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Influence of environmental factors on the breeding success of Cinereous Vultures *Aegypius monachus*

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Abstract. Breeding success determines the fate of bird populations and, therefore, understanding its determinants is an important issue for the application of conservation measures for endangered species. Breeding success depends on diverse, not mutually exclusive, effects such as the life strategies developed by species, environmental, ecological and anthropogenic factors. The influence of nest and nest tree characteristics, landscape composition and human disturbance on the breeding success of the vulnerable Cinereous Vulture *Aegypius monachus* in breeding colony in central Spain was analysed. A number of variables characterising the vegetation around the nest-tree, the nest-tree, and the nest itself were selected and analysed. We found that bigger and less deteriorated nests, taller nesting trees and a higher shrub coverage in a radius of 100 m around the nest resulted in an increased breeding success. Although nesting sites characteristics and nest quality can be related to birds' age and breeding experience, our findings show that geographical orientation of the slope where the nest is located as well as nest accessibility and habitat selection have an influence on Cinereous Vulture breeding success. We recommend that mature forests, steeper slopes should be carefully conserved and protected from anthropogenic disturbances in order to strengthen the conservation of breeding areas of this forest-dwelling endangered raptor species.

Key words: *Aegypius monachus*, forest management, vegetation influence, conservation practice, threatening factors, human disturbance, landscape features

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INTRODUCTION

Birds exhibit a number of diverse life-history traits with large, long-lived species typically showing low fecundity and high adult survival rates (Cody 1971, Badyaev & Ghalambor 2001). This is more evident in many birds of prey with highly specific nutritional and habitat requirements whose life strategies are influenced by environmental factors (Erikstad et al. 1998, Margalida et al. in press). The study and knowledge of the inherent details of species life-history traits is essential if suitable management measures are to be applied, mainly when their populations are threatened (Pullin et al. 2004, Margalida et al. in press).

A trade-off between survival and reproduction is a key aspect in the understanding of bird life strategies (Linden & Møller 1989). Thus, for a long-lived species it is more important in terms of fitness to attain high adult survivorship than to rapidly produce numerous offspring (Hirshfield & Tinkle 1975, Erikstad et al. 1998). This means that from a demographic point of view, a priority task for the successful conservation of large threatened birds is the reduction of non-natural adult mortality rather than to increase their fecundity (Oro et al. 2008, Ortega et al. 2009). But eradication of the use of illegal poisoned baits, which is the most affecting factor in non-natural mortality of vultures in the Western Palearctic (Margalida 2012), is still far in light of the sheer variety of motivations, methods and emplacements that characterize this practice (see Hernández & Margalida 2008). Thus, additional conservation efforts targeting other demographic parameters such as pre-adult survival or breeding success has been implemented (i.e. supplementary feeding, nest vigilance) to buffer the negative effects of non-natural mortality (Arroyo & Razin 2006, Oro et al. 2008).

Breeding success in birds is dependent on a wide range of factors. For instance, the survival of newly hatched chicks is affected by climatic conditions (Kostrzewa & Kostrzewa 1991, Margalida et al. 2007), as well as by landscape features, the possibilities of finding food and the ability to avoid predators (Lind & Creswell 2005, Wilkin et al. 2009). Moreover, human presence, which generally involves activities that are likely to have a negative impact on breeding attempts, affects the number of chicks fledged, even if the disturbance occurs after the beginning of breeding (González et al. 2006, Margalida et al. 2011). Disturbances not only influence breeding success during a breeding attempt, but can also lead to changes in distribution patterns and, even, changes in individual behaviour (Sutherland 2007).

An understanding of which factors determine habitat choice or breeding success is a basis for successful recovery programmes of threatened species (Lindenmayer et al. 2008). An abundant body of literature exists on habitat selection by threatened raptors (e.g. González et al. 1992, Margalida et al. 2008). However, knowledge on factors that determine the breeding success is scarce (Arroyo & Razin 2006, Bionda & Brambilla 2012). In this study we evaluated the influence of environmental and human-related factors on the breeding success of Cinereous Vulture *Aegypius monachus* in order to understand which factors are the most relevant and, thus, to be able to take them into account in the management of the areas this raptor inhabits.

The Cinereous Vulture is the largest Palearctic raptor and is considered Near Threatened (7,200–10,000 pairs, BirdLife International in IUCN 2010). In Spain a total of 2,068 breeding pairs occur (Moreno-Opo & Margalida in press) and the species is regarded as Vulnerable (Ministry of Environment, Rural and Marine Affairs 2011). Its habitat is to be found in upland areas in the south-west of the Iberian Peninsula and on the island of Mallorca. It breeds colonially in forests and builds large nests on treetops (Donázar 1993). Nests occupied by different pairs are located at varying distances from each other (average distance 556.6 ± 606.9 m, Morán-López et al. 2006a). Only one chick per breeding attempt fledges. The Cinereous Vulture belongs to the bird species with the longest breeding cycle in the Palearctic (Cramp 1998); in Spain, the mating behaviour begins in late December and lasts until February, eggs are produced between February and April. After about 59 days of incubation (range 51–68) chicks hatch, and they start their first flights at 114 days, which usually occurs during August and September (Cramp 1998). As a scavenger species, it feeds on the carcasses and remains of different species, mainly domestic cattle, but also on wild lagomorphs and ungulates (Costillo et al. 2007), which are found in agricultural and livestock managed areas and forests (Donázar 1993).

METHODS

Study area

Fieldwork was carried out in the breeding colony of Umbría de Alcudia, Castilla-La Mancha, central Spain, the fourth largest in Spain with 104 breeding pairs (Moreno-Opo & Margalida in press). This site is protected as a Special Protected Area (SPA) for birds and consists of an upland area at altitudes of 736–1,115 m a.s.l. The vegetation on the slopes of the nesting colony is dominated by typical Mediterranean trees such as holm oak *Quercus rotundifolia*, cork oak *Q. suber*, strawberry-tree *Arbutus unedo*, prickly juniper *Juniperus oxycedrus*, Lusitanian oak *Q. faginea* and, to a lesser extent, associated shrubs in areas with a developed shrub layer.

Field work and studied variables

Fieldwork was carried out from February 2005 to January 2006. During the 2005 breeding season, a monitoring program was developed to check nest occupation and success of Cinereous Vultures. Fortnightly surveys from February 1st were conducted to record the breeding status in those nests where the Cinereous Vulture pairs started incubation, in 89 focal breeding pairs of the colony. The successful nest was defined as the one in which a chick fledged, while an attempt was considered unsuccessful when the clutch was abandoned or chick died before fledging. In order to reduce disturbances from the field technicians, the occupied nests were checked after the end of the breeding season (October–January) (Table 1). The nests in which a chick fledged (n = 50) were compared with nests that failed to fledge a young bird (n = 39).

Independent variables were selected on the basis of their possible influence on the Cinereous Vulture breeding success, as reported in previous studies (Donázar et al. 2002, Morán-López et al. 2006b), or as factors related to the management of the selected habitats (Poizaridis et al. 2004). Five types of variables were taken into account: tree and nest characteristics, geomorphologic variables, variables related to the vegetation, and variables linked to human disturbance (in total 20 variables, Table 1). Quantitative variables were obtained by direct observation in the field, applying GPS devices, measuring tapes or visual estimates, or by GIS and aerial photographs, depending on the type of variable. On the other hand, the qualitative variables were issued after training and standardization of field technicians to predetermined values. In the case of *quality status of the nest*, the overall quality of the nesting structure, the shape and the amount and type of material, which are variable between breeding pairs, the assessments were done after the breeding season, taking into consideration that Cinereous Vultures build and / or repair the nest before they start incubation. Climatic variables were considered to be irrelevant in this study, given the relatively small study area (total 11,115 ha), and they were not included in the analyses. The success or failure of a breeding attempt was chosen as the response variable (Guisan & Zimmerman 2000).

Statistical analyses

To select the independent variables to be included in the models, correlation between the continuous candidate variables was checked using Spearman's rank correlation (ρ) index. The variables *%_Qrot* and *%_scree-rock* as well as *%_scree-rock* with *%_othersp* (see Table 1) showed strong correlations ($\rho = -0.61$ and $\rho = -0.66$, respectively). Therefore, the two pairs of variables were removed from further modelling. In order to explore the influence of each group of variables on Cinereous Vulture breeding success, we established a set of a priori competing generalized linear models (6 models, see Table 2). The response variables were binary (success/failure) and so we used binomial family errors and logit-link functions. We checked for overdispersion inspecting the dispersion parameter which was calculated for each model by dividing the residual deviance

Table 1. Independent variables considered in the analysis of the characteristics that determine the breeding success of the Cinereous Vulture. [a] — continuous variable, [b] — categorical variable.

Study level	Variable	Description
Tree characteristics	*Sp_tree*[b]	Tree species
	H_tree[a]	Total height of nest tree (m)
Nest characteristics	*Nest_cons*[b]	Quality status of the nest: "good" = well structured, with upper herbaceous cover, circular or squared shaped, "not good" = with any imperfection, with upper herbaceous cover but not circular or squared shaped, "bad" = old, not structured nor renewed, without upper herbaceous cover, partially collapsed or fallen
	D_nest[a]	Length of the longer diameter of the platform of the nest (cm)
Geomorphologic	*Alt*[a]	Altitude (m asl)
	Scree[b]	Presence of nest tree in a natural scree "yes"/"no"
	Orient[b]	Geographical orientation of the slope where nest tree is located "N", "S", "W", "E"
	D_scree[a]	Distance from nest tree to nearest natural scree (m)
Vegetation	*Rad25_tree*[a]	Number of trees higher than 4m existing around the nest tree in a 25m radius
	H_shrub[a]	Average height of the shrub in a 100m radius to nest tree (m)
	%_tree[a]	Percentage of tree coverage in a 100m radius around nest tree (%)
	%_shrub[a]	Percentage of shrub coverage in a 100m radius around nest tree (%)
	%_scree-rock[a]	Percentage of scree or rock outcrop coverage in a 100m radius around nest tree (%)
	%_Qsuber[a]	Coverage of cork oak *Quercus suber* in tree covered surfaces in a 100m radius around the nest tree (%)
	%_Qrot[a]	Coverage of holm oak *Quercus rotundifolia* in tree covered surfaces in a 100m radius around the nest tree (%)
	%_othersp[a]	Coverage of other tree species in tree covered surfaces in a 100m radius around the nest tree (%)
Human disturbance	*Long_tracks*[a]	Length of not paved tracks in a 500m radius around the nest tree (m)
	D_road[a]	Distance from the nest tree to the nearest paved road (m)
	D_const[a]	Distance from the nest tree to the nearest human building (m)
	D_track[a]	Distance from the nest tree to the nearest unpaved track (m)

by the residual degrees of freedom (Crawley 2007). No model showed dispersion parameters greater than 1.5, so that we did not have to compensate for overdispersion (Crawley 2007). Model selection was done using Akaike's Information Criteria (AIC), duly corrected for small sample size, as well as Akaike's weights (wj, for each model j) as an index of the strength of evidence of each model (Burnham & Anderson 2002). All analyses were conducted with the software R.2.12.0 (R Development Core Team 2008).

RESULTS

The most parsimonious model describing probability of breeding success included the effect of nest and tree characteristics, together with variables describing vegetation around each nest (Table 2). From this model, we found that breeding success increased with height of the nest-tree (see coefficients and standard errors in logarithmic scale in Table 3), the abundance of trees higher than 4 m around the nest-tree, the height of the shrub and a greater coverage of shrub but a lesser coverage of trees within 100 m around the nest (Fig. 1).

DISCUSSION

Our results suggest how variables related to the solidity of the nest structure, to the height of the nest-tree, to the length of the diameter of the nest and to the vegetation at landscape scale may influence the breeding success of the Cinereous Vulture. Basically, an adequate support for the nest is a precondition for successful incubation and chick-rearing (Margalida & Bertran 2000). For this reason, breeding vultures constantly furnish the nest with additional material to ensure it is always in a good state of repair. Taller nesting trees facilitate the tasks involved in successful nesting: they make it easier for birds to access the nest (Donázar et al. 2002), increase the possibility of detecting predators or other sources of disturbance (Margalida et al. 2011) and can support the weight of large nests (Fargallo et al. 1998). At the vegetation level, the determinant variables in breeding success could be related to 1) accessibility: dense forests with high shrub hamper access by pedestrian, potential predators or other elements liable to cause disturbance (Aubad et al. 2010), and 2) a positive selection of certain plant communities, in this case, cork-oak forests or prickly juniper (authors unpubl. data).

The results of the present study differ from those reported by previous studies that have evaluated factors determining reproductive success of the Cinereous Vulture in other Spanish colonies (Donázar et al. 2002, Morán-López et al. 2006b). First of all, the present work has been achieved for one breeding season, so conclusions might take into account that accuracy of the results are less biased with long-term data series (Brotons et al. 2007). In terms of the variables at the landscape scale, in all previous studies greater breeding success was found to occur in areas at higher relative altitude, on steeper, more rugged slopes, and on slopes not facing north (Donázar et al. 2002, Morán-López et al. 2006b). Another important issue is the effect of human disturbance on breeding success (Margalida et al. 2011). In colonies studied by Donázar et al. (2002), less human presence had a positive effect on breeding success. This factor is generally important in nesting habitat selection in the Cinereous Vulture (Moreno-Opo et al. 2012). Moreover, previous

Table 2. Models assessing the effect of tree, nest, vegetation, geomorphologic characteristics, and human-related disturbance on Cinereous Vulture breeding success; n — number of variables, AIC_c — Akaike's Information Criterion corrected for small sample size, w_i: Akaike weight of each model. The most parsimonious model is in italics.

Model	Deviance	n	AIC_c	ΔAIC_c	w_i	% explained deviance
1. *Tree characteristics + Nest characteristics + Vegetation*	*114.73*	*12*	*100.57*	*0.00*	*0.87*	*24.84*
2. Tree characteristics + Nest characteristics + Vegetation + Geomorphologic + Human disturbance	113.60	20	104.44	3.87	0.13	32.29
3. Vegetation	118.66	8	114.00	13.43	0.00	9.59
4. Tree characteristics + Nest characteristics	114.73	4	115.73	15.15	0.00	4.98
5. Geomorphologic	111.54	4	121.45	20.88	0.00	1.39
6. Human disturbance	118.66	4	122.24	21.67	0.00	0.67

Table 3. Coefficients of the variables included in the most parsimonious model explaining the breeding success of the Cinereous Vulture in logarithmic scale. The estimate value of the variable and its relationship (+/-) on breeding success, and the standard error, are shown.

Variable	Estimate	Standard Error
Intercept	-6.28	2.39
Sp_tree (holm oak)	1.42	0.85
Sp_tree (prickly juniper)	2.27	1.51
H_tree	0.43	0.15
Nest_cons (bad)	-2.43	1.51
Nest_cons (good)	1.18	1.44
D_nest	0.13	0.52
Rad25_tree	0.11	0.05
H_shrub	0.73	0.41
%_tree	-0.06	0.02
%_shrub	0.04	0.01
%_Qsuber	0.01	0.01
%_othersp	0.02	0.01

studies on the Cinereous Vulture breeding success considered other types of variables, such as climatic ones, obtaining that higher temperatures, less rain during the time chicks are in the nest and more rain in the preceding winter favour breeding success (Morán-López et al. 2006b).

One important variable determining the breeding success of Cinereous Vultures not taken into account in the present and other studies is the individual quality of the breeding birds (Sanz-Aguilar et al. 2008). There is a correlation between the physical characteristics of the individual (i.e. age, experience, etc.) and the quality of the breeding site (Velando & Freire 2001). Additionally, the quality of the breeding site may also be related to the birds' preferences or to the direct effects of environmental characteristics on the breeding success (Lascroel et al. 2009). The consideration of these factors in the study might have increased the accuracy and repre-sentativeness of the results, but a priori assessment of the breeding quality of birds was not feasible.

Different non-controlled variables could also contribute to the breeding success in this species, which may influence the results, as the values of explained variance or deviance would seem to suggest for the studied colonies in Donázar et al. (2002) (0.02, 0.03), Morán-López et al. (2006b) (0.15, 0.59, 0.63) and the present study (0.24). The non-controlled variables could be a product of physiological, health or genetic aspects of the birds themselves (Ricklefs & Wikelski 2002, Hogstad 2005), or mortality factors that affect certain individuals according their age class or sex (Hernández & Margalida 2008).

Implications for the conservation of endangered forest species

Firstly, mature, well-developed forests harbouring tall trees must be conserved. Such forest are the source areas and guarantee sufficient numbers

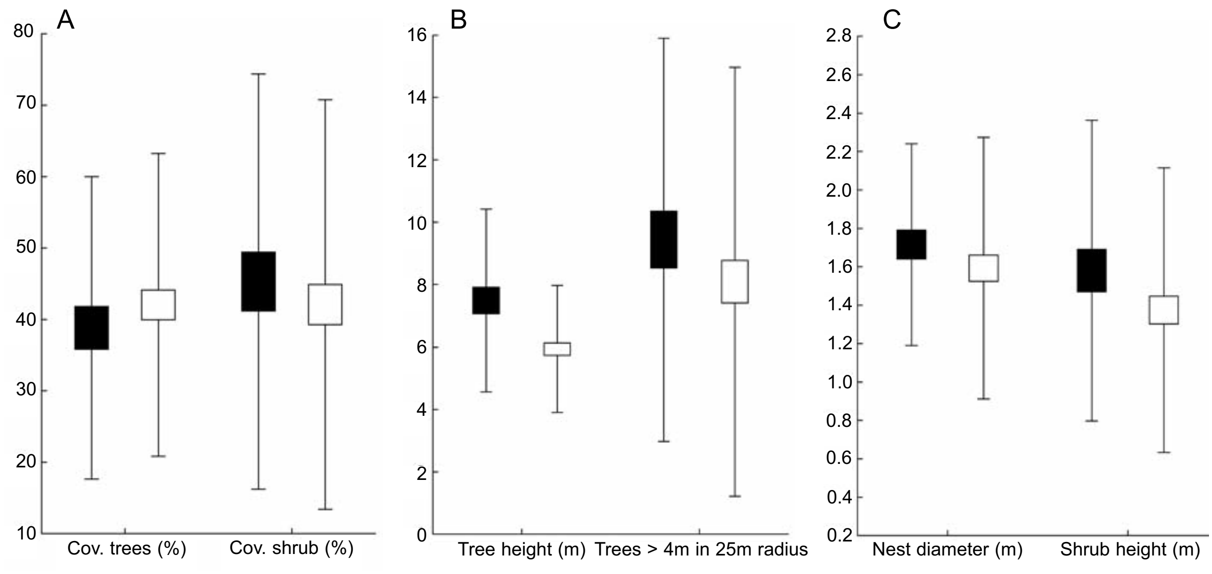

Fig. 1. Mean values ± 95% confidence interval of the variables included in the most parsimonious model (model 1 in Table 2) in relation to the breeding success (successful breeding: black columns; unsuccessful breeding: white columns). A — Percentage of coverage of trees and shrub around a radius of 100 m around the nest, B — Tree height (in m) and number of trees taller than 4 m height within a radius of 25 m around the nest, C — Nest diameter and shrub height (in m).

of offspring to increase the relative abundance of the species (Lindenmayer et al. 2000) and to mitigate the effects of non-natural mortality (Hernández & Margalida 2008). Secondly, areas of mature forest in wild landscapes with steep slopes are the most critical breeding areas for large forest raptors such as the Cinereous Vulture. Finally, due to the negative influence of human presence and activity (Donázar et al. 2002, Martínez-Abraín et al. 2010) it is essential to establish buffer areas to avoid disturbance by forestry management (Arroyo & Razin 2006, González et al. 2006) and/or reach collaboration agreements with local agents (Margalida et al. 2011).

Nevertheless, these recommendations should not avoid the aspects that most affect the conservation of a long-lived raptor species: 1) the need to guarantee a high survival rate of adult birds (Oro et al. 2008, Ortega et al. 2009), and 2) the maintenance of a minimum surface area of habitat in good conservation status in which birds can carry out their breeding, feeding and fulfil other requirements (Harris et al. 2005).

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STRESZCZENIE

[Czynniki wpływające na sukces lęgowy sępa kasztanowatego]

U ptaków żywotność populacji jest determinowana m.in przez sukces lęgowy, dlatego określenie czynników, które mogą mieć na niego wpływ jest ważne z punktu widzenia ochrony zagrożonych gatunków.

W pracy określano związek pomiędzy sukcesem lęgowym sępa kasztanowatego i 20 czynnikami, które przyporządkowano do jednej z pięciu kategorii: charakterystyki gniazda, charakterystyki drzewa, na którym umiejscowione było gniazdo, charakterystyki roślinności w najbliższym otoczeniu gniazda, czynników krajobrazowych i czynników związanych z antropopresją (Tab. 1). Badania prowadzono w liczącej 104 pary kolonii zlokalizowanej w centralnej Hiszpanii.

Stwierdzono, że na sukces lęgowy największy wpływ mają czynniki związane z charakterystyką gniazda, charakterystyką drzewa, na którym umiejscowione jest gniazdo oraz charakterystyką roślinności w najbliższym otoczeniu gniazda (Tab. 2). Szansa wyprowadzenia młodych w badanej kolonii wzrastała wraz ze zwiększeniem średnicy platformy gniazdowej, wzrostem wysokości drzewa, na którym umiejscowione było gniazdo, wzrostem liczby drzew wyższych niż 4 m w promieniu 25 m od gniazda, wzrostem wysokości krzewów, wyższym pokryciem terenu przez krzewy i niższym przez drzewa w promieniu 100 m od gniazda (Tab. 3, Fig. 1).

Autorzy wskazują, że w celu zwiększenia liczebności sępa kasztanowatego należy chronić dojrzałe lasy z wysokimi drzewami porastające strome zbocza. Powinny one być oddzielone strefą buforową od terenów poddanych gospodarce leśnej.