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Habitat use and population density of the houbara bustard *Chlamydotis undulata* in Fuerteventura (Canary Islands)

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Abstract

The houbara bustard in the Canary Islands is included into the category 'Endangered' on the Spanish Bird Red List according to suspected declines in bird numbers, the loss of previously occupied areas and the suggested endemicity of the taxon. This paper deals with the population size and the distribution pattern of the houbara bustard in Fuerteventura (the largest island occupied by the species in the Canary archipelago, 1730 km^2) and analyses its habitat use according to topography, soil, vegetation and human impact variables. We employ distance sampling on 1471 (early spring) and 602 (summer) 500-m transects and measure habitat characteristics within the transects to estimate local densities and population sizes and to test whether the features of the used habitats (as measured in transects where the species was recorded) differed from those available (measured in the whole sample). Topographic and anthropic features are the main determinants of the habitat use of the species, while other descriptors related to vegetation structure and substrate characteristics play a minor role in its habitat preferences. The slope of the terrain is the most important habitat feature constraining the occurrence of the houbara bustard. The proximity of urban areas, the density of paved roads and rural tracks and the extension of agricultural fields also adversely influence its distribution pattern in Fuerteventura. These habitat patterns does not change between summer and early spring considering the whole population of the species (i.e. without considering sexual or age-related differences). Population size is estimated at 177 birds for the whole Fuerteventura island during the breeding season (90% confidence interval: 108–258 birds). Only five areas comprising 247 km^2 include 80.8% of the total population in this island, although four of them are not included into the regional network of protected natural sites.

Key words: arid environments, Canary Islands, habitat selection, Houbara Bustard, human disturbances, population density

Résumé

L'outarde houbara des îles Canaries est inscrite dans la catégorie «en danger» de la Liste rouge des oiseaux espagnols en raison du déclin suspecté du nombre d'oiseaux, de la perte d'aires jadis occupées et de l'endémisme probable de ce taxon. Cet article traite de la taille de la population et du schéma de distribution de l'outarde houbara sur Fuerteventura (la plus grande des îles occupées par l'espèce dans l'archipel des Canaries, 1730 km^2) et analyse l'utilisation de l'habitat selon les variables de topographie, de sol, de végétation et d'impact humain. Nous employons l'échantillonnage à distance sur 1471 transects de 500 m (au début du printemps) et sur 600 transects (en été) et nous mesurons les caractéristiques de l'habitat dans les transects pour estimer la densité et la taille des populations locales et pour tester si les particularités de l'habitat fréquenté (telles qu'elles sont mesurées dans les transects où l'espèce a été rapportée) diffèrent de celles qui sont disponibles (mesurées pour l'ensemble de l'échantillon). Les caractéristiques topographiques et anthropiques sont les principaux déterminants de l'utilisation de l'habitat par cette espèce, et certains autres descripteurs liés à la structure de la végétation et aux caractéristiques

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du substrat jouent un rôle mineur dans les préférences en matière d'habitat. La pente de terrain est la caractéristique de l'habitat la plus importante dans la limitation de la présence de l'outarde houbara. La proximité de zones urbaines, la densité de routes pavées et de sentiers ruraux et l'extension des terres agricoles influencent aussi négativement son schéma de distribution sur Fuerteventura. Ce schéma de l'habitat ne change pas entre l'été et le début du printemps si l'on considère l'ensemble de la population de l'espèce (c.-à-d. si l'on ne tient pas compte des différences liées au sexe ou à l'âge). La population est estimée à 177 oiseaux pour toute l'île de Fuerteventura pendant la saison de reproduction (intervalle de confiance à 90% : 108–258 oiseaux). À elles seules, cinq zones totalisant 247 km^2 abritent 80,8% de la population totale de l'île, bien que quatre d'entre elles ne soient pas incluses dans le réseau régional de sites naturels protégés.

Introduction

The management and conservation of animal species requires knowledge on habitat use and preferences, distribution patterns and population size (Johnson, 1980; Cody, 1985). This issue is highly relevant for the conservation of endangered species in populated or managed areas, where such knowledge is frequently used as a tool to forecast the potential effects of land-use changes or new developments, to design mitigation measures and to eventually revert the decline of the species (Caughley & Gunn, 1996; Norris, 2004).

The population of houbara bustard of the Canary Islands (*Chlamydotis undulata fuertaventurae* [Rothschild & Hartert, 1894], present in Fuerteventura, Lanzarote, and the small islet of La Graciosa) is the only one inhabiting insular environments throughout its geographical range, from north-eastern Africa to Central Asia (Urban, Fry & Keith, 1986; Del Hoyo, Elliot & Sargatal, 1996). The houbara bustard has been catalogued as 'Near Threatened' worldwide until 2004, when its threat status was upgraded to 'Vulnerable' (IUCN, 2004), because of an alarming estimate of decline of 35% over three generations. Most of the available data on population declines belong to the Asian populations (*Chlamydotis* [*undulata*] *macqueenii*; Tourenq *et al.*, 2005; Combreau, Launay & Lawrence, 2005), although the range and population trends of the two African subspecies (*Chlamydotis* [*undulata*] *undulata* for the mainland and *C. u. fuertaventurae* for the Canary Islands) probably also underwent a decreasing trend and a reduction in the distribution area during the twentieth century (Goriup, 1997).

The last Spanish Bird 'Red List' (Madroño, González & Atienza, 2005) qualified the Houbara Bustard population of the Canary Archipelago into the category 'Endangered' according to suspected declines in bird numbers, the loss of previously occupied areas and the endemicity of the taxon (Pitra *et al.*, 2002; Idaghdour *et al.*, 2004; *C. u. undulata* and *C. u. fuertaventurae* diverged just recently 20,000–25,000 years ago). However, this evaluation of the threat status is supported only on conjectures because there is a lack of quantitative studies on habitat preferences and recent population sizes within the Canary Islands (but see: Collar & Goriup, 1984; Martín *et al.*, 1996, 1997; Medina, 1999; Carrascal *et al.*, 2006), which precludes firm assessments of population trends. This is particularly true for Fuerteventura, where traditional agriculture and grazing have given way to more intensive agricultural exploitation and an increasing urban and infrastructure development, which conflicts with nature conservation (Gangoso *et al.*, 2006). In this island, there is an urgent need of a more accurate ecological knowledge of the species and a detailed estimate of population size and distribution to evaluate its actual threat status, the magnitude of the Fuerteventura population within the Canary archipelago and to assess the potential impacts of new developments.

This paper tries to quantify regional variation in local densities of the houbara bustard in Fuerteventura (the largest island occupied by the species in the Canary archipelago, 1730 km^2) to estimate the current population size in the island and to describe the species' habitat use according to topography, soil, vegetation and human impact variables.

Materials and methods

Study area

Fuerteventura (N28°27′, W14°00′; 1730 km^2) is the easternmost main island of the Canary archipelago, lying only 100 km far from the North-African coast. The island has a smooth relief (maximum altitude of 812 m) in accordance with its ancient geological history and subsequent erosion (20–22 million years). The combined effects of direct Saharan influence on climate and a flat to gently undulating topography result in a predominance of scarcely vegetated arid steppe-like landscapes, which have been extensively grazed and cultivated. The impoverished native plant communities mostly consist of a few species of xerophytic shrubs (*Launaea arborescens* Murb., *Lycium intricatum* Boiss., *Salsola vermiculata* L, *Suaeda* spp. and *Euphorbia* spp.), therophytic forbs and annual grass species (Rodríguez, García & Reyes, 2000; Santos, 2000). However, the degree of development of vegetated patches is relatively diverse because of local conditions such as humidity, slope of terrain, grazing by the goat and human uses. With regard to soil lithology and compactness, the island also comprises a broad range of conditions, from stony lava fields to loose sand dunes. Although the cities are widely spread throughout the island, they are particularly dense and large near the sea shore as a result of tourist activities.

Bird and habitat data

Bird surveys were carried out in 2005 and 2006, during the first fortnight of March, by five and three equally experimented observers respectively. The survey method was the line transect, frequently used in extensive assessments of abundance, general distribution patterns and habitat preferences of birds (Bibby *et al.*, 2000), because (i) it offers an optimal trade-off between field effort and census area covered and (ii) it allows an easy calculation of detectability estimates thus increasing the reliability of population densities. A total number of 1471 line transects of 0.5 km (measured by means of portable GPSs) were made focused on the main steppe-like and desert areas, although other habitats (e.g. traditional cultivations, hilly slopes) were also considered, increasing the environmental variability surveyed for the species (Fig. 1). Transects were 500 m in length so as to compromise to obtain a large number of sampling units covering a significant area in relatively homogeneous habitats. Transects are not considered a cost-effective survey method in larger continental areas (see Noir, Barbraud & Judas, 2004; Le Cuziat *et al.*, 2005a and references therein), but they suit our study area because most of the Fuerteventura island is open to public access, not many places are reachable by car and [2] relatively easy to walk.

The transects were carried out on windless and rainless days, walking cross-country or by little used dirt tracks at a low speed (1–3 km h^{-1} approximately), during the 4 h [3] after dawn and the 2.5 h before dusk. For each detected houbara, the perpendicular distance to the observer's trajectory was estimated (a few overflying birds sighted were disregarded). Training with a laser range-finder (Leica Rangemaster LRF 900) helped to reduce inter-observer variability in the distance estimates. Only birds observed at least 250 m from the transect were considered in the [4] following analyses.

Sampling effort varied among different geographical–environmental strata according to their extent and because we visited them until we felt confident a reliable [5] estimate of density could be obtained. The sampling locations and the approximate number of transects to gather on them were roughly determined in proportion to the surface in the islands of each type of main landscape. Apart from the mere availability of a safe place to park the car, the starting point of each sampling line was randomly determined. Next, the observers walked through the target area trying: (i) to perform 0.5-km transects as homogeneous as possible considering habitat structure and topographic characteristics and (ii) to attain an extensive cover of the sampling location. The transect lines were not biased by an *a priori* potential of the habitat to have houbaras, because the field work was not exclusively focused in sampling this species and because most locations were so intensively sampled that there is little room for any geographical bias (Fig. 1).

We also repeated 602 transects in the first fortnight of August 2006 (same observers as in spring 2006) to analyse seasonal changes in average habitat preferences of the whole population in Fuerteventura (i.e. breeding versus summer season). These transects were selected to attain a high variability of habitat types censused and a large sample size in each geographical stratum (see below).

Twelve habitat variables were used to characterize the 0.5-km transects. Eight variables were measured during field transects by means of the averages of three visual estimations (at 125, 250 and 375 m within the line transect) on 25-m radius circular plots: coverages of (i) grass, (ii) annual forbs, and (iii) shrubs (in percentages); (iv) mean height of the shrub layer (in cm); (v) rocky cover (in percentage); (vi) soil typology (according to the following ordinal multinomial classes: 0 – lava fields, 1 – stone/gravel soils, 2 – compact soils, 3 – sandy soils and 4 – loose sand dunes); (vii) altitude above sea level (measured with GPS receptors); and (viii) the amount of any agricultural land-use (estimated in 125-m width bands on each side of the transect and expressed in percentage). Afterwards, four more variables were measured on the most recent national topographic 1 : 25,000 maps

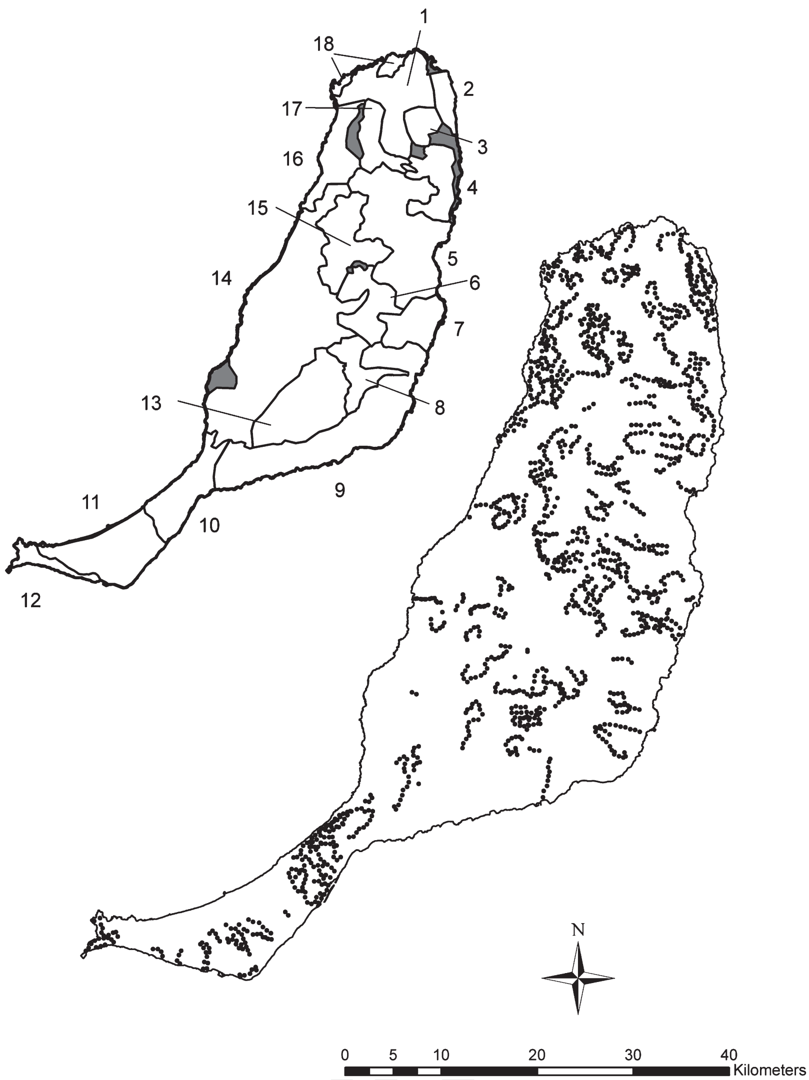

Fig 1 Left: location of the sampling strata (clockwise): 1 Malpaíses North, 2 Corralejo, 3 Montaña Lengua, 4 Fimapaire-Finimoy, 5 Tetir-Puerto del Rosario, 6 Triquivijate, 7 Castillo, 8 Malpaíses South, 9 Vigán-Giniginamar, 10 Jandía (sandy soils and dune area), 11 Jandía mountains, 12 Morro Jable, 13 Tuineje, 14 Betancuria, 15 Tefía-Ampuyenta, 16 Tindaya, 17 Lajares-Oliva, 18 Cotillo-Majanicho. Right: each dot locates the centre of the 0.5-km transects (n = 1471). Grey colour shows unsurveyed areas having distinct habitats from the surroundings

(Instituto Geográfico Nacional, years 2000–2005) within circles of radius 250 m from the centre of each transect: (ix) the distance to the nearest city (in m); (x) the average slope of the terrain (in percentage); and the length of (xi) dirt tracks (in m) and of (xii) paved roads. Table 1 summarizes the mean values, standard deviations and ranges of variation of these twelve variables in the 1471 transects sampled.

Abundance estimates

The abundance of the species was estimated with distance sampling methods (Thomas *et al.*, 2002). For modelling the detectability, the sightings from Fuerteventura and the neighbouring islands of Lanzarote and La Graciosa (very similar regarding the vegetation and landscape features that affect bird detectability; obtained from Carrascal *et al.*, 2006) were pooled. The detection distances were right-truncated excluding outliers as recommended by Buckland *et al.* (2001; i.e. disregarding the 5% of the longest perpendicular distances from the transect line, which were those longer than 250 m). We fitted three models (half-normal, negative exponential and hazard-rate, trying in each one to include a suitable series expansion) that are commonly used to explain the loss of detectability as a function of the distance from the transect line (the further the distance the lower the probability of detecting an individual). These models were used to estimate the prob-

Table 1 Environmental characteristics (mean ± standard deviation) of the 0.5-km transects occupied by the houbara bustard in the breeding season (n = 22) and summer (n = 14) and the whole sample of transects (n = 1471) in Fuerteventura (Canary Islands; mean, range)

	Availability Fuerteventura			Habitat use				Habitat selection	
				Spring		Summer			
	Mean	SD	Max.	Mean	SD	Mean	SD	*t*	*P*-value
DMIN-URB	2.8	1.9	14.8	2.7	1.5	3.2	1.7	1.91	0.065
L-TRACKS	204.5	294.7	1850.0	182.0	228.7	181.4	239.5	2.17	0.037
L-ROADS	46.2	145.3	1100.0	18.2	85.3	0.0	0.0	3.41	0.002
C-AGRIC	1.0	13.8	90.0	0.1	0.6	0.0	0.0	45.54	0.000
ALTITUDE	158.6	104.2	617.0	131.2	80.0	125.4	81.2	0.12	0.901
SLOPE	11.2	10.5	116.0	4.8	3.6	4.7	2.8	3.15	0.003
SOIL INDEX	2.1	1.2	4.0	2.3	0.8	2.9	0.9	3.94	0.000
C-ROCK	32.5	27.7	100.0	27.6	19.7	21.6	26.4	0.54	0.595
C-FORBS	11.1	12.3	78.0	13.3	16.1	11.3	11.7	0.54	0.595
C-GRASS	4.1	9.2	76.3	3.3	8.1	3.1	7.2	0.01	0.990
C-SHRUB	9.3	7.6	57.3	9.7	6.3	8.2	7.9	0.88	0.387
H-SHRUB	24.7	24.1	210.0	26.2	12.2	25.9	10.3	0.76	0.454

DMIN-URB: minimum distance to the nearest city (in km); L-TRACKS: length of unpaved tracks (in m) per 20 ha; L-ROADS: length of paved roads (in m) per 20 ha; C-AGRIC: cover with agricultural uses (in %); ALTITUDE: mean altitude above sea level (in m); SLOPE: average slope of the terrain (in %); SOIL INDEX: index size of soil grain (0: volcanic soils; 1: stony soils; 2: compact sandy soils; 3: sandy soils; 4: loose dunes); C-ROCK: cover of rocks and stones (in %); C-FORBS: cover of forbs (in %); C-GRASS: cover of grass (in %); C-SHRUB: cover of shrubs (in %; mostly chamaephytes and small phanerophytes of genus *Suaeda*, *Salsola*, *Launaea*, *Lycium* and *Euphorbia*); H-SHRUB: mean height of the shrubs (in cm). Results of *t*-tests comparing the observed means (the combined sample of transects where the species was present both in spring and summer) with the average of the island (null hypothesis of average habitat availability) are also shown.

ability of detection and the effective census strip width (ESW = the truncation distance of 250 m multiplied by the probability of detection) within the truncated distance (see above). Models were evaluated according to AICc. We calculated a weighted average of the detection probabilities derived from the three *i* canonical models according to weights (W) obtained from AICc values, where $Wi = \exp[-0.5\ \Delta\text{AICc}]/\Sigma\exp[-0.5\ \Delta\text{AICc}]$ (Burnham & Anderson, 2002). A global detection function was calculated and used to calculate the density of the species in the whole Fuerteventura (expressed in birds per km^2) assuming that the detectability of the individuals did not differ among the studied geographical areas within the island. Detectability models were built with DISTANCE 5.0 software (Thomas *et al.*, 2004).

The 1471 transects sampled in the first fortnight of March were grouped in eighteen strata according to their habitat characteristics and geographical proximity (Fig. 1). The environmental characteristics of these strata are shown in the Appendix. The population size of the houbara bustard per stratum was estimated following a randomi-

Table 2 Models fitted to the detection distances truncated at 250 m (n = 63 contacts with 82 individuals), ordered increasingly according to their AICc values (i.e. from larger to smaller reliability)

	ΔAICc	AICc	*W*	*P* (95% CI)
[17] Negative exponential	0.00	657.20	0.64	0.31 (0.23–0.41)
Half-normal (cosine adjustments)	2.79	660.00	0.16	0.37 (0.29–0.37)
Hazard-rate	3.02	660.23	0.14	0.35 (0.24–0.53)
Half-normal (polynomial adjustments)	5.07	662.27	0.05	0.47 (0.40–0.56)
Weighted average				0.33 (0.25–0.45)

W is the weight given to each model according to the formula $W_i = \exp(-0.5\ \Delta\text{AICc})/\Sigma\exp(-0.5\ \Delta\text{AICc})$ (Burnham & Anderson, [18] 2002). It is also given the detection probability within 250 m and its 95% confidence interval (*P*). Two series expansion (simple polynomials and cosine adjustments) were tried for each main family model but only the half-normal function needed them to provide a better fit.

zation-resampling procedure. First, we generated 2000 possible values of the ESW from its log-normal distribution obtained in the previous analysis of detectability (Table 2). Second, we generated 2000 random subsets of 2/3 of transects within each stratum (as if each of our sampling units was a random sample of 2/3 of the original 0.5-km transects). Then, the density of houbaras was calculated considering the number of individual birds recorded, the length of the transects made and the ESW randomly assigned. The total number of individuals per stratum was calculated multiplying the estimated density (in birds per km^2) by the area of each stratum. Finally, we took the 5% and 95% percentiles of the 2000 estimations to give the 90% confidence interval of the abundance within each stratum. When the lower end of the confidence interval for a particular stratum was zero but we did actually observed houbaras and used the number of individuals detected as the lower end of the confidence interval. To obtain the abundance estimate of the species for the whole island, we repeated the same procedure but using a number of transects per stratum proportional to its surface within the island (that is, if a particular stratum covered 10% of Fuerteventura, then 10% of each random subset of transects were obtained for that stratum).

Habitat use

We used the average environmental values of the transects where the species was observed to assess the general habitat use of the houbara bustard and the seasonal changes in habitat characteristics (n = 36; 22 in the breeding season and 14 in summer; Table 1). To assess whether the species used the same habitats in the breeding season and summer time, a preliminary MANOVA test was carried out with the environmental variables. The MANOVA was not significant (Wilks' lambda = 0.68, $F_{12,23} = 0.89$, $P = 0.573$) showing a similar pattern of habitat characteristics of the species in both seasons. Therefore, the following analyses were carried out with the whole sample of transects where the species was found.

To analyse the global pattern of habitat use and preferences of the houbara in the island, we tested whether the average of variables measured in the line transects, where the species was observed in both seasons (i.e. representing the average used habitat), differed from the mean of the whole sample of 1471 transects (representing the mean habitat features in the transects sampled). The differences between the set of observed mean figures (habitat use) and the set of expected values (availability) were tested with a multivariate Hotelling's *T*-test, and with *a posteriori t*-tests separately for each variable. The Hotelling's *T*-test (and the *a posteriori t*-tests with original variables) deals with a habitat selection approach within environmental gradients by comparing between the locations used in the study region (only the patches with bird detections) with those available (all of the patches sampled). This approach is a more stringent analysis on habitat use of the houbara bustard, not assuming that the 'absence' of the species in the transects sampled necessarily entails unsuitable habitat (i.e. the 'absences' of the species may be merely because of chance, considering both the scarcity of the houbara and its detection probability). This test may not seem adequate for soil index but indeed it is because the index is an ordered multinomial variable resulting from average of three measures, which in practice means that we are not longer dealing with an integer variable, but rather with a real (continuous) number; moreover, the residuals of this variable did not significantly deviate from normality. All statistical analyses were carried out using STATISTICA 6.0 (Statsoft, 2001).

Results

Bird densities and population size

The best model among the three fitted to the detection distances was the negative exponential key function with no term for series expansion, while the others were weaker alternatives (ΔAICc ranging from 2.79 to 5.07; Table 2). The estimated average probability of detection was 0.33 (95% confidence interval: 0.25–0.45). Accordingly, the average ESW was 82.5 m (95% confidence interval: 62.5–112.5 m).

The species was recorded in eight out of eighteen strata in early spring (Table 3). Average density of the houbara bustard for the whole island was 0.11 birds per km^2. The maximum densities were recorded in Tindaya and Triquivijate with 0.78 and 0.72 houbaras per km^2 respectively. Population size is estimated at 177 birds for the whole Fuerteventura island during the breeding season (90% confidence interval: 108–258 birds, Table 3). The most important areas where the species are located include Tindaya, Triquivijate, Tefía-Ampuyenta and Fimapaire-Finimoy (Fig. 1). These sectors cover 247 km^2 (or 16%) of Fuerteventura and include 80.8% of the total population in this island.

Table 3 Population density (birds per km^2) and population size estimates (number of birds with the 90% confidence interval) for the houbara bustard in each geographical area of Fuerteventura (the numbers in brackets refer to areas in Fig. 1)

	Birds per 10 km	Breeding density and population size			
	spr, sum	km^2	Birds per km^2	Mean	(90% CI)
ISLAND		1584	0.11	177	108–258
Tindaya (16)	1.3, 0.3	54	0.78	42	24–61
Triquivijate (6)	1.2, 0.8	61	0.72	44	26–63
Fimapaire-Finimoy (4)	0.9, 1.6	53	0.54	29	15–43
Cotillo-Majanicho (18)	0.8, 0.0	13	0.46	6	1–9
Tefia-Ampuyenta (15)	0.6, 0.0	79	0.35	28	9–43
Castillo (7)	0.3, 0.0	51	0.17	9	1–13
Malpaíses North (1)	0.2, 0.0	102	0.13	14	1–21
Jandia (10)	0.2, 0.9	71	0.09	7	1–10
Betancuria (14)	0.0, 0.0	343	0.00	0	0–0
Corralejo (2)	0.0, 2.4	22	0.00	0	0–0
Jandia mountains (11)	0.0, 0.0	104	0.00	0	0–0
Lajares-Oliva (17)	0.0, 0.7	38	0.00	0	0–0
Malpaises South (8)	0.0, 0.0	44	0.00	0	0–0
Montaña Lengua (3)	0.0, 0.0	24	0.00	0	0–0
Morro Jable (12)	0.0, 0.0	20	0.00	0	0–0
Tetir-Rosario (5)	0.0, 0.0	178	0.00	0	0–0
Tuineje (13)	0.0, 0.3	122	0.00	0	0–0
Vigan-Giniginamar (9)	0.0, 0.0	205	0.00	0	0–0

The surface of each sampling area is given in km^2. The geographical areas are ordered according to the population density. The relative abundance (birds per 10 km) of houbaras in spring and summer (spr, sum) in each geographical area is also presented.

Habitat use

The average figures of the houbara bustard in the twelve environmental variables significantly differed from the averages of all transects in the whole island (Table 1; Wilks' lambda = 0.01; $F_{12,24} = 142.04$, $P < 0.0001$). That is to say, the species showed an intense habitat use pattern preferring positions on the environmental gradients that were apart from the average habitat characteristics of Fuerteventura.

The 36 transects where the species was detected had environmental averages significantly higher than the average figures measured in the whole island for the soil index (towards the sandy extreme) and lower for the slope of the terrain ($P = 0.003$), both the length of dirt tracks and paved roads ($P = 0.037$ and $P = 0.002$ respectively), and the cover of ground devoted to agriculture ($P < 0.001$). There is a marginally significant selection pattern ($P < 0.065$) for the longest distances to the nearest city, specially marked in summer time. Habitat structure variables potentially affecting the average habitat preferences of the species were far away from significance ($P > 0.33$ for two soil and four vegetation traits). To summarize, the houbara bustard occupied preferentially flat and isolated locations with a low rock cover and with a low impact of any human activity (agriculture, urban development, and network of rural tracks and paved roads), being fairly generalist according to other habitat structure characteristics.

In spite of the lack of habitat use differences between the breeding season and summer in the houbara population in Fuerteventura ($P = 0.573$; see Materials and methods), the distribution of relative abundances within the island was not significantly correlated in both seasons ($r = 0.162$, n = 18 strata, $P = 0.522$; see Table 3 for relative abundances measured in birds per 10 km of transects). This result shows a seasonal change in the distribution pattern of the species within the island, with large summer increases in the sandy areas of Jandia jable, Corralejo and Lajares-Oliva, and important decreases in Cotillo-Majanicho, Tindaya and Tefia-Ampuyenta.

Discussion

Main patterns of habitat use

This study shows that both topographic and anthropic features determine the habitat use of the houbara bustard, while other descriptors related to vegetation structure and substrate characteristics play a minor role in its distribution over Fuerteventura. In this island, the houbara behaves as a habitat generalist according to habitat structure features, which is in agreement with the niche expansion hypothesis in island environments (Blondel, 1979; Wiens, 1989). Overall, the houbara bustard in Fuerteventura occupies similar habitats to those preferred on continental Africa: arid flat or gently undulating terrain with little shrub cover (Le Cuziat *et al.*, 2005a,b; Hingrat *et al.*, 2007; see also Martín &

Lorenzo, 2001). This general habitat selection pattern does not change between summer and early spring. However, it should be noted that our aim was to make estimates for the whole population and thus we did not consider age or sex groups, whose habitat preferences may vary seasonally. Thus, the habitat use pattern of the species we describe in this study has to be considered as average for the whole houbara population in Fuerteventura. In the northern African population, it has been reported that habitat preferences of the females differed from those of the males and vary seasonally, because female breeding birds, during spring, select areas richer in preys (beetles) with higher vegetation (Hingrat *et al.*, 2007). Nevertheless, Hingrat *et al.* (2007) did not detect seasonal variation in male habitat use. Both habitat cues and the presence of conspecifics determine the settlement patterns of bustard species (Hingrat *et al.*, 2004; and see Lane, Alonso & Martin, 2001 for great bustard *Otis tarda*), so that the birds (particularly males) may show fidelity to sites somewhat regardless of the availability of suitable habitat elsewhere.

Notably, an excessive slope of the terrain and a rocky substrate were the only non-anthropic habitat features constraining the occurrence of the houbara bustard, whereas none of the four vegetation variables considered [7] was an important predictor of the species distribution. Recently, several papers on arid environments have shown that topographic abiotic features are the primary factors determining regional bird distribution patterns, both at the species (Knight & Beale, 2005; Seoane *et al.*, 2006; Palomino *et al.*, 2007) and the community levels (Kaboli, Guillaumet & Prodon, 2006). In the particular case of the houbara bustard, the positive selection of the flattest plains with a compact or sandy (but not rocky) substrate could be related to the high energy demands of upward walking for such a large cursorial bird (1.2 kg mean weight) with long tarsi (Lachica & Aguilera, 2000; Daley & Biewener, 2003; Gabaldón, Nelson & Roberts, 2004). Thus, the locomotion on steep slopes, or up and down over a rocky substrata with large stones or massive rocks (e.g. 'malpaíses') may pose clear limits to the habitat distribution of the houbara bustard in this mountainous volcanic island.

Disturbances from human origin are currently the primary environmental effects to modify and mitigate in endangered or vulnerable houbara populations (Lavee, 1985; Osborne, Launay & Gliddon, 1997; Le Cuziat *et al.*, 2005a,b). Fortunately, some anthropic risks have been almost eradicated for the houbara bustard in the Canary Islands (e.g. hunting, one of the most important menaces for the species in many places: Mian, 1986; Goriup, 1997; Combreau, Launay & Lawrence, 2001; Chammem *et al.*, 2003), or are receiving particular attention (casualties on power lines: Lorenzo, 1995; and see also http:// [8] www.seo.org/lifehubara/Ingles/AccionesProyecto7.htm). This work identifies the impact of a threatening factor to be urgently corrected such as the highly uncontrolled urban sprawl and the associate road network in the flattest, steppe-like habitats of the island. The negative effect of the proximity of urban areas and the density of paved roads on the occurrence of the houbara bustard will likely increase if the prevailing models of urbanization and tourism resort penetrate the interior flat steppe-like area. Thus, there is a conflict between the development of rural areas (for urbanization and agriculture) and the houbara in Fuerteventura, both of which favour flat and vegetated plains [9] (see also Osborne, Launay and Gliddon, 1997). Our results also show that the houbara bustard is sensitive to the extension of agricultural fields, which negatively affects its habitat use (Lavee, 1985; Goriup, 1997; Le Cuziat *et al.*, 2005a,b; Hingrat *et al.*, 2007; but see Medina, 1999 for partially positive influences of some agricultural practices in summer time). The density of rural tracks, regularly traversed either by tourist trekkers or sports motor-vehicles, also adversely influences the distribution pattern of the species in Fuerteventura. Uncontrolled traversing of wild and solitary areas during the breeding season (e.g. looking for mushrooms 'criadas' accompanied by dogs), and riding with quads and motorcycles at any time of the year, in those areas maintaining the large proportion of the Fuerteventura houbara population, should be limited and strictly regulated. This may be the reason for some of the seasonal changes observed in the geographical distribution of the species within the island, that is for example, a low relative abundance of houbaras in some places supporting large number of visitors in early spring (e.g. Jandía, Lajares-Oliva and Corralejo sandy areas; Table 3).

Population size and conservation status

Despite apparently having a large availability of potential habitat (as judged by the non-significant differences in many habitat structure variables), the mean densities and overall population of the species in Fuerteventura are low (0.11 birds per km^2 and 177 birds respectively), otherwise consistent with its large body size (Carrascal & Telleria, 1991). The probable population trend of the houbara bustard in Fuerteventura can be inferred considering the previously published information. The two most exhaustive censuses of the houbara population in Fuerteventura reported 241 birds in 1994 (Martín *et al.*, 1997) and 256 birds in 2000 (Anonymous, 2000). These estimations lay inside the 90% confidence interval, in 2005–2006 (108–258), measured in this paper. Therefore, the population size of the houbara bustard has remained stable or has probably shown a slight decrease during the last 6 years in Fuerteventura, which poses some conservation concerns according to its low population size (≤250 birds). This pattern contrasts with that observed in the nearby smaller island of Lanzarote (846 km^2), separated from Fuerteventura by a narrow stretch of 11 km: mean density of 1.63 birds per km^2 (the highest recorded in the whole geographic range of the species in northern Africa and central Asia), population size reaching 500 birds and average 40% increase in the last 6 years (Carrascal *et al.*, 2006).

These contrasting differences for two subpopulations within the Canary metapopulation lead to some important ecological and conservation consequences. First, the between-island differences in population density and size can be easily explained considering the annual productivity, vegetation development and local rainfall, which are higher in Lanzarote than in Fuerteventura (Morales & Pérez-González, 2000; compare also the forb and grass covers of Fuerteventura in Table 1 in this study – 11.1% and 4.1%– with 20.6% and 6.8%, respectively, measured 10 in Lanzarote according to Carrascal *et al.*, 2006). Second, the contrasting population status and trends would suggest very different conservation concerns leading to a favourable protection status in Lanzarote and to a worrying conservation status in Fuerteventura and would suggest making necessary and immediate assessment of 11 management priorities. The coexistence of disparate or antagonistic conservation status within the same Canary population weakens if the different subpopulations are viewed as several parts of the same Canary pool, and if possible inter-island movements influenced by between-years and between-areas differences in rainfall are taken into account. Indeed, it is known that the houbara bustard shows dispersive and migratory habits in other parts of its range (Cramp & Simmons, 1980; Johnsgard, 1991; Hingrat *et al.*, 2004; Le Cuziat *et al.*, 2005a), and that movements occur not only within but also among islands in the Eastern Canaries (Martín *et al.*, 1997).

Four geographical strata supporting 4/5 of the whole island population (Tindaya, Triquivijate, Tefía-Ampuyenta and Fimapaire-Finimoy), are not included into the regional network of protected natural sites (http://www.gobcan.es/cmayot/ espaciosnaturales/informacion/fuertev_todo. 12 html). On the contrary, some historical areas of the species located on protected areas maintain very low densities during the breeding season (sand dunes of Corralejo and Jandía), perhaps because of being increasingly visited by tourists during the breeding season of the houbara. Therefore, it is necessary to reconsider the current design of the natural reserves in the practical conservation of the houbara bustard in Fuerteventura. For future conservation planning, we recommend that representative subset of areas in Fuerteventura be censused repeatedly to detect population trends. This census program should be carried out by means of extensive line transects using detectability estimates to correct observed population densities. Censuses should be concentrated in the most important areas for the species that include 80% of the total population in this island and only cover 250 km^2 (Tindaya, Triquivijate, Tefía-Ampuyenta and Fimapaire-Finimoy; Fig. 1), thus minimizing the required number of qualified observers or economic resources available for censusing.

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Appendix

Environmental average characteristics of the eighteen strata studied in Fuerteventura (see Fig. 1 for their location within the island). The number of 0.5-km transects made in each stratum is shown in brackets. DMIN-URB: minimum distance to the nearest city (in km); L-TRACKS: length of unpaved tracks (in m) per 20 ha; L-ROADS: length of paved roads (in m) per 20 ha; C-AGRIC: cover with agricultural uses (in %); ALTITUDE: mean altitude above sea level (in m); SLOPE: average slope of the terrain (in %); SOIL INDEX: index size of soil grain (0: volcanic soils; 1: stony soils; 2: compact sandy soils; 3: sandy soils; 4: loose dunes); C-ROCK: cover of rocks and stones (in %); C-FORBS: cover of forbs (in %); C-GRASS: cover of grass (in %); C-SHRUB: cover of shrubs (in %; mostly chamaephytes and small phanerophytes of genus *Suaeda*, *Salsola*, *Launaea*, *Lycium* and *Euphorbia*); H-SHRUB: mean height of the shrubs (in cm).

	DMIN-URB	L-TRACKS	L-ROADS	C-AGRIC	ALTITUDE	SLOPE	SOIL INDEX	C-ROCK	C-FORBS	C-GRASS	C-SHRUB	H-SHRUB
Betancuria (140)	1.8	123.0	83.6	2.0	278.1	29.6	1.6	40.2	12.4	7.3	10.4	0.54
Castillo (73)	3.2	254.9	94.5	0.0	86.0	8.9	1.8	39.3	13.1	2.4	8.5	0.33
Corralejo (69)	3.7	63.0	27.5	0.0	29.7	3.4	3.9	5.7	4.8	0.0	9.0	0.25
Cotillo-Majanicho (26)	3.2	230.4	145.8	0.0	16.7	3.5	3.7	15.0	9.8	0.0	11.3	0.20
Fimapaire-Finimoy (90)	1.5	190.8	50.4	0.4	113.7	8.1	2.2	28.7	6.0	3.3	6.6	0.22
Jandia (130)	3.0	242.5	44.0	0.0	101.6	11.2	3.5	8.3	15.7	0.4	11.8	0.32
Jandia mountains (59)	1.9	165.9	54.9	0.0	216.4	31.3	0.8	39.1	19.6	2.3	14.0	0.56
Lajares-Oliva (81)	2.3	218.4	17.9	0.2	159.8	6.5	2.4	23.9	5.7	1.7	8.4	0.28
Malpaises North (91)	3.8	81.5	33.1	0.0	97.7	6.0	1.4	72.9	6.9	3.9	13.1	0.49
Malpaises South (14)	6.6	115.0	0.0	0.0	139.7	7.7	0.0	81.1	7.7	1.7	6.5	0.83
Montana Lengua (37)	3.4	352.4	19.5	0.0	130.9	5.5	2.1	32.6	12.6	0.5	6.8	0.16
Morro Jable (32)	10.9	322.9	205.9	0.0	24.9	5.9	2.0	36.3	5.5	0.1	7.1	0.27
Tefia-Ampuyenta (101)	1.7	252.3	20.4	3.3	200.9	6.1	1.9	29.2	13.0	4.2	9.0	0.28
Tetir-Rosario (104)	1.7	123.0	13.3	0.2	246.0	19.9	1.0	32.5	12.9	10.0	9.0	0.35
Tindaya (127)	3.2	255.3	15.7	0.5	66.3	4.6	2.3	28.1	4.2	1.0	6.0	0.21
Triquivijate (117)	2.3	229.1	26.2	0.3	222.5	5.4	2.2	27.2	17.3	11.7	10.9	0.32
Tuineje (108)	1.8	242.9	55.6	1.7	137.2	9.4	1.8	47.8	11.8	3.9	8.1	0.32
Vigan-Giniginamar (72)	5.4	294.0	55.6	5.8	132.3	21.4	1.5	32.3	14.3	5.6	8.4	0.47