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POSSIBLE CHANGES IN FAVOURABILITY AREAS FOR MONTAGU'S AND HEN HARRIERS IN SPAIN ACCORDING TO CLIMATE CHANGE SCENARIOS

POSIBLES CAMBIOS EN LAS ÁREAS FAVORABLES PARA LOS AGUILUCHOS CENIZO Y PÁLIDO EN ESPAÑA DE ACUERDO A ESCENARIOS DE CAMBIO CLIMÁTICO

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SUMMARY.—We modelled the distribution of Montagu's harrier *Circus pygargus* and hen harrier *Circus cyaneus* in Spain under current conditions. Current favourability for Montagu's harrier was highest throughout Western Spain, whilst for hen harrier it was concentrated in the Northern half of Spain. We also calculated their future climatic favourability according to two climate scenarios. Both forecast a contraction of the favourable areas for both species during future periods. Specifically, the model for the Montagu's harrier forecast that high favourability areas will be concentrated in Castilla y León, and in the case of hen harriers in the Northern mountain areas of Spain.

RESUMEN.—Se ha modelado la distribución de los aguiluchos cenizo *Circus pygargus* y pálido *Circus cyaneus* en España según las condiciones ambientales actuales. Las áreas más favorables para el aguilucho cenizo se sitúan en el oeste de España, mientras que las del aguilucho pálido se concentran en la mitad norte de España. También se calculó su favorabilidad climática futura según dos escenarios climáticos. Ambos pronostican una reducción de las áreas favorables para ambas especies en periodos futuros. Concretamente, las zonas favorables para el aguilucho cenizo estarán concentradas en Castilla y León, y las del aguilucho pálido en las áreas más montañosas del norte de España.

Predicting how large-scale environmental variables affect the likely occurrence and distribution of a species is not only one of the core objectives of ecology, but has broad applicability in conservation biology. In particular, predicting environmental favourability has become a fundamental component in disciplines such as conservation planning or wildlife management, and in the assessment of the impact of climate change (Estrada *et al*., 2008; Real *et al*., 2010).

Montagu's harriers *Circus pygargus* and hen harriers *Circus cyaneus* are two ground-nesting raptors listed on Annex 1 of the EC

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Birds Directive 1979. The Montagu's harrier is considered vulnerable in France and the Iberian Peninsula, the strongholds of the Western European population (Arroyo and García, 2008). Similarly, the hen harrier is considered vulnerable within Spain, although the proportion of the European population within Spain is lower than for Montagu's harrier (Arroyo and García, 2008). There are a number of conservation programmes in many of the Spanish administrative regions for both species. García and Arroyo (2001) showed that the probability of occurrence of both species at the European scale depended on climatic variables, with the Montagu's harrier being more common in hotter climates, whereas the opposite occurred for the hen harrier. Similarly, the occurrence of hen harriers within Europe has been shown to fit climatic variables (Anderson *et al*., 2009). At a national scale in Spain, a virtual atlas (http://161.111.161.171/Atlas/indexPatron.html) relates the frequency of appearance of these species with environmental factors, and also identifies some climatic factors as being important for hen harriers. Therefore, climate change may have important effects on distribution of both species. Knowing how climatic suitability may change in the future would constitute important information to highlight areas where conservation programmes should be implemented (Muñoz *et al*., 2005). Our objective in this study was thus to assess the favourable areas for both species in relation to large-scale environmental variables, and how the distribution of optimal areas is likely to change according to climate change scenarios.

We used presence/absence data for both species in a grid of 10 x 10 km UTM cells from the most recent atlas for breeding birds in Spain, compiled in 2003 (Martí and Del Moral, 2003). We related these data to the variables detailed in table 1. For climatic variables we used the data produced by the Agencia Estatal de Meteorología (AEMET) according to the atmosphere-ocean global circulation model CGCM2 from the Canadian Climate Centre for Modelling, and the greenhouse gases emission scenarios A2 and B2 (Brunet *et al*., 2007), for the period 1961-1990.

The steps followed in the modelling procedure were as follows. We first selected a subset of variables significantly related to each species' distribution by performing logistic regressions of each species presence/absence on each variable separately. To control for the increase in type I error due to multiple tests (Benjamini and Hochberg, 1995; García, 2003), we controlled the false discovery rate (FDR) using the procedure for all forms of dependency among statistics proposed by Benjamini and Hochberg (1995), only accepting the variables that were significant under a FDR of $q < 0.05$.

As our objective was to project species climatic favourability to future periods, it is important to know if the relationship between climatic variables in those periods is different as in the present one (1961-1990). If this happens, the models would be less transferable. Thus, we controlled the multicollinearity between precipitation and temperature variables separately using Spearman's correlation coefficient (*rho*). Groups of correlated variables were subjectively defined using an absolute *rho* value 0.5 and $P < 0.01$. For each of these groups (in the period 1961-1990) we selected just one variable per group, namely the variable that was most significantly related to each species distribution.

Then we performed forward-backward stepwise multiple logistic regression of presence/absence data on the subset of significant predictor variables of the period 1961-1990. We then applied the favourability function (Real *et al*., 2006), which allows direct comparison of predicted values for species with different prevalence. We thus obtained for each species two multivariate favourability models (one for each emission scenario). The relative importance of each variable within

TABLE 1

Explanatory factors and associated variables used in models. Variables that form part of the CGCM2-A2 models for each species are indicated in the MH (Montagu's harrier) or HH (hen harrier) columns. Values in the latter columns are the sign of the coefficient (S), and the Wald value (W).
[Factores explicativos y variables asociadas empleadas en los modelos. Las variables que conforman los modelos CGCM2-A2 para cada especie se indican en sus respectivas columnas. MH: aguilucho cenizo; HH: aguilucho pálido; S: signo del coeficiente; W: valor de Wald.]

			MH		HH	
Factors	**Code**	**Variables**	**S**	**W**	**S**	**W**
Spatial situation	Lati	Latitude (ºN) [1]	+	13.075	+	169.495
	Long	Longitude (ºE) [1]	–	174.166	–	23.577
Topography	Alti	Mean altitude (m) [2]	–	7.730	+	51.463
	Slop	Slope (º) (calculated from altitude)	–	174.426	–	17.157
	SE	Southward exposition degree [3]	–	8.796		
	WE	Westward exposition degree [3]	+	8.975	–	6.181
Human activity	DHi	Distance to the nearest highway (km) [1]	–	93.890		
	U100	Distance to the nearest urban center with more than 100,000 inhabitants (km) [1]			–	10.583
	U500	Distance to the nearest urban center with more than 500,000 inhabitants (km) [1]	–	22.215	–	100.105
	HPd	Human population density in 2000 (Number of inhabitants/km^2) [4]	–	20.740		
Lithology	Perm	Soil permeability [5]				
Climatic	PAn	Annual precipitation (mm) [6]				
	PSp	Spring precipitation (mm) [6]				
	PSu	Summer precipitation (mm) [6]	+	7.685	–	25.181
	PAu	Autumn precipitation (mm) [6]				
	PWi	Winter precipitation (mm) [6]	–	51.089		
	TAn	Annual maximum temperature [6]			–	7.514
	TJa	January maximum temperature [6]	–	38.128		
	TJu	July maximum temperature [6]				
	TSp	Spring maximum temperature [6]				
	TSu	Summer maximum temperature [6]				
	TAu	Autumn maximum temperature [6]				
	TWi	Winter maximum temperature [6]				

[1] IGN (1999);
[2] US Geological Survey (1996);
[3] Shuttle Radar Topography Mission (SRTM), Farr and Kobrick (2000);
[4] ORNL (2001);
[5] IGN (1999);
[6] Agencia Estatal de Meteorología of Spain (AEMET), Ministerio de Medio Ambiente (http://www.aemet.es/es/elclima/cambio_climat/escenarios).

the model was assessed using the Wald test (Muñoz *et al*., 2005; table 1).

Finally, we obtained the projected climatic favourable areas of each species in the future by replacing current climatic values in the stepwise model with those expected according to each climate change scenario for each period (2011-2040, 2041-2071, 2071-2100, respectively), while values of the spatial, lithological, topographic and human variables were not modified. In this way, we obtain a future climatic favourability, but not the future distribution of the species (as this may also depend on changes on other factors).

Table 1 shows the variables that form part of each species model in the period 1961-1990. Both species are affected by climatic, topographical, spatial and human activity variables. Taking into account the Wald parameter, climate variables (mainly precipitation) are the fourth in order of importance, while variables related to other factors have more weight in the models (table 1). In particular, Montagu's harrier favourability was mostly related to longitude (increasing in the West) and slope (increasing in flatter areas). Hen harrier favourability was mostly related to latitude (being higher in Northern areas) and altitude (increasing in higher areas).

Figure 1 shows the predicted climatic favourability at each 10 x 10 km UTM square of mainland Spain for Montagu's and hen harriers according to the climatic model CGCM2-A2 and for each period. Maps obtained for the B2 emission scenario were very similar as those obtained for the A2 emission scenario. Both emission scenarios forecast a reduction in the area favourable for both

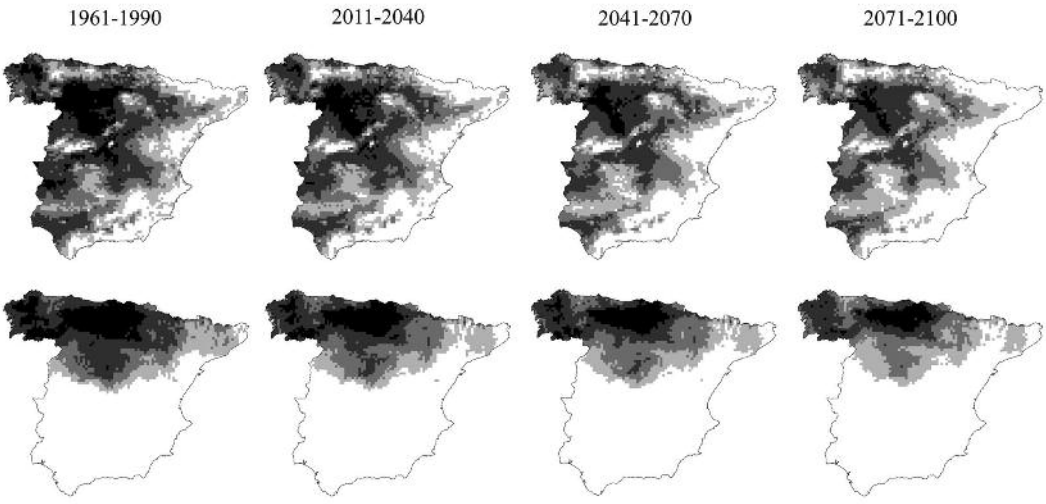

FIG. 1.—Favourability predicted at each 10 x 10 km UTM square of mainland Spain for Montagu's harrier (above) and hen harrier (below) according to the climatic model CGCM2-A2 and for each period. Black squares represent areas of higher favourability for the species, white squares represent unfavourable areas, and grey squares represent intermediate favourability areas.
[Favorabilidad predicha en cada cuadrícula UTM de 10 x 10 km de España peninsular para los aguiluchos cenizo (arriba) y pálido (abajo) según el modelo climático CGCM2-A2 y en cada periodo. Las cuadrículas en negro representan áreas de alta favorabilidad para las especies, mientras que las blancas representan áreas desfavorables y las grises valores intermedios.]

species during future periods. Specifically, if climate change scenarios are achieved, the model for the Montagu's harrier forecasted that high favourability areas for this species will be concentrated and reduced to Castilla y León, and in the case of hen harriers they will be concentrated in the Northern mountain areas.

It is important to remark that our models reflect favourability in relation to large-scale environmental variables. Thus, they have some limitations, and interpretation of results have to take these into account. Favourability values refer to environmental likelihood of presence, but not necessarily actual distribution or breeding density. In the case of the Montagu's harrier, the latter may be important, because this species is semi-colonial, and breeding density varies strongly among sites according to the degree of coloniality (Arroyo *et al*., 2004). Additionally, models of climatic favourability are insufficient to forecast the distribution of the species. Human variables and, in particular land use (which has not been taken into account and reflects availability of nesting habitats) are likely to change in the future and this may have strong effects on future distribution irrespectively of future climatic favourability for both species. However, our approach allows knowing the way in which climate may affect the species favourable areas, identifying trends and thus risks for the species.

Another limitation is related to the uncertainty of the climate scenario. There are more than 20 atmosphere-ocean global circulation models and 40 emission scenarios (Real *et al*., 2010) which forecast different temperature and precipitation data. We thus have to be conscious that our models represent just two of many possible change scenarios. Nevertheless, our results indicate that environmental favourability areas for both species are likely to decrease in the future, according to climate change predictions, which suggests that their conservation status may be more fragile than currently assessed (even in the absence of land use changes or a loss in breeding habitat availability or quality). Huntley *et al*. (2007) also forecasted a reduction in the potential distribution of both species at the end of the 21st century at a European scale, although in both cases, they forecasted a stronger range reduction within Spain than that obtained in this work (predicting, even, almost the extinction of hen harriers). Our study also ranks favourability areas, highlighting those that are particularly important for the species and where conservation programmes should be implemented.

In that context, it is noteworthy that regular conservation programmes of Montagu's harrier exist in many Spanish regions except in Castilla y León, despite being a highly favourable area both currently and in the future. In particular, very little is known about the ecology of this species in this area, which may be very influenced by the strong vole density variations experienced there in recent decades (Arroyo and García, 2008). It would be particularly important, given this, that monitoring programmes (potentially leading to conservation plans) are developed in this region.

The case of the hen harrier is also interesting, as this species increased its distribution markedly within Spain in recent decades, with current most favourable areas distributed throughout the whole of the Northern part of Spain. However, future favourability will be reduced to the past distribution of the species. It would be interesting to evaluate to what point the past distribution expansion was related to an improvement in the environmental conditions at the Southern limit of its distribution range.

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