areas not only helps to conserve biodiversity, but also contributes to the livelihood of local communities (Tsiafouli et al. 2013, Watson et al. 2014) and is also a determinant in the success of conservation networks (Hockings 2003, Coad et al. 2015). For example, management practices for raptor species such as guarding and protecting nests, reducing disturbances, and/or correcting human impacts can play an important role in increasing productivity and reducing mortality of protected species (Tintó et al. 2010, Zuberogoitia et al.

2014, Oppel et al. 2016). The Natura 2000 is a protected area network that aims at the long-term preservation of the most valuable contributors to European biodiversity, which is one of the greatest environmental challenges for the European Union (Kati et al. 2015, Kukkala et al. 2016). However, recent studies have questioned the effectiveness of the Natura 2000 network for the conservation of terrestrial and freshwater biodiversity (Maiorano et al. 2007, Albuquerque et al. 2013, Hermoso et al. 2015).

Outside protected areas, land-use decisions and human-induced changes may result in habitat loss (Françoso et al. 2015) and may directly affect the persistence of protected species within reserves (Janzen 1986). For example, the absence of effective management in non-protected areas may increase the risk of mortality in many threatened terrestrial vertebrates due to habitat alteration, illegal human activity, and the proliferation of human infrastructures in more inhabited areas (Berger 2004, Woodroffe et al. 2007, Pérez-García et al. 2011, Williams et al. 2017). In addition, habitat loss and a decline in survival rates could be critical factors affecting the stability and dynamics of the breeding segment of populations, especially for threatened species (Penteriani et al. 2005, Cushman 2006, Basille et al. 2013, Boulanger and Stenhouse 2014, Vickers et al. 2015). However, comparative studies on the suitability of non-protected vs. protected areas for the conservation of target species have seldom been conducted (Dupain et al. 2004, Western et al. 2009, Balme et al. 2010), even though direct persecution, non-natural mortality due to human activities, and loss of suitable habitat may contribute to their decline (Oppel et al. 2016). Moreover, top predators and vagile species may regularly forage far away from their core areas (Martínez et al. 2007, Elbroch and Wittmer 2012, Mattisson et al. 2013, Almpanidou et al. 2014), so information on home range behavior could provide critical information for the management of conservation target species (Arroyo et al. 2014).

Our model species, the Eurasian Eagle-owl (*Bubo bubo*; Fig. 1), is listed under Annex I of the European Union Birds Directive and Appendix II of the Bern Convention. It is also considered as a target species for the designation of Special Protected Areas for the conservation of birds (SPAs)

Fig. 1. Photograph of a male Eurasian Eagle-owl taken in the study area. Photo credits: José Alfonso Lacalle.

within the Natura 2000 network. This large owl is an apex predator, whose population is estimated at more than 2000 pairs in Spain (Martínez and Zuberogoitia 2003). In southern Spain, this species is relatively common and its reproductive performance is high, mainly because of the abundance of its local preferred prey, the European Rabbit *Oryctolagus cuniculus* (Martínez and Calvo 2001, Pérez-García et al. 2012).

In the present study, we used long-term monitoring data to examine the role of non-protected areas for conserving Eurasian Eagle-owls in southeastern Spain. Our specific objectives were to assess (1) whether breeding performance, as estimated from long-term monitoring data, was different inside and outside protected areas and (2) whether the size of Eurasian Eagle-owl home range and adult survival, estimated by radio-tracking, were different among areas. Our hypothesis was that the persistence of Eurasian Eagle-owl in southeastern Spain is higher in protected areas than in non-protected areas due to higher habitat quality and effective conservation actions within protected areas. Thus, we predicted that the number of breeding territories, breeding performance, and survival would be greater in protected areas and that home range size would be greater outside protected areas.

Materials and Methods

Study area

The study was conducted on a Eurasian Eagle-owl population in the east of the province of

Murcia (southeastern Spain 37°45′ N, 0°57′ W; Fig. 2). This area, covering ~240,000 ha, is a quaternary sedimentary basin surrounded by two mountainous systems with high densities of Eurasian Eagle-owl pairs and rabbits (Espín et al. 2014, León-Ortega et al. 2014). We focused on a protected area network that includes regionally designated protected areas (RPA; http://www.murcianatural.carm.es/) and the Natura 2000 Network, that is, sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs). The protected areas network covers ~55,000 ha in the study area (Fig. 2) and includes three SPAs (coded ES0000199, ES0000264, and ES0000269), nine SCIs (ES6200001, ES6200002, ES6200006, ES6200013, ES6200015, ES6200024, ES6200025, ES6200040, and ES6200044), and four RPAs ("Carrascoy y El Valle," "Sierra de la Muela, Cabo Tiñoso y Roldán," "Cabezo Gordo," and "Calblanque, Monte de las Cenizas y Peña del Águila"). The protected area landscape is hilly and covered by small forests of Aleppo Pines (*Pinus halepensis*) and wide areas of scrubland and other open habitats (pastures), interspersed with mostly dry farming (fallow lands, cereals, olives, and almonds). Most of the area is managed for game hunting (mainly partridges and rabbits) and for traditional agroecosystems (cropland and livestock). The non-protected area (~185,000 ha) is situated in the center of the study area and is characterized by low hills with gentle slopes covered by small scrub patches, and intensively cultivated or urbanized valley floors. The climate is arid and semiarid Mediterranean with 275–400 mm of annual rainfall and an average annual temperature of 19°C.

Fieldwork

Breeding territories and reproductive parameters.— Between 1999 and 2014, an intensive monitoring of 127 territories was carried out during the breeding season, from mid-December to early May. The presence of a breeding pair was determined when signs of territorial or mating behavior were observed (Martínez et al. 2003, Ortego and Díaz 2004), including courtship and responses (e.g., elicited and spontaneous vocalizations, approaches), copulations, nest material and prey transfers, the presence of large amounts of extremely white feces and prey feathers on posts and plucking sites in the proximity of the nest site (Penteriani and Delgado 2008), and direct observations of adults and of their activity in rocky areas or in the nest. Nest sites were checked at least three times: during female

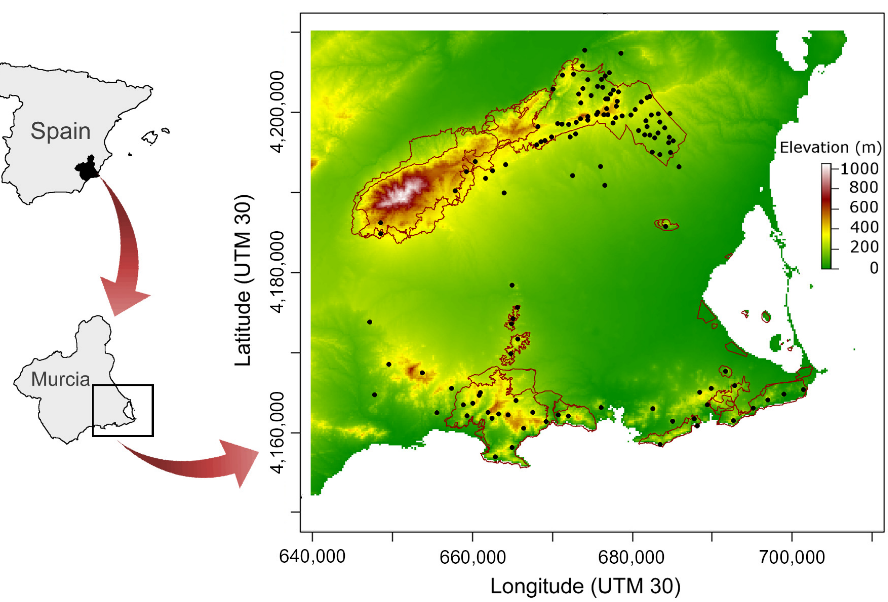

Fig. 2. Map of the sampled area showing the distribution of the Eurasian Eagle-owl territories (dots). Red lines delineate protected area boundaries. The rest of the area is unprotected.

incubation, when chicks were 20–30 d old to assess brood size, and when chicks were 45–50 d old to record the number of fledged young (Marchesi et al. 2002). Following Steenhof and Newton (2007), a breeding pair was established as one which laid eggs, and a successful pair as one which raised at least one chick to fledging age. Breeding success rate was defined as the ratio between the number of successful pairs and the number of breeding territories. Productivity was defined as the mean number of fledged young per occupied territory (Steenhof and Newton 2007).

*Trapping and radio-tracking.—*From 2007 to 2010, 30 individuals (15 males and 15 females) from different territories of the study population were haphazardly chosen to be captured and radio-tracked. Each individual was fitted with a 30-g radio-transmitter (Biotrack; Wareham, Dorset, UK; http://www.biotrack.co.uk) using a Teflon ribbon backpack harness, which contained a mortality sensor. Eurasian Eagle-owls were trapped using two methods: (1) simulation of territorial intrusion using a combination of a taxidermy mount of a Eurasian Eagle-owl and a mist-net to capture the territorial bird when it responded to the simulated intruder (Penteriani et al. 2007) and (2) using a bow-net placed at the nest when nestlings were 20–35 d old (León-Ortega et al. 2016). No adverse effects of the back-packs were recorded on individuals and their breeding performance. Birds were sexed by discriminant functions based on body measurements that classified 98.4% of the birds correctly (Delgado and Penteriani 2004). Owls were radio-tracked from four-wheel drive vehicles using three element hand-held Yagi antennas (Biotrack) with either Stabo (XR-100) portable ICOM receivers (IC-R20) or Biotrack-SIKA radio-tracking receivers. The locations of radio-tagged individuals were determined by triangulations for at least twice a month (León-Ortega et al. 2016), estimating the status (alive, dead) at the same time.

Statistical analyses

*Reproductive parameters.—*Differences in reproductive parameters related to the Eurasian Eagle-owl territories were examined inside and outside the protected areas using data from the 127 territories monitored. Generalized linear mixed models were used to test whether the probability of breeding success and productivity were influenced by the location of territories (inside or outside of protected areas). Territory number and year were considered as random effects (random intercepts only), and territory location was considered as fixed effect. The probability of breeding success was modeled as a binary variable (1 = breeding success; 0 = no breeding success), and a logit-link function (with binomial error distribution) was used to estimate the probability of breeding success. Territory productivity was estimated as the number of young fledged (0–5) per year, and a log-link function (with Poisson error distribution) was used for the productivity models. Analyses were performed with R version 3.3.1 (R Core Team 2016), using the "lme4" package (Bates et al. 2015).

*Survival estimation.—*To examine survival, we used the 30 encounter histories ($\mathbf{h}_i$) obtained by relocating the radio-tracked individuals, considering a total of 32 three-month intervals (León-Ortega et al. 2016). To estimate survival rates, we used the known fate model with the logit-link function in the program MARK (White and Burnham 1999). Known fate analysis is an appropriate method for estimating survival parameters in radio-tracking studies in which the status (dead or alive) of all tagged animals is known on each sampling occasion (Cooch and White 2016). Three-month survival rates were estimated using a model with territory location (inside or outside the protected areas) as a covariate. This model was compared with the null model (a model with no covariates) using a likelihood ratio test (Cooch and White 2016). Because survival rates are different between male and female Eurasian Eagle-owls in the study area (León-Ortega et al. 2016), we also considered an interaction model with sex and territory location as covariates.

*Home ranges.—*To examine home range size, we used radio-tracking data of 22 breeding individuals (11 males and 11 females) from which a minimum number of 30 radio-locations (Kenward 2001, Campioni et al. 2013) were recorded. Home range sizes were determined using the 95% fixed kernel estimator, using the package "adehabitatHR" (Calenge 2006) for the R software. A preliminary examination of the distribution of radio-locations showed that individuals tagged in territories located inside but close to the boundaries of protected areas were radio-located on a large number of occasions (>40%) outside these areas. Accordingly, we classified home ranges into three types: inside, border, and outside. Differences in home range sizes in relation to the location of territories and the sex of the individuals were tested using linear models.

Results

Breeding territories and breeding performance

During the study period, we recorded 857 territorial occupations and monitored a total of 706 breeding events. The average annual breeding success rate was 0.81 (range: 0.33, 1.00), and the average annual productivity (mean number of fledged young per occupied territory) was 2.10 (range: 0.70, 2.62).

We found 96 breeding territories inside and 31 breeding territories outside the protected areas. No significant differences were observed in breeding success rate or in productivity between territories located inside and outside the protected areas (Table 1).

Survival rates

Results from known fate analyses showed that the best model was the null model (Table 2), which estimated a 90-d survival rate of 0.93 (95% CI: 0.88, 0.96). Although the model considering territory location as covariate was a plausible alternative to the null model ($\Delta AIC_c < 2.0$), the likelihood ratio test between both models showed no significant differences among survival rates in territories inside and outside protected areas (Table 1).

Home range sizes

The average number of locations per individual was 31.4 (range: 12, 52). Home range sizes (95% fixed kernel estimator) were highly variable, with an overall average of 859.3 ha (range: 96.2–2393.3; Table 3). Radio-tracked individuals breeding in territories close to the boundaries of protected areas had variable percentages of radio-locations and home range areas outside protected areas (Fig. 3).

Our analysis did not show differences in the home range sizes between sexes ($F_{1,20} = 0.878$, $P = 0.360$). However, we found significant differences that depended on territory location ($F_{2,19} = 5.692$, $P = 0.012$), being lower (400.4 ± 203.7 ha) for individuals breeding inside than for those breeding outside the protected areas (1248.8 ± 635.1 ha; $t_{19} = 3.006$, $P = 0.007$; Table 1), and lower than for those breeding in territories located at border (1115.5 ± 660.1 ha; $t_{19} = 2.650$, $P = 0.016$).

Table 1. Comparison of breeding parameters, three-month survival rates, and average home range sizes between Eurasian Eagle-owls breeding in territories located inside and outside protected areas.

Parameters	Inside	Outside	Statistic	*P*
Breeding success	0.75 (0.72, 0.78)	0.77 (0.69, 0.83)	$z = -1.367$	0.172
Productivity	2.05 (1.94, 2.16)	2.07 (1.83, 2.30)	$z = -0.788$	0.431
Survival rate	0.94 (0.87, 0.97)	0.91 (0.81, 0.96)	$\chi^2_1 = 0.466$	0.495
Home range size (ha)	400.4 (196.7, 604.1)	1248.8 (613.7, 1883.9)	$t_{19} = 3.006$	0.007

Note: 95% confidence intervals are given in parentheses.

Table 2. Known fate survival model selection results for Eurasian Eagle-owls, using territory location (inside/outside protected areas) and sex as covariates.

Models	AIC_c	ΔAIC_c	w_i	*K*	Deviance
S{null}	88.035	0.000	0.595	1	86.010
S{territory_location}	89.619	1.584	0.270	2	85.544
S{territory_location * sex}	91.001	2.966	0.135	4	82.75.1

Notes: The asterisk denotes an interaction model. Models are ranked according to Akaike information criterion (AIC_c). Headers for columns are change in AIC_c relative to the highest ranked model (ΔAIC_c), Akaike weight (w_i), number of model parameters (*K*), and deviance (−2 × log-likelihood).

Table 3. Radio-locations and average home range sizes (95% fixed kernel estimator) of Eurasian Eagle-owls inside, close to the borders, and outside protected areas (PAs) in southeastern Spain.

			Radio-locations		Home ranges (ha)	
Territory location	Sex	*n*	Number	% inside PAs	Average size (±SD)	% inside PAs
Inside	Males	6	205	98.1	364.6 (±253.5)	95.1
	Females	3	93	100.0	472.0 (±329.9)	96.1
	Overall	9	298	98.7	400.4 (±265.0)	95.4
Border	Males	4	145	44.8	1183.5 (±870.0)	45.0
	Females	3	61	31.4	1024.9 (±609.3)	39.3
	Overall	7	206	39.0	1115.6 (±713.7)	42.5
Outside PAs	Males	1	32	0.0	1111.2	0.0
	Females	5	155	4.6	1276.3 (±672.4)	9.9
	Overall	6	187	3.8	1248.8 (±605.2)	8.2

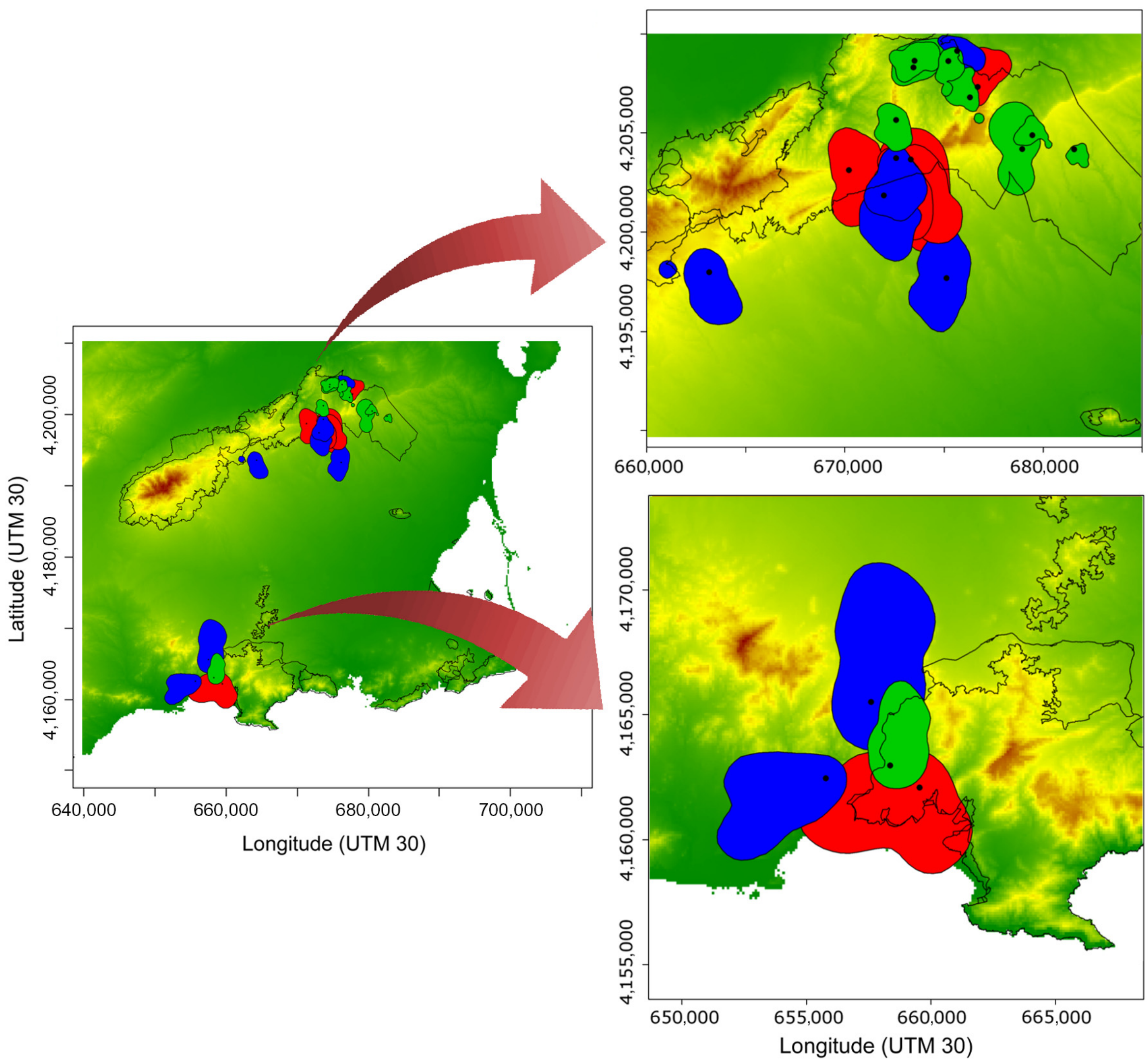

Fig. 3. Spatial distribution of the home ranges (95% fixed kernel estimator) of 22 Eurasian Eagle-owls breeding inside (green filled), close to the border (red filled) and outside (blue filled) protected areas.

Discussion

Our results underline the effectiveness of the protected areas networks for breeding populations of Eurasian Eagle-owls, since the number of nesting sites was notably higher within protected areas than outside protected areas (76% vs. 24%). Such a difference was probably the result of the higher quality of nesting and foraging habitat in the protected areas. In our study area, high densities of Eurasian Eagle-owls are usually associated with irregular topography and the proximity to open habitats and prey availability (León-Ortega 2016). These characteristics are consistent with the findings of previous studies on nesting habitat selection, which suggested that Eurasian Eagle-owls prefer to settle in areas linked with rugged relief in a heterogeneous landscape but with a preference for open patches (Penteriani et al. 2004, Ortego 2007), probably in an attempt to avoid sources of human disturbance and predation (Martínez and Calvo 2000, Martínez et al. 2003, Ortego 2007) and to obtain more profitable preys (Penteriani et al. 2001, Marchesi et al. 2002, Ortego and Díaz 2004).

Our study shows no differences in reproductive success and productivity between Eurasian Eagle-owls inside and outside the protected areas. This result could be due to the considerably high abundance of rabbits throughout the study area (Pérez-García et al. 2012), and consequently, the availability of the Eurasian Eagle-owl's main prey may not be a sufficiently strong limiting factor to cause any great variation in reproductive performance between territories (Campioni et al. 2013, Lourenço et al. 2015). Thus, a saturation of food supply could explain why productivity in our study population is among the highest reported for Eurasian Eagle-owls (Marchesi et al. 2002).

Explanations of home range behavior in Eurasian Eagle-owls have included their biological cycle and both internal (sex and health) and external (habitat features) factors, as well as prey abundance, prey size, and profitability (Campioni et al. 2013, Lourenço et al. 2015). Our results indicated that the average home range size for Eurasian Eagle-owls was less inside than outside protected areas, probably due to differences in foraging habitat quality and rabbit abundance, or also to the higher density of individuals within the protected areas (Benson et al. 2006, Efford et al. 2016). Lourenço et al. (2015) found a strong effect of edge on home range behavior, which was correlated with rabbit abundance and possibly their availability to Eurasian Eagle-owls. In our study area, protected areas may have favored the preservation of large tracts of open habitats interspersed with patches of agricultural crops, resulting in a heterogeneous countryside favorable for the Eurasian Eagle-owl. This spatial heterogeneity and consequent availability of rabbit in foraging areas could affect the size of the home range within protected areas (Campioni et al. 2013). By contrast, the larger home ranges outside the protected areas may be a response to the increased homogeneity around nesting sites, following the gradual substitution of natural habitats by intensive monocultures and human infrastructure, land-use changes that diminish the heterogeneity of the landscape and rabbit density. Human-altered landscapes are a major source of hazards for animals such as birds of prey (Schaub et al. 2010). However, survival rates were similar for our radio-tracked Eurasian Eagle-owls both inside and outside protected areas. These results are contrary to our expectations, but should be treated with caution because of the low sample size (Naef-Daenzer and Grüebler 2014).

Our results showed that most individuals use an area for foraging that is much smaller than the actual size of the area where the species is protected (e.g., SPAs designated for them). This further supports the idea that the area within the SPAs was suitable to provide Eurasian Eagle-owls with sufficient resources for foraging. In contrast, other studies have found that protected areas designated for raptor species do not satisfy their foraging requirements (Martínez et al. 2007, Fernández and Gurrutxaga 2010, Guixé and Arroyo 2011). For example, Martínez et al. (2007) found that booted eagles (*Hieraaetus pennatus*) nesting in a protected forest area mainly forage in the surrounding, unprotected agricultural fields. Although this may be the case for individuals nesting close to the limits of protected areas, they appear to be of sufficient size to support the bulk of the reproductive population and conserve a suitable area for foraging. On the other hand, this study highlights the importance of non-protected areas for supporting a noteworthy population of breeding Eurasian Eagle-owls and their important role as settlement areas for inexperienced floaters. Our results suggest that conservation policies should be focused on both protected and non-protected areas. These actions should include measures aimed at (1) favoring the maintenance of low-intensity agroforestry activities inside protected areas, where prey availability, mainly rabbits, is higher (Moreno and Villafuerte 1995), and (2) minimizing mortality due to electrocution on power lines, a measure that should enhance Eurasian Eagle-owl's survival and subsequent population growth (López-López et al. 2011).

Acknowledgments

We thank Juan Capel, Mari Paz Aldeguer, Pilar Gómez, Aida Salas, Francisco Alberto García-Castellanos, José Manuel Zamora, Mario Gallego, Antonio Zamora, Irene Arnaldos, José Alguazas, Adrian Ruíz Rocamora, and Domingo Gómez for their help in the field work. Authorization for the study was provided by the Dirección General de Medio Ambiente of the Autonomous Community of Murcia, which regulates the management of wildlife and endangered populations in the study area. The suggestions and comments of two anonymous reviewers considerably helped to improve the manuscript.

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