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HUMAN ACITIVITIES AFFECT THE POTENTIAL DISTRIBUTION OF THE HOUBARA BUSTARD *CHLAMYDOTIS UNDULATA UNDULATA*

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SUMMARY.—*Human activities affect the potential distribution of the Houbara Bustard* Chlamydotis undulata undulata.

Aims: Human activities have been reported to impinge on the distribution of the endangered Houbara Bustard *Chlamydotis undulata undulata*. The present study intends to investigate spatial relationships between Bustard and pastoral distribution in order to identify avoidance patterns and potential exclusions of the species from still-suitable grounds.

Location: The study was conducted on a 600 km^2 area within the semi-arid steppe-lands of Eastern Morocco.

Methods: Spatial relationships between sheep flocks and Houbara flocks were explored and tested using the spatial point pattern analytical framework.

Results: Significant mutually-exclusive distribution patterns between sheep and goat flocks and bustards were detected throughout the whole year. Bustards' avoidance of sheep flocks appeared to be a spatially variant and temporally scaled process.

Conclusions: Exclusion patterns are identified and discussed. Subsequent conservation implications are briefly presented.

Key words: Maghreb, pastoralism impacts, seasonal variations, spatial patterns of occurrence, Ripley's K function.

RESUMEN.—*Las actividades humanas afectan a la distribución potencial de la Hubara* Chlamydotis undulata undulata.

Objetivos: Se ha argumentado que las actividades humanas afectan a la distribución de la amenazada Hubara *Chlamydotis undulata undulata*. En el estudio presente se pretende investigar las relaciones espaciales entre las Hubaras y la distribución de los pastores para identificar patrones de evitación y exclusiones potenciales de esta especie de lugares que podrían ser aún adecuados.

Localidad: El estudio se llevó acabo en un área de 600 km^2 en la estepa semi-árida del Este de Marruecos.

Métodos: Las relaciones espaciales entre los rebaños de ovejas y los bandos de las Hubaras se exploraron utilizando modelos estadísticos («spatial point pattern statistical framework»).

Resultados: Se encontró un modelo significativo de distribución mutuamente excluyente entre las ovejas y cabras y las Hubaras a lo largo de todo el año. La evitación por parte de las Hubaras de los rebaños domésticos parece ser un proceso espacialmente variable y poseer una escala temporal cambiante.

Conclusiones: Se han identificado y discutido los procesos de exclusión y además, se han brevemente expuesto las implicaciones futuras para la conservación de esta especie.

Palabras clave: Zagreb, impactos de rebaños, variación estacional, modelos espaciales de ocurrencia, función K de Ripley.

INTRODUCTION

The Houbara Bustard *Chlamydotis undulata undulata* is an endangered desert-bird species inhabiting semi-arid steppe-land areas in North-Africa (Collar, 1980; Goriup, 1997). A recent taxonomic revision has distinguished the Houbara Bustard per se from the Macqueen's Bustard *Chlamydotis macqueenii*, which is native to Middle-East and Asian countries (Gaucher *et al*., 1996; D'aloia, 2001; Broders *et al*., 2003). This revision means that its conservation status

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must be reconsidered, which in turn requires an improvement in ecological knowledge of the species. The North African Houbara Bustard is likely to represent no more than 10% (10.000 birds) of the entire world population of the former 'Houbara Bustard' group (Birdlife International, 2000).

The Houbara Bustard (*s.l.*) is classified as Vulnerable because it has undergone rapid population decline of an estimated 35% over three generations, due largely to unsustainable hunting levels (Birdlife International, 2004). The Houbara (*s.l.*) remains the favoured quarry of Arab falconers and is still hunted throughout its entire range (Combreau *et al*., 2001; Tourenq *et al*., 2004, 2005). The North African Houbara Bustard species, which seems to be mainly sedentary or erratic (Brosset, 1961; Etchécopar & Hue, 1964; Cramp & Simmons, 1980; Hingrat, 2005), is, furthermore, on the point of being greatly affected by habitat loss or degradation (Birdlife International, 2004), owing to recent changes in land use in sub-sahelian regions (notably the sedentarization of former nomadic populations), which has lead to switches in animal herding management practises and to local increases in pastoral loads (Dregne, 1986; Mainguet, 1994; Bencherifa, 1996; Swearingen & Bencherifa, 1996; Ouled Belgacem & Sghaier, 2000).

Le Cuziat *et al*. (2005) have recently identified the hierarchy of environmental constraints governing the distribution of the Houbara Bustard within a large study area in Eastern Morocco. The study underlined the important role of grazing activities in this hierarchy of constraints. In fact, whether extensive pastoralism activities can indirectly influence bird populations by changing vegetation structure, food supply and predation pressure (Pain *et al*., 1997; Fuller & Gough, 1999); grazing livestock, even at low density, can also directly affect spatial distribution and population dynamic by disturbing breeding birds (Hart *et al*., 2002), destroying nests by trampling (Pavel, 2004), and hindering access to suitable grounds (this study).

The present study aims to bring new insights to the understanding of the influence of spatial and temporal patterns of pastoral activities upon the distribution of the Houbara Bustard in a large study area that experiences significant nomadic pastoralism. (1) Evidence will be given of negative hierarchical correlations between livestock flocks and the Houbara spatial distribution over a year-round cycle. (2) Functional mechanisms underlying the observed process will be discussed in relation to the Houbara Bustards' breeding behaviour, and (3) conservation implications will be presented.

Material and methods

Study area

The study area represents a 600 km^2 surface within the stronghold of the Houbara Bustard in the semi-arid steppe-lands of Eastern Morocco. The area has been protected from hunting since 1996, and houses an important breeding population of Houbaras (Hingrat *et al*., 2004; Le Cuziat *et al*., 2005). The entire region is extensively exploited by local shepherds as pasture for sheep and goat grazing. The pastoral load is continuous throughout the year, although it varies in intensity according to the climatic conditions. Domestic animal flocks are actually a mix of sheep and goats, but will hereafter be referred to as sheep flocks for simplification.

Houbara and domestic animal flock data

Bustard distribution data was provided by systematic points count surveys conducted in the area four times during the year 2002 (Buckland *et al*., 1993; Le Cuziat *et al*., 2005). In addition, the locations of Houbaras sighted occasionally during field surveys were all systematically recorded by field technicians. Bustard locations were compared to pastoral load data recorded by exhaustive monthly aerial censuses of the distribution of animal flocks over the study area (Norton-Griffiths, 1978).

Spatial point pattern analysis

Spatial pattern analysis of this coordinate-based data was realized within the spatial point pattern statistical framework (Cressie, 1993; Diggle, 2003; Wiegand & Moloney, 2004). Local densities of each pattern (sheep flocks and bustard distribution) were derived from kernel smoothing (Wand & Jones, 1995), whereas univariate and bivariate Ripley's K functions, res-

pectively, (Ripley, 1976, 1977) were used to identify clustering, randomness or regularity in the distribution pattern of Houbaras and to assess spatial dependences between spatial distributions of sheep flocks and bustards according to scale. Briefly, kernel smoothing estimates the local density of points located on a study area, according to a given bandwidth (in this case, $\sigma = 1.5$ km), and can be seen as a continuous extension of the discrete 'quadrat counting' method. Ripley's K functions, on the other hand, evaluate the spatial relationship that each point of the pattern shares with each of the others. The K function is estimated according to the number of neighbours for each point within given distance lags. Each possible distance lag is considered in turn up to the limit imposed by the extent of the study area. Usually, L functions, that is, square root transformations of K functions, are thought (Besag, 1977) to allow more intuitive interpretations of graphics: $L > 0$ suggests aggregation, $L = 0$ a random distribution of points, and $L < 0$ a regular distribution pattern. Lotwick and Silverman (1982) proposed an extension of the univariate K – L functions to analyse the joint spatial distribution of several types of points on the same study area (in this instance, sheep flocks and bustard distributions). In this case, positive or negative cross-L values suggest positive or negative spatial associations between the points of each pattern. The significance of pattern structures suggested by values of estimated L or cross-L functions are tested by Monte Carlo simulations. For the present analysis, one thousand simulations of the Poisson process (CSR – Complete Spatial Randomness) were effected, and the L function evaluated for each in order to construct confidence envelopes. Spatial analysis was conducted within a restricted sub-area, representing the potential distribution range of Houbara when environmental constraints, as identified by Le Cuziat *et al*. (2005), are taken into account.

RESULTS

Aggregation of bustard distribution pattern throughout the year

The spatial distribution of Houbara Bustard observations exhibit significant aggregated patterns throughout the whole of the year 2002 (Fig. 1). The global aggregation of bustard observations, and hence of the underlying bustard population (assuming that the sample surveys are representative), increase from February to May, and reach a maximum in August, before decreasing until November (Fig. 2). The aggregative process acts on different spatial scales: first, aggregation increase on a large spatial scale (more than 4 km) from February to May; then it increases on a smaller scale (less than 4 km) up to large scale aggregation values in August; and finally, small-scale aggregation decreases up until November (Fig. 1 and 2). Assuming such repetitive cycle acting from one year to another, large scale aggregative pattern is expected to decrease in turn to reach the outcome observed in February.

Houbara exclusion from flock-frequented places

Local density layers (Fig. 3a and 3b) evidence a mutually-exclusive distribution pattern between animal flocks and Houbara throughout the year 2002. It is, moreover, noticeable that the pastoral activities are of a continuous higher intensity on the whole south-western part of the potential distribution range of the Houbaras.

Avoidance scale variations

Figure 3c shows the estimated bivariate Ripley's K functions expressing spatial relationship between sheep flocks and bustards for each season. Avoidance was significant for all periods and was interpreted as the result of bustard disturbance by sheep flocks. Scales of significant avoidance patterns vary during the year. Only one local avoidance scale (0 – 1 km lag) is detected at the beginning of the Houbara breeding season, and is still detected during all successive seasons (during breeding or inter-breeding periods). From the second segment of the Houbara breeding season (May) until the close of the inter-breeding period, a second significant avoidance scale is detected. This second scale has a progressively increasing spatial lag, which then decreases at the approach of the next breeding cycle. This suggests variations in spatial interactions between sheep flocks and bustards throughout the year.

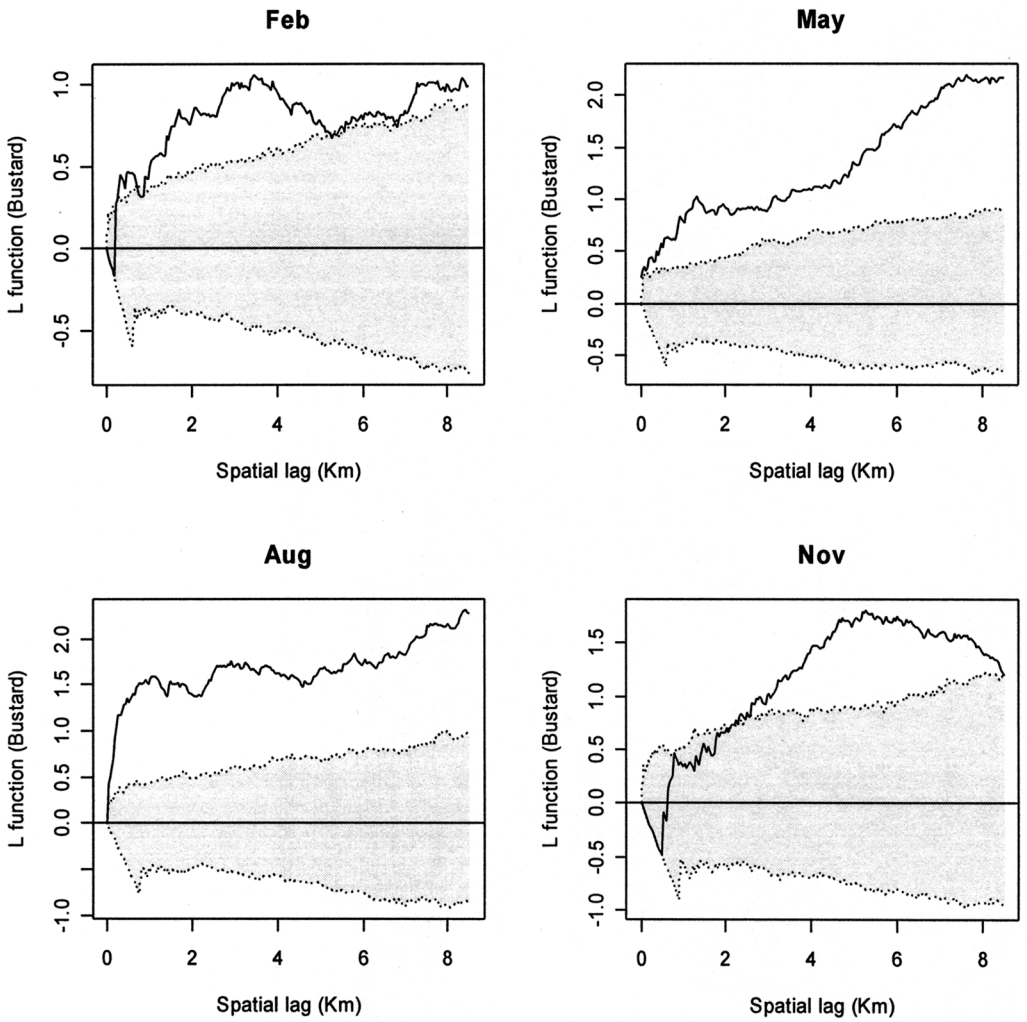

FIG. 1.—Structure of the spatial distribution of Houbara Bustard observations according to scale, for each period throughout the year 2002, as estimated by univariate L functions (Positives values suggest aggregation). Grey patterns represent the 1% confidence interval evaluated from 1000 Monte Carlo simulations of the CSR process.
[Estructura de la distribución especial de la Hubara observada según distintos tipos de escala y para periodo de tiempo a lo largo del año 2002, en base a las estimas de la function univariable L (valores positivos sugieren agregación). Las zones gríses representan el 1% del intervalo de confianza de 1000 simulaciones de Montecarlo de los procesos CSR.]

DISCUSSION

The continuously higher pastoral loads in the south-western section of the area relates to the higher density of wells in that area. It restricts the accessibility of the Houbara to potentially highly-suitable grounds throughout the whole year (Le Cuziat *et al.*, 2005). The Houbara avoidance of sheep flocks appears nevertheless, to be a spatially-scaled and temporally-variant process (Fig. 3c). The first significant avoidance scale, from 100 meters to 1 km, can

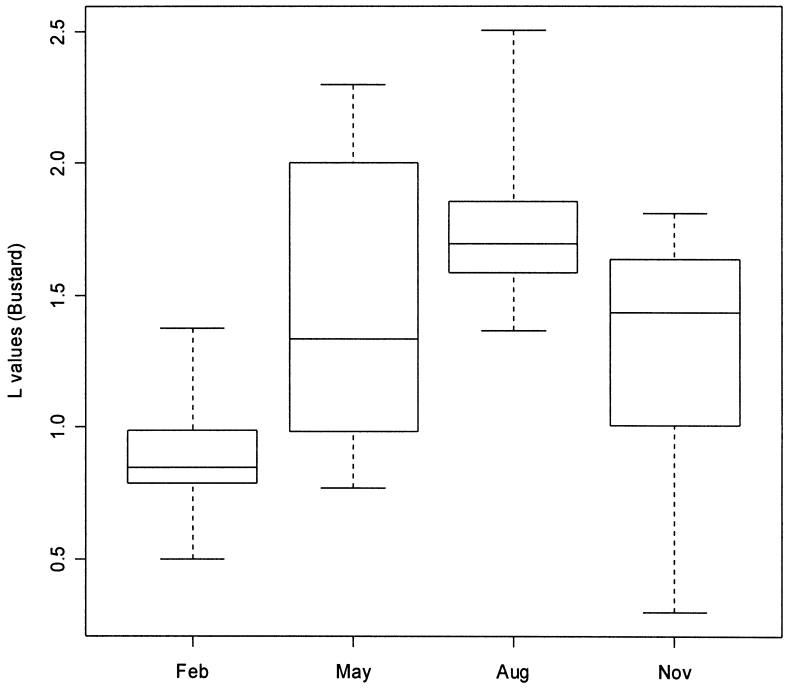

FIG. 2.—Box plot summary of the estimated structure of Houbara distribution patterns for each period throughout the year 2002. Each box represents the distribution of univariate L-function values across spatial lags (i.e. scales): median, first, and third quartiles; and the extent of the distribution of values. This representation identifies the variation of the global amount of aggregation (median) and variability across scales (extent) exhibited by patterns among periods.
[Gráfica resumen de la estructura estimada del modelo de distribución de la Hubara para cada periodo a lo largo del año 2002. Cada bloque representa la distribución de la function univariante L a lo large de distintas escales: mediana, primero y tercer cuartil, y la extension de la distribución de los valores. Esta representación identifica la variación de la cantidad total de agregación (mediana) y la variabilidad a lo largo de las escalas exhibidas por los patrones entre periodos.]

be interpreted as individual bustards deliberately avoiding passing sheep flocks. This significant local avoidance pattern has been detected from bustard observations throughout the year. The second significant avoidance scale is detected only from the second segment of the Houbara breeding season. It represents a larger clustering process of bustard observations. Houbaras tend to regroup progressively in places less frequented by sheep flocks during the course of their breeding cycle. Surprisingly, the spatial scale of the clustering process appeared to be smallest during spring when pastoral load on the area is at a maximum, and when Houbaras are expected to be more sensitive to disturbance as a function of their breeding stage. This suggests an intricate balance between influences at work, or a temporal gap between disturbances events and responses by the whole Houbara population.

At the beginning of the breeding season, Houbara males are looking for suitable breeding sites within their area, whereas females are looking for displaying males to mate with. This first distribution of individuals over the whole suitable area possibly happens initially without regard to pastoral loads. Suitable breeding sites are probably chosen exclusively according to the environmental context. Breeding males exhibit strong fidelity to their displaying sites (Hingrat *et al.*, 2004), whereas broody hens are linked to their nest to ensure clutch

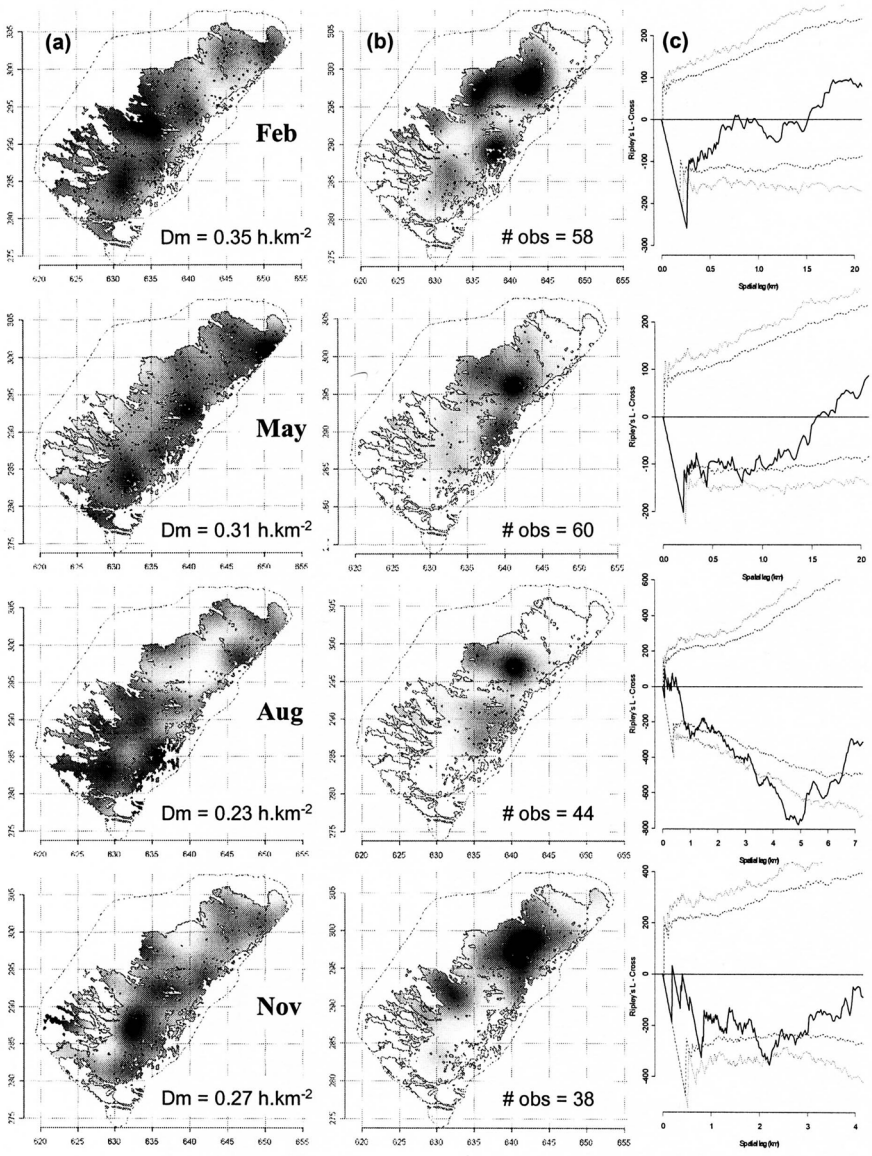

FIG. 3.—Sheep and goats flocks (a) and Houbara local densities (b) estimated by kernel smoothing (Gaussian kernel, bandwidth sigma = 1.5 km) within the potential distribution range of Houbaras. (c) Bivariate Besag's L function, the variance stabilized version of the bivariate Ripley's K function. Dashed and dotted lines represent Monte-Carlo confidence envelopes 5% and 1% respectively (simulations N=1000). NB: the mean overall density of flocks (Dm) is expressed in # flocks per km^2, whereas the total number of Houbara observations (point counts + occasional sightings) is given for each period.

[Bandos (a) y densidad local de Hubaras (b) estimadas por «kernel smoothing» (Gaussina Kernel, ancho de la banda sigms = 1,5 km) en el rango potencial de distribución de las Hubaras. (c) Función bivariable de Besag, la version con varianza estabilizada de la function K de Ripley. Las líneas de puntos y rayas representan lo intervalos de confianza de Monte-Carlo al 1% y 5%, respectivamente (simulación, n = *1000). NB: densidad media de bando (DM) se da en número de bandos por km^2, mientras que el número de Hubaras observadas (censos puntuales + avistamientos locales) se dan para cada periodo.]*

incubation. Both sexes are, therefore, spatially tied to particular places during the breeding season. Displaying sites that are spread throughout the Houbara habitat, and females' home-ranges that encompass males' territories (Hingrat *et al*., 2004), explain the relatively low but significant aggregative pattern of the spatial distribution of Houbaras detected in February (Fig. 1 and 2). Breeding sites that are located in areas that support larger pastoral loads will undergo more frequent disturbance events moving forwards. The frequency of disturbance probably reaches a threshold; leading birds to prefer places within less flock-frequented areas. The clustering process, therefore, gradually acts upon the Houbara population and can be detected from the second segment of the Houbara breeding season onwards. Nesting female Houbara are known to be very sensitive to disturbance (Lavee, 1985, 1988). This tends to increasingly reinforce the avoidance pattern between sheep flocks and bustards until the beginning of the inter-breeding period. During the period from July to September, this mutually-exclusive pattern is at its most significant, despite pastoral load being at its lowest, as shepherds escape from the summer drought. The persistence of the distribution pattern of Houbaras can be explained either as possible remnants of the progressive shaping process experienced during breeding time (temporal gap between disturbance and response at the population scale), or as potential habitat degradation caused by over-grazing on areas that have undergone higher pastoral loads during springtime (inter-breeding bustards therefore tend to forage in the remaining suitable areas). Houbara Bustards are known to exhibit some gregariousness during inter-breeding times (Hingrat, 2005). However sheep flock foraging is a very small-scale aggregation process and, in the absence of disturbance events, is expected to occur randomly within the bustards' habitat. Therefore, the significance of aggregation detected for this period (August), on both small and large scales, means that the pattern cannot be explained by the social behaviours of the Houbaras only. Later on, the approach of the next breeding cycle gradually drives Houbaras to redeploy over their entire habitat to find favourable breeding sites, and can be detected by Ripley's K and cross-K functions through the decrease in small-scale aggregation of the Houbara pattern (Fig. 1), and the spatial lag decrease of the avoidance of sheep flocks by bustards (Fig. 3).

Human disturbances impinging on bustard populations through pastoral activities were reported elsewhere for the Macqueen's Bustard in a similar context in Israel (Lavee, 1985, 1988), and in the Arabic peninsula (Seddon *et al*., 1995; Osborne *et al*., 1997; Van Heezik & Seddon, 1999). The influence of agricultural management practices on the conservation of bird populations is an issue currently receiving a great deal of attention (Pain *et al*., 1997; Vickery *et al*., 2001; Watkinson & Ormerod, 2001; Wolff, 2001; Wolff *et al*., 2001; Bretagnolle & Inchausti, 2005). Recent shifts in agricultural practices or policy, and in grazing activities in particular, are expected to have numerous and varied consequences on populations or bird communities, depending on bioclimatic conditions. Grazing activities that change range-lands vegetation, modify in turn bird habitats (Fuller, 1992; Fleischner, 1994; Moreira, 1999; Mcculloch & Norris, 2001; Calladine *et al*., 2002): their structure (height, density and cover); their plant-species composition; or even their nature (trees, grasses or shrubs). Vegetation changes may in turn impinge on habitat-available resources, such as vegetation or invertebrate fauna (Fuller & Gough, 1999). The opening of the vegetation shelter may increase predation rates (Fuller & Gough, 1999; Silva *et al*., 2004), whereas increasing vegetation cover could lead to habitat unsuitability, according to species' preferences (Fuller & Gough, 1999; Calladine *et al*., 2002). All these considerations relate to the indirect influences of grazing on birds through the alteration of habitats' suitability. However, grazing can also have direct consequences on the population of ground-nesting birds, through clutch destruction by trampling (Hart *et al*., 2002; Pavel, 2004), or through direct disturbances of breeding or feeding behaviours, especially within open habitats (Gill *et al*., 1996, 2001). According to Cingolani *et al*. (2005) the impact of grazing on the vegetation of semi-arid range-land that has a long history of grazing, is expected to be a slow process, which will entail fewer consequences for habitat characteristics than in sub-humid conditions. Furthermore, semi-arid climates trigger a low and sparsely-covered vegetation physiognomy that generally leads to wide-open habitats. By

reason of the significant impact our results show, and the short timescale of the present study, it is argued that direct influences of grazing activities on semi-arid steppe-lands birds are about to play a major role in the trade-off between indirect and direct outcomes. These direct influences will have rapid and heavy consequences on the population dynamics of endangered birds, like the Houbara Bustard, by impinging on breeding success or by hindering access to large parts of suitable habitats.

Conclusion

Results clearly suggest that Houbara Bustards are excluded from potentially-suitable grounds because of disturbances related to human pastoral activities. Neither the hypothesis of a bustard population potentially less than the carrying capacity of its habitat (thus exhibiting spatial gaps in its distribution), nor social behaviours of Houbara Bustards (breeding or interbreeding), appear sufficient to explain the evident mutually-exclusive patterns detected throughout the year, as well as the significant negative correlations between sheep and goats flocks and bustards distribution patterns.

It is thus important to account for spatial and temporal variations of the distribution of human activities into Houbara distribution models in order to satisfactorily portray the aggregation patterns detected in Houbara Bustard spatial distributions during both breeding and inter-breeding periods. Both sheep and goats flocks and bustards exploit the same grounds during the key period of the Houbara breeding season. From a conservation perspective, it is therefore evident that pastoral activities must be managed in order to preserve breeding sites from degradation and breeding Houbaras from disturbance; thus ensuring breeding success in the wild. Designating large areas of the identified habitat of the Houbara Bustard as benefiting from a removal or a drastic reduction of pastoral load during the key periods of the breeding season will ensure that breeding males can occupy larger areas of their habitats and therefore increase the potential number of established mating systems. It will also prevent nesting females from clutch loss and will consequently increase the breeding success of the population.

The setting aside of reserves often trigger controversial debates regarding traditional land use and management by the native human populations (Bencherifa, 1996; Saberwal, 1996, 1998; Mishra & Rawat, 1998; Steinmann, 1998). Socio-economic studies of traditional herding management, conducted in conjunction with local shepherds, are needed and may provide valuable insights in helping to design sustainable pastoral management plans, while preserving the remaining wild populations of the Houbara Bustards.

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