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Distance to international border shapes the distribution pattern of the growing Little Bustard *Tetrax tetrax* winter population in Northern Iran

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Summary

The Little Bustard *Tetrax tetrax* is a Near Threatened grassland bird that is fully migratory within its eastern population, wintering in large numbers across the south Caucasus and northern parts of Iran. The species' habitat selection has been comprehensively studied in its western European range, but very limited information is available for its eastern population. Surveys carried out between 2010 and 2015 show a considerable population increase and probable range expansion in the region. We modelled the suitability of potential winter habitat for the species and found that distance to country border, land cover and altitude were the most important variables in predicting habitat suitability. There is still considerable hunting pressure in Iran and distance to border is likely to be related to strict hunting prohibition along the border belt imposed for military purposes. This represents an opportunity for the conservation of the species, where management efforts should aim at ensuring the maintenance of suitable land cover.

Introduction

The Little Bustard *Tetrax tetrax* is a Palearctic, ground-nesting, medium-sized grassland bird (Cramp and Simmons 1980). It is listed as 'Near Threatened' globally and as a vulnerable species in Europe (BirdLife International 2016) due to a dramatic population decline in recent years. Agricultural intensification, habitat loss and degradation across the species' geographical range are thought to be the main factors depleting its populations (e.g. Silva *et al.* 2004, García de la Morena *et al.* 2007, Suárez-Seoane *et al.* 2008, De Juana 2009, Delgado *et al.* 2009, Iñigo and Borov 2010).

Two widely separated breeding populations are recognized: the western population is found across Morocco, Spain, Portugal, France and Italy and the eastern population from China to Ukraine and Iran (Iñigo and Borov 2010). In contrast to the western European populations which are mostly short-distance migrant birds (García de la Morena *et al.* 2015), except for the French Atlantic populations, the eastern population is fully migratory (Cramp and Simmons 1980), wintering in the Caucasus, Azerbaijan and Iran (Gauger 2007). Recent Little Bustard winter counts in these wintering sites highlight the importance of the Iran/Azerbaijan region as a wintering site (Gauger 2007, Sehhatisabet *et al.* 2012), possibly comprising the large majority of the eastern population (Iñigo and Borov 2010). Azerbaijan holds by far the highest known winter concentrations of Little Bustards in the world, with an estimated 150,000 birds found wintering in the region (Gauger 2007).

This is a remarkable figure considering the world population of the Little Bustard is estimated at 260,000 individuals (Iñigo and Borov 2010). While the western population is declining across most of its range (e.g. Inchausty and Bretagnolle 2005, De Juana 2009), the eastern population until 2000 was described as recovering, significantly increasing its population size (Gauger 2007, Iñigo and Borov 2010) and gaining international importance.

The population of Little Bustard that winters in Iran probably breeds in Kazakhstan and Russia (Gauger 2007, Aghayari-Samian *et al.* 2014) as the species is also a wintering migrant in the areas immediately north of Iran (Sehhatisabet *et al.* 2012). Every year between November and February, Iran harbours an important wintering population with an estimated size of 5,000–10,000 individuals (Sehhatisbet *et al.* 2012). While alfalfa and other favourable agricultural crops for the species are expanding rapidly across northern parts of Iran and providing attractive winter habitat, hunting has been identified as a major threat (Sehhatisbet *et al.* 2012).

The winter ecology of the Little Bustard has been extensively studied for the western populations. Here they were found mostly associated with cereal stubbles within the extensive cereal agricultural system (Silva *et al.* 2004) and alfalfa in more intensified agricultural sites (García de la Morena *et al.* 2007). However, its habitat preferences in its eastern range are largely unknown, and the environmental factors driving wintering area selection are likely to differ. Since the Little Bustard is now greatly dependent on landscapes shaped by man (Iñigo and Borov 2010), outlining adequate management and conservation actions is essential to ensure the preservation of the species. Hence, the objectives of this work are (1) to update wintering counts and assess population trends and range modification of the Little Bustard in northern Iran and (2) to understand the main environmental factors influencing its occurrence and predict areas with greater habitat suitability for the species during winter.

Material and methods

Data collection

Winter surveys were carried out during October–February in 2010–2015 in northern Iran. A first assessment of the species' distribution and population size was made by Sehhatisabet *et al.* (2012). This earlier study, carried out between 2003 and 2010, identified the main wintering habitats used by the species in five northern Iranian provinces including the plains of Ardebil, Gilan, Mazandaran, Golestan and Khorasan-e-Razavi. In the present study we covered all Little Bustard areas previously identified by Sehhatisabet *et al.* 2012 plus another 38 sites dominated by open agricultural landscapes that had not been surveyed in northern Iran. These sites were of variable size (mean = 2,136 ha, SD = ± 4,463) and surveyed by covering all available roads and tracks by car at slow speed and with regular stops to scan for Little Bustard flocks using binoculars. Overall we surveyed 49 sites covering the agricultural lands in the six northern provinces of Iran (Figure 1). We surveyed those sites annually that were occupied by Little Bustards. Each flock when counted in flight was carefully watched and we noted where it landed to avoid double counts.

Predictor variables

To predict the suitable ranges for the Little Bustard across the northern parts of Iran, we used three categories of eco-geographic factors, including climate, topography and land-cover variables (Table 1) previously known to influence the species' occurrence (Martínez 1994, Silva *et al.* 2004, 2007, Sehhatisabet *et al.* 2012). All environmental variables were mapp at with 1 km^2 (30 × 30 arcseconds) grid size.

Climatic variables were obtained from the WorldClim database (Hijmans *et al.* 2005). This database consists of 19 climatic variables which result from the interpolation of data derived from climatic stations. Land cover data were obtained from the National Land Cover map (IFRWO 2016)

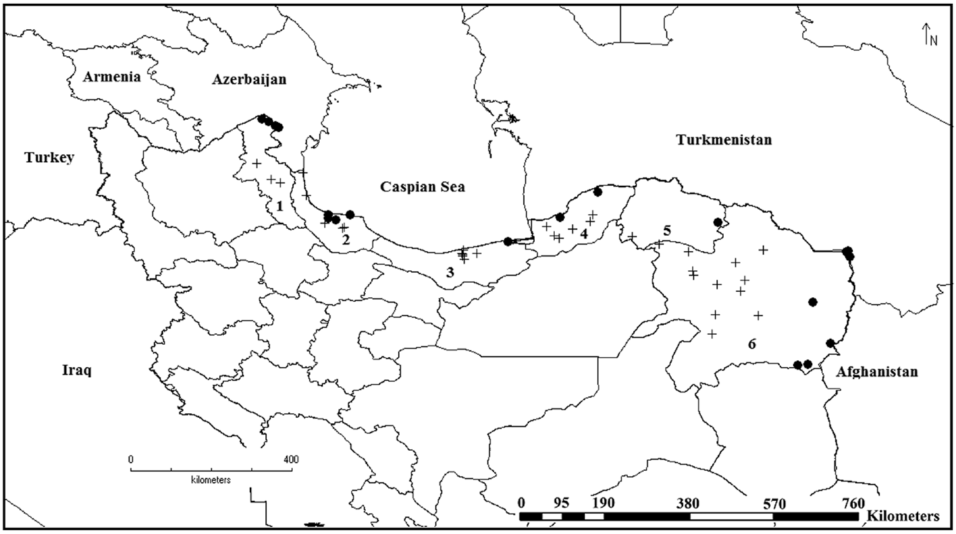

Figure 1. Presence records (dots) and unoccupied habitats (crosses) of the Little Bustard in northern Iran in winter. Ardebil province (1), Gilan province (2), Mazandaran province (3), Golestan province (4), Khorasan-e-Shomali province (Northern Khorasan) (5) and Khorasan-e Razavi province (6).

based on the Landsat Enhanced Thematic Mapper Plus - ETM+ which consists of imagery for conterminous Iran in the year 2010. Using the Shuttle Radar Topography Mission (SRTM) elevation model, two topographic explanatory variables were compiled: altitude and slope.

We also used distance to the border in order to test our hypothesis that vicinity to an international border influences the distribution pattern of Little Bustard in Iran, as this relates to areas where hunting is forbidden and disturbance is possibly reduced. For this purpose, we calculated the Euclidian distance of each cell of the grid in the study area to the international border using ArcMap Spatial Analyst tools. The climatic variables were found highly correlated (Pearson > 0.70) and therefore to prevent multicollinearity we chose annual precipitation to run in the model (Tabachnick and Fidell 1996) because this had most support

Table 1. List of predictors variables used for modelling Little Bustard distribution in the north of Iran.

Variable	Description	Unit	Source
Topographic	Altitude: Elevation above sea level	m	Jarvis *et al.* 2008
	Slope steepness	%	Jarvis *et al.* 2008
Land cover	Agricultural types with two categories including irrigated and non-irrigated crops		
	Rangeland with three categories: range type 1 (Rangelands with more than 50% canopy cover), range type 2 (Rangelands with 25–50% canopy cover) and range type 3 (Rangelands with 5–25% canopy cover)		IFRWO, 2010
Climatic	Annual precipitation	mm	Hijmans *et al.* 2005
	Minimum Temperature of Coldest Month	°C	Hijmans *et al.* 2005
	Mean Temperature of Wettest Quarter	°C	Hijmans *et al.* 2005
	Precipitation of Coldest Quarter	mm	Hijmans *et al.* 2005
Distance to border	Euclidian distance of each grid in the study area to Iran international border	Degrees	

from the literature (e.g. Delgado and Moreira 2010). The remaining environmental variables (Table 1) showed lower correlation values. The pairwise correlations were calculated using ENMtools (Warren *et al.* 2010).

Data analysis

We used the maximum entropy algorithm (Phillips *et al.* 2006) to build a habitat suitability map for Little Bustard in an area of about 249,166 km^2 in northern Iran. This algorithm can be used to predict the suitability of the study area for the species under a specified set of environmental constraints (Phillips *et al.* 2006) and is known to perform well even with limited presence data (Pearson *et al.* 2007). MaxEnt was set to run with a maximum of 1,000 iterations, convergence threshold of 0.0001 and 10,000 background points. Overall, 20 Little Bustard occurrences were recorded within the 1 km^2 grid within 16 sites. We used these 20 occurrence points in MaxEnt analysis, 16 points for training and four points for test.

The performance of the model was assessed using the Area under the Curve (AUC) metric of a Receiving Operator Characteristic (ROC) (Phillips *et al.* 2006), which is considered adequate to assess the accuracy of SDMs (Fourcade *et al.* 2014). MaxEnt plots all sensitivity values (true positives) against specificity (false positive) values and calculates the AUC to provide a threshold-independent metric of overall accuracy, ranging between 0.5 (no predictive ability or randomness) and 1.0 (perfect predictive ability). Variables contributing less than 1% to the model were sequentially removed until all variables entered in the model contributed over 1%. Models with AUC > 0.75 are considered adequate and > 0.90 are considered excellent (Swets 1988, Elith 2002). We used the 10-percentile training presence logistic threshold (Young *et al.* 2011), defined at 0.27, to convert the continuous suitability predictions into binary suitable/unsuitable maps.

To confirm MaxEnt outcomes, we additionally carried out a binomial Generalized Linear Model (GLM) with a logit link function. The 49 surveyed sites resulted in 16 presences and 33 absences. To reduce autocorrelation, one location was selected per site: for presence sites that recorded more than one flock the location was randomly selected; and for absence sites the location was chosen taking into account its habitat suitability for the species according to Sehhatisabet *et al.* (2012), principally the proportion of open area and presence of irrigation. To reduce collinearity, we eliminated all variables showing correlations over 0.7 (Tabachnick and Fidell 1996) and selected the one of greater biological importance based on the literature (Silva *et al.* 2004, Delgado and Moreira 2009). This reduced the number of variables to three: distance to border; land cover and annual precipitation. In the analysis, for the categorical variable land cover, we used irrigated crop as the reference category. We computed GLM models with all possible variable combinations, resulting in a total of seven models. Akaike's information criterion adjusted to small data sets (AICc) was used for model selection (Burnham and Anderson 2002). We defined our top concurrent models as those that fell within five AICc (Δ AICc < 5). We then used model averaging (Burnham and Anderson 2002) of this best set of models to determine the relative importance of each parameter for explaining the variance. Analyses were performed in R (R Development Team 2016), using the MuMIn package (Bartón 2016).

Results

Winter counts

Over a five-year period, populations appeared to be increasing, with a count of 57,086 individuals recorded in the last survey year of 2014–2015 (Table 2). We obtained 20 Little Bustard records within 16 sites in Northern Iran (Figure 1), five of which correspond to new areas, where the species was not previously recorded: four new localities in Khorasan-e-Razavi province and one new locality in Khorasan-e-Shomali.

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Table 2. Number of Little Bustard counted in each province along with maximum number of Little Bustards in each province counted by Sehhatisabet *et al.* (2012). "-" stands for no data available and "0" means that no birds were counted at that giving site.

Province and locality name	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Maximum number in Sehhatisabet *et al.* 2012
Ardebil Moghan Plain	-	9,500	24,500	19,217	50,000	10,050
Gilan						
Boujagh National Park	5	18	48	1336	16	
Anzali wetland	1	0	21	200	2	
Roudsar-Lalaroud coast	2	0	5	310	3	
Alman village	-	-	-	-	1	
Siah Darvishan	1	0	4	17	2	2
Mazandaran Miankaleh peninsula	26	32	30	20	25	300
Golestan						
Alagol wetland	98	98	73	123	210	
Kerend (east of Atrak river)	-	12	7	27	6	450
Khorasan-e-Shomali Shirvan, Faruj	-	-	-	-	5	-
Khorasan-e-Razavi						
Sarakhs plain	2125	1640	1850	5212	6268	
Torbat Jam, Jafarabad	-	-	-	-	10	
Taybad, Rahneh	-	-	-	-	516	
Khaf	-	-	-	-	3	
Khaf, Hoseinabad	-	-	-	-	7	
Dashtebayaz	-	-	-	-	12	3670
Little Bustard counts per year	2258	11300	26538	26462	57086	14472

Habitat suitability

Results of habitat suitability modelling indicated that irrigated agricultural land in low-elevation plains in north, north-east and north-west Iran that are close to the international border provided the most suitable wintering habitats for Little Bustard (Figure 2). Unsuitable habitats were mostly located in the southern parts of study area as well as in areas far away from Iran's international border with high elevation, as in Alborz and Kopet-Dagh Mountains, stretching to northern and eastern Iran.

Variable importance

The variables that most influenced the habitat suitability model were distance to border (44.6%) followed by land cover (25.8%), irrigated land and altitude (15.2%) (Appendix S1 in the online supplementary material). Response curves (Appendix S1) indicate that an increase in distance from the border reduces the habitat suitability for the Little Bustard. A similar pattern was also obtained for altitude, indicating that the Little Bustard prefers low elevation plains with predominantly agricultural landscapes. In contrast, there was a positive relationship between the species, probability of occurrence and minimum temperature of coldest month. This may suggest that areas with higher temperatures would be of greater suitability for the species during their wintering period in Iran. The modelling procedure also indicates that there is a clear preference for irrigated agricultural land. The overall predictive ability of the model (AUC = 0.971 for training and 0.971 for test data) showed high discriminatory capacity in determining suitable and unsuitable habitats.

As for the GLM models, four concurrent models had a $\Delta AICc < 5$ and were retained (Table 3). Model averaging of these models then showed that there was a higher probability of occurrence

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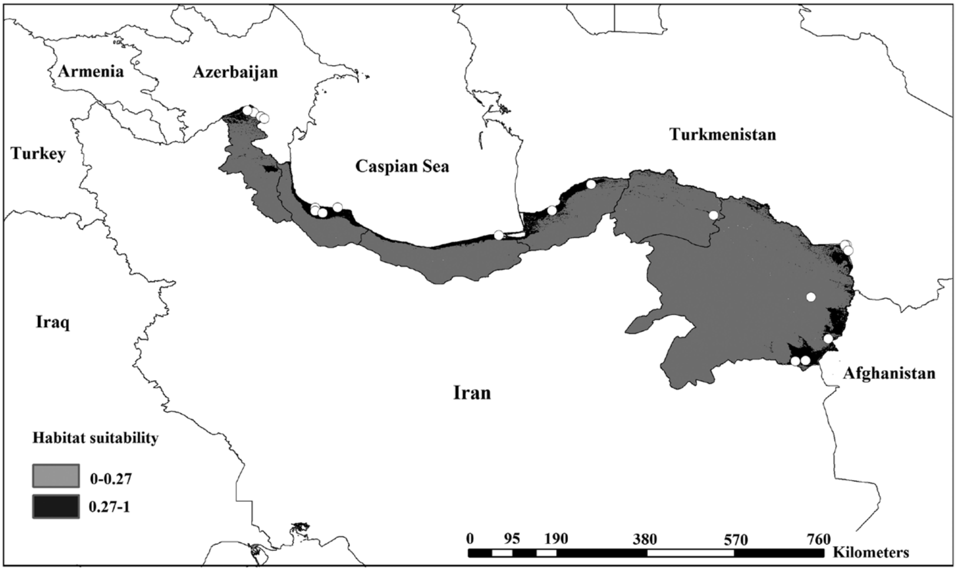

Figure 2. Predicted suitable and unsuitable habitats for Little Bustard in Iran along with presence records (white dots).

of Little Bustard flocks next to the border, coinciding with areas with lower annual precipitation, selecting irrigated crops and avoiding areas with greater canopy area (Table 4). Distance to border was the most important variable explaining the variance (with the maximum importance of 1) followed by annual precipitation (0.74) and land cover (0.07). The GLM and model averaging procedure therefore corroborated the MaxEnt analysis, that the distance to the international border was the most important predictor in the variables we considered.

Discussion

Winter population and range increase in Iran

Sehhatisabet *et al.* (2012) surveyed probable Little Bustard habitats in northern Iran from 2003 to 2010 and confirmed its presence in 15 localities. Maximum counts in 2010 were of approximately 14,000 birds (Sehhatisabet *et al.* 2012). Since then yearly counts have shown a steep increase (Table 2). Now maximum counts are of 57,086 which represents more than four times what was counted in 2010. Ardebil province alone registered in 2015 a total count of approximately 50,000 individuals which is five times more than the maximum wintering population estimated

Table 3. AICc results for the combination of all models, also indicating ΔAICc.

	Annual Prec	Dist_border	Land cover	AICc	ΔAICc
mod1	**x**	**x**		**50.1**	**0.00**
mod2		**x**		**52.5**	**2.38**
mod3	**x**	**x**	**x**	**54.9**	**4.81**
mod4		**x**	**x**	**55.0**	**4.89**
mod5			x	63.0	12.89
mod6	x		x	65.5	15.38
mod7	x			66.1	16.00

Table 4. Coefficients of the model averaging procedure, indicating the relative importance of the variables.

	Intercept	Dist_border	Annual_Precip	Land cover			
				non-irrigated	Range 1	Range 2	Range 3
Coefficients	1.400864	-3.978302e-05	-0.001434301	-0.06763442	-2.081135	2.074678	0.1511882
Variable importance	---	1	0.74	0.07			

for the province in 2010 (Sehhatisabet *et al.* 2012). The Little Bustard was found in five new locations, including two new regions: Khorasan-e-Razavi and Khorasan-e-Shomali, indicating that its winter range may also be expanding. Our work now updates the Little Bustard winter range and maximum counts in Iran.

Even though we cannot fully exclude the possibility of birds being double counted at different sites at different times, or that there might have been an increase in survey effort, our repeated counts at the different sites show a trend of increasing numbers.

Within the eastern population, the most important breeding Little Bustard populations coincide with the former Soviet Union (Iñigo & Borov 2010). In the late 20th century, with the break-up of the former Soviet Union, vast areas of arable fields were abandoned and pristine steppe left ungrazed, resulting in a period of significant population increase for many steppe species (Kamp *et al.* 2011), including the Little Bustard (Gauger 2007). This possibly also led to a population increase in their wintering range. However, since 2000 there has been an intensification of agricultural and pastoral systems, which will tend to increase with the recent reclamation of abandoned land and consequently lead now to the decline of steppe birds (Kamp *et al.* 2011). Therefore, the population and range increase of wintering Little Bustards in Iran is more likely related to a higher level of concentration of the wintering population within the Caucasus region, than by an actual population increase, due to the safe heaven provided by the non-hunting zone combined with the increase of attractive agricultural crops.

Factors influencing Little Bustard winter distribution in Northern Iran

Both MaxEnt and the GLM and model averaging approaches showed that distance to a border was the most important predictor of Little Bustard occurrence in Iran. Iran's international borders are likely to strongly influence the species' distribution pattern, due to the severe military restriction as a non-hunting area, and therefore providing safe habitats for Little Bustards. Hunting has been identified as a major threat for the species leading to high rates of non-natural mortality and considerable disturbance (Gauger 2007, Sehhatisabet *et al.* 2012). A vast area next to the border, including next to the Caspian Sea, which can cover a belt of more than 10 km with strict non-hunting policy may therefore play a crucial role in providing refuge areas for the species.

Land cover is another important predictor of Little Bustard distribution in Iran. Little Bustard distribution was shown to be associated with irrigated crops, likely including crops such as alfalfa, which is a known preference for the species during winter (García de la Morena *et al.* 2007). Even though a land cover map discriminating all land uses was not available for our study area, alfalfa is a crop that is expanding in Iran and is well represented in irrigated areas. A previous study in Iran also found a significant proportion of the wintering population in alfalfa crops (Sehhatisabet *et al.* 2012). These legume crops offer a suitable vegetation structure for the species and are of high nutritional value, providing a suitable food resource (Bretagnolle *et al.* 2011) that can support large wintering flocks (Iñigo and Borov 2010).

As for elevation, its importance in the model probably relates to the preference for lowland agricultural sites with milder temperatures. Altogether, the Little Bustard preferred sites closer to the border within lowland irrigated agricultural landscapes. For the GLM models, because elevation was found to be highly correlated with distance to border, it was removed from analysis, however areas of lower annual precipitation are mostly located in plains closer to the border.

Our study is the first to address winter habitat selection of the eastern Little Bustard population, although previous studies have identified some patterns of habitat use (Gauger 2007, Sehhatisabet *et al.* 2012). The predicted distribution map produced in this study largely matched the distribution outlined by Sehhatisabet *et al.* (2012) based on extensive fieldwork, which further confirms the ability of MaxEnt to accurately predict the suitable areas for the species even with limited data availability. MaxEnt and GLM analysis agree that distance to border is the most important variable explaining the pattern of Little Bustard occurrence in Northern Iran. Although land cover also enters in both modelling procedures, they disagree on its relative importance. This discrepancy is likely related to the difference in land cover variation captured by the absences (with the GLM analysis) and background points (with the MaxEnt). Species distribution models are useful tools to identify potential new areas for target species (Williams *et al.* 2009, Yousefi *et al.* 2015). In this study, the MaxEnt model highlighted some new patches that seem to connect known areas. Further monitoring is needed to confirm the importance of these areas.

Iran now holds an important wintering population of the eastern Little Bustard population. Because these birds can aggregate in large numbers in relatively small areas, depending on highly anthropogenic habitats, it is essential that conservation action takes place. The non-hunting area next to the border represents a rare opportunity for the conservation of this species. Here the priority should be given to maintaining suitable habitats for the species. Additionally, in suitable agricultural areas, further from the border, poaching could be prevented by promoting awareness campaigns next to farmers and hunters and add greater protection to agricultural sites next to areas of greater habitat suitability.

Supplementary Material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0959270917000181

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