Muntaner, J. y Mayol, J. (Eds.) 1996.
Biología y Conservación de las Rapaces Mediterráneas, 1994.
Monografías, nº 4. SEO, Madrid.

STATISTICAL MODEL OF NEST-SITE SELECTION FOR THE BEARDED VULTURE (*GYPAETUS BARBATUS*) IN THE PYRENEES AND EVALUATION OF THE HABITAT AVAILABLE WITH A GEOGRAPHICAL INFORMATION SYSTEM

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SUMMARY.-*Statistical model of nest-site selection for the Bearded Vulture* (Gypaetus barbatus) *in the Pyrenees and evaluation of the habitat available with a geographical information system.* In a study carried out in the Pyrenees comparing Bearded Vulture (*Gypaetus barbatus*) nesting cliffs versus cliffs selected at random Donázar *et al.* (1993) proved that topographic irregularity, distance to other breeding pairs, altitude, and distance to inhabited villages were important variables in the selection of nesting sites.

In this work we explore the possibility of using 1.1,000,000-scale digital information derived from the Digital Chart of the World (DCW) to make spatial predictions from this statistical model. First we obtained digital covers on the 1:1,000,000 scale for the variables of interest (altitude, slope and distance to the nearest village) in the Pyrenees. We estimated the values of the variables for each cliff on the new scale and refitted the model. We estimated the distribution of the adequate nesting habitat in the Pyrenees in a 1:1,000,000 scale with a Geographical Information System (GIS).

This new model was used to extrapolate predictions on the distribution of adequate nesting habitat for the Bearded Vulture in the Alps, testing the predictions with the information on the location of old nesting sites in the canton of Grisons (Switzerland).

The results show the possibilities derived from integrating a statistical model with a GIS to make spatial predictions. Due to the low predictive ability of the Bearded Vulture nest-site selection model on a 1,000,000 scale we suggest that future research on the species is addressed at smaller scales.

Key words: Bearded Vulture, *Gypaetus barbatus*, Pyrenees, Statistical Model of Selection, nest-site, habitat, Geografical Information System (GLIS), Generalized Linear Models (GLM).

RESUMEN.-*Modelo estadístico de selección del enclave de nidificación del Quebrantahuesos* (Gypaetus barbatus) *en los Pirineos y evaluación del hábitat disponible mediante un Sistema de Información Geográfica.* En un estudio realizado en los Pirineos en él que se compararon los cortados seleccionados por Quebrantahuesos (*Gypaetus barbatus*) para nidificar frente a otros cortados seleccionados al azar Donázar *et al.* (1993), se demostraron la importancia de la irregularidad topográfica, distancia a otras parejas, la altitud y la distancia a pueblos en la selección del cortado de nidificación.

En este trabajo se explora la posibilidad de utilizar información geográfica digital a escala 1:1.000.000 derivada de la Digital Chart of the World (DCW) para realizar predicciones espaciales derivadas del modelo. Primero se obtuvieron coberturas digitales a

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escala 1:1.000.000 para las variables de interés en los Pirineos (altitud, pendiente y distancia a pueblos), se recalcularon los valores de las variables predictoras a esta nueva escala y se reajustaron los parámetros del modelo. Mediante un Sistema de Información Geográfica se calculó la extensión geográfica y distribución del hábitat disponible en la cadena Pirenaica a escala 1:1.000.000.

Este nuevo modelo se utilizó para extrapolar las predicciones sobre la distribución espacial y extensión del hábitat de nidificación del Quebrantahuesos a los Alpes y se evaluaron los resultados mediante la información histórica sobre la distribución de antiguos nidos en el cantón de Grisons (Suiza).

Los resultados muestran la posibilidad de compaginar un modelo estadístico con un Sistema de Información Geográfica para realizar predicciones espaciales. Debido a la baja capacidad predictiva del modelo de selección de enclave de nidificación del Quebrantahuesos a escala 1:1.000.000 parece aconsejable que los estudios futuros se realicen a escalas menores.

Palabras clave: Quebrantahuesos, *Gypaetus barbatus*, Pirineos, Modelo Estadístico de Selección, enclave de nidificación, hábitat, Sistema de Información Geográfica (SIG), Modelos Lineales Generalizables (GLM).

INTRODUCTION

The Bearded Vulture (*Gypaetus barbatus*) is a cliff-nesting accipitrid vulture inhabiting Old World mountain ranges and feeding on bones (Hiraldo *et al.*, 1979; Brown, 1988; Brown & Plug, 1990). After a dramatic reduction in its range during the XIX and XX centuries, its distribution in Europe has been restricted to the Pyrenees, Southern Balkans and the islands of Corsica and Crete (Hiraldo *et al.*, 1979).

The factors that influence nest-site selection, breeding density and breeding success of the Bearded Vulture in the Pyrenees were studied by Donázar *et al.* (1993) by means of statistical models of environmental factors measured on 1:50.000 maps. The nest-site selection model obtained indicated that the Bearded Vulture selects cliffs in rugged areas, at an average altitude, far from other breeding pairs and far from villages. With a Geographical Information Sytem (GIS) we could make spatial predictions derived from this statistical model provided we had digital information for all the relevant variables at the 1:50,000 scale. The predictive map derived from this model would allow scientists and technicians with knowledge of the ecology and distribution of the species in the area, even if unfamiliar with statistics, to evaluate the performance of the model. Provided that the model had a high predictive ability, the maps derived from it could be used to help in the management of the species.

In this study we tested if the digital information provided by the Digital Chart of the World (DCW) at a 1:1,000,000 scale, could be used to generate predictive maps of nesting habitat available for the Bearded Vulture by means of a Geographical Information System (GIS). Initially we tested if the 1:50,000-scale model could be translated to a 1:1,000,000-scale model, and how much of the predictive ability of was maintained. Then we tested if the model could be extrapolated to other areas like the Alps and we tried to use historical nest sites in the canton of Grisons in Switzerland to validate the results.

MATERIAL AND METHODS

The Digital Chart of the World (DCW) is a comprehensive 1:1,000,000-scale vector map of the world elaborated by The Environmental Systems Research Institute, INC. (ESRI), and based primarily on the Operational Navigation Charts (ONC).

A GIS was developed for two study areas the Pyrenees and the Alps. Vector coverages of hypsography at a scale of 1:1,000,000 from the DCW containing 300-m contours and altitude points (HYNET, HYPOINT, HSLINE and HSPOINT) were converted to a vector format compatible with the GIS software IDRISI (Clark University, USA). Initial DCW vector maps in Lambert Conformal projection were projected to the Universal Transverse Mercator projection (zone 30 North for the Pyrenees, and zone 32 North for the Alps), WGS84 datum, with the PROJECT module of IDRISI. Altitude contour lines and altitude points were rasterized in 500-m grid cells and a Digital Elevation Model (DEM) was interpolated using the INTERCON module. The inital DEM was filtered with a mean filter and contracted to 1-km grid cells. A slope map (%) with the same resolution was calculated from the 1-km DEM with the SURFACE module. The vector maps with the location of populated places (PPPOINT) and the polygons defining urbanized areas (PPPOLY) were rasterized in 500 m grid cells. A distance map to the nearest populated area (m) was calculated with the DISTANCE module. The distance map obtained was contracted to a 1-km resolution grid.

The initial statistical model of nest-site selection developed by Donazar *et al.* (1993) was calculated comparing 111 cliffs were Bearded Vultures had nested in the southern slopes of the Pyrenees with another 111 cliffs were the species had not nested, selected at random in the same area. Thirteen explanatory variables representing physiography, land-use and degree of human disturbance were measured for each cliff on 1:50,000 topographic and land-use maps. We fitted each of the explanatory variables in turns to the response variable (the presence or absence of a Bearded Vulture nest) using a generalized linear model (GLM) with a binomial error and a logistic link function with the statistical program GLIM (Baker, 1987). Only statistical significant variables were retained in the model and the best model was built using a modification of a forward stepwise procedure. More details of the model development, statistical analysis and statistical validation of the models are given in Donázar *et al.* (1993).

To translate the initial model to a 1:1,000,000 scale we obtained the UTM coordinates of nest sites and random points from the previous work with 100-m precision from 1:50,000 topographic maps. The points were digitized and information for the 1-km grid cell in which they were included was extrated from the GIS coverages for altitude, slope and log of distance to a the nearest village. Initially a the same model obtained by Donázar *et al.* (1993), excluding distance to the nearest neighbouring breeding pair, was fitted to the data, using the estimates obtained from the GIS. Distance to the nearest breeding pair was excluded because we were interested in model of potential nesting habitat independent on the presence or absence of the species. The model included a quadratic response to altitude, a positive linear response to slope and and a positive linear response to log distance from the nearest village. The statistical significance of each variable was assesed in turns by stepwise backward elimination from the initial model.

A new variable that could be estimated in the GIS, altitudinal difference with the valley (m), which we thought could be a better predictor than altitude above sea level alone, was tested for improvement of both the null model and the final model, with and without altitude. This new variable was estimated by considering as 'valley' all grid cells crossed by a river or lake (DNNET coverage from the DCW). The difference in altitude with the valley was estimated for each cell as the difference in altitude with the nearest grid cell classified as 'valley'. Altitudinal difference with the valley was cero for grid cells classified as 'valley'.

We also tested if the initial relief index, measured in 1:50,000-scale maps could significantly improve the models in which slope, measured in the GIS, had been included.

Predictive maps were calculated by the GIS as the probability each 1-km grid cell had of holding a nest site based on its altitude and slope (assuming that cliffs and neighbouring breeding pairs were not limiting factors).

To test if the model could be extrapolated to other European mountains we selected the canton of Grisons in the Swiss Alps, where the geographical location of records of Bearded Vultures in the XIX century was available. We digitized the approximate location of 11 nest sites known between 1800 and 1884 (O. Lardi, unpub. data) and selected 16 stratified random coordinates in the same area. The precise location of most nest sites was not known but it was assumed that they had been in a 5-km radius of the selected coordinate (J. P. Müller pers. comm.). We obtained the maximum predicted probability in a 5-km radius from the 11 historical nest sites and compared it with the maximum predicted probability in a 5-km radius from the random points.

RESULTS

From the initial 111 Bearded Vulture nest sites from the Pyrenees only 77 were more than 1 km apart and could provide independent estimates of the predictive variables. We fitted a full GLM model with binomial errors and a logistic link to the 77 nest sites and 111 random points using as predictive variables the altitude above sea level (m), the slope (%) and the log of the distance from the nearest inhabited village (m) as measured in the 1-km grid cells from the GIS. Stepwise backward elimination of each variable proved that log distance from the nearest village had no significant effect in the model (Increase in Scaled Deviance = 0.01, df = 1, ns). The elimination of slope (ISD = 14.50, df = 1, $P < 0.001$), altitude (ISD = 17.0, df = 2, $P < 0.001$), or the simplification of the quadratic function of altitude to a linear one (ISD = 13.42, df = 1, $P < 0.001$) produced a significant increase in the Scaled Deviance of the model. So, the final model included an quadratic response to altitude and a linear positive response to slope (Table 1).

Considering those points with a probability > 0.5 as nest sites this model classified correctly 67.6 % of the 188 points (50.6 % of nest sites and 79.2 % of random points). The classification was 30 % better than chance (kappa = 0.3095, Z = 4.26, $P < 0.0001$) (Titus *et al.*, 1984).

The variable 'difference in altitude with the valley' did not improve significantly the final model, neither when a linear (ISD = -0.00, df = 1, ns) nor when a quadratic function (ISD = -1.70, df = 2, ns) was tested. We also tested the inclusion of this variable in a null model or in a model with slope only, but neither were significant.

The relief index measured by Donázar *et al.* (1993) in a 1:50,000 scale (number of 20-m contours crossed by four 1-km lines starting from the nest in directions

TABLE 1

GLM model for nest-site selection of the Bearded Vulture in the Pyrenees, using binomial error and logistic link, with variables measured in a 1-km grid of a 1:1,000,000-scale GIS. (*Modelo GLM para selección de enclave de nidificación del Quebrantahuesos en los Pirineos, con una distribución binomial del error y una función de enlace logística. Las variables se midieron sobre cuadrícula d 1 km en un Sistema de Información Geográfica en raster a escala 1:1,000.000.*)

	Parameter estimate	Standar error
Constant	-5.927	1.700
SLOPE	0.07628	0.02133
ALTITUDE	0.007779	0.002583
$(ALTITUDE)^2$	-3.007E-06	9.134E-07
Residual deviance	222.33	
df	184	

N,S,E and W) significantly improved the final model (ISD = -13.59, df = 1, $P <$ 0.001). If this variable was included the variable slope was no longer significant (ISD = 2.61, df = 1, ns).

The spatial predictions for the Pyrenees derived from the final model are shown in figure 1. The same model was applied to the GIS of the Alps, and the spatial predictions for the canton of Grisons are presented in figure 2. When the geographical location of historial records of Bearded Vulture in the canton of Grisons (records of observations, birds shot and nest sites) is overlayed it can be seen that a great majority of them fall on high probability areas according to the model. However, There are no significant differences between the maximun probability in a 5-km radius circle arround the 11 historial nest sites and a 5-km circle around random points (Nest site median = 0.707, Random point median = 0.82, Man-Whitney test, U = 86.0, ns).

DISCUSSION

The statistical model of nest-site selection for the Bearded Vulture developed by Donázar *et al.* (1993) can be translated from a 1:50,000 to a 1:1,000,000 scale. Although the new model is statistically significant, it looses aproximately 25% of its predictive ability when compared to the old one. The classification of the new model is only 30% better than chance while that of the old model was 56% better (Donázar *et al.*, 1993).

As the old model, the new one indicates that the Bearded Vulture prefers to nest at intermediate altitudes and in rugged areas. We did not find a significant relation with distance from the nearest village, probably because the Bearded Vulture only avoids cliffs very close to villages (< 2km) and the DCW only included an eclectic selection of the villages recorded on 1:50,000 topographic maps. Most cliffs were further from villages according to the GIS developped from the DCW than they actually were according to 1:50,000 topographic maps.

Although we thought initially that the effect of altitude in the model could be due to the Bearded Vulture avoiding cliffs that were high in relation to the average altitude of the home range, the variable 'difference in altitude with the nearest valley' had no significant relation with nest-site selection in the Bearded Vulture. This suggest that there may be climatic reasons for the Bearded Vultures selecting intermediate altitudes.

The fact that the relief index measured on a 1:50.000 scale significantly improved the final model indicates that valuable information about the relief had been lost with the change in scale. This, probably together with the lack of enough information on the location of inhabited villages in the GIS, explains the lower predictive ability of the new model.

One should consider with caution the spatial predictions derived from the model (Fig. 1). First the predictive ability of the model, although statistically significant, is low. Second it only makes predictions of availability of adequate nesting sites, assuming that cliffs are present in the 1-km grid cell and that there are no other Bearded Vulture breeding pairs in the neighbourhood (< 8km). Third, the model also assumes that other factors like food availability or climate are not limiting.

The extrapolation of the model to the canton of Grisons in the Alps, although promising, is still very rough. Recorded observations of Bearded Vultures in

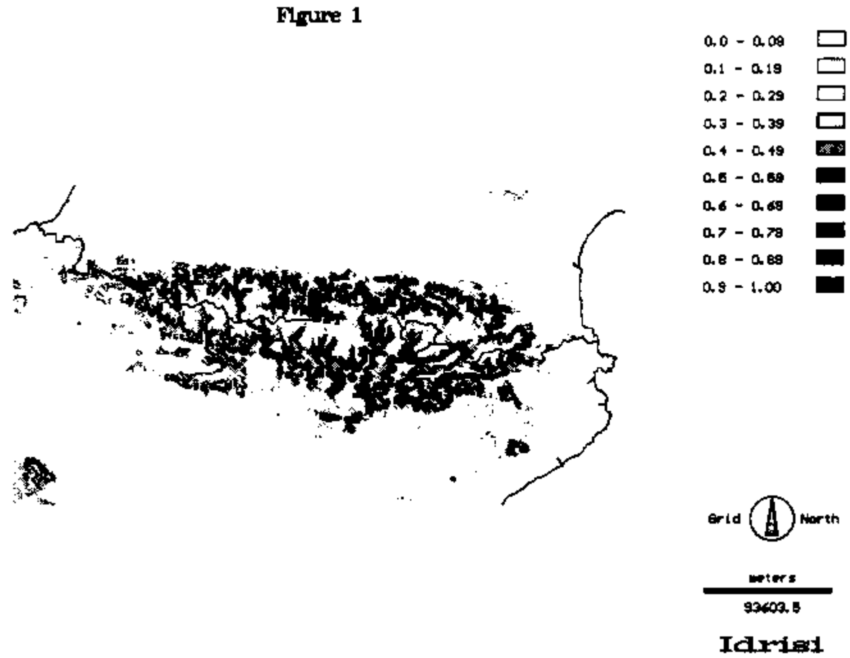

FIGURE 1.- Probability map of the distribution of adequate nesting sites for the Bearded Vulture in the Pyrenees. The estimates are for 1-km grid cells and the model assumes that availability of cliffs and proximity to other breeding pairs are not limiting factors.
[Mapa de probabilidad de la distribución de lugares adecuados para la nidificación del Quebrantahuesos en los Pirineos. Las estimas son para cuadrículas 1 km de lado, y el modelo asume que la disponibilidad de cortados y la proximidad a otras parejas reproductoras no actuan como factores limitantes].

the XIX century tend to concentrate close to areas of high probability according to the model. Unfortunately only few old nest sites are known, and in most instances the location is not known precisely enough. All this makes that the recorded locations of historic nest sites do not differ statistically from random points according to our model.

CONCLUSIONS

The idea of this contribution was to show how the combination of statistical models and a GIS can be used to generate spatial predictions. The interest of the maps generated in this way is that they give the predictions of the statistical model in a way that is clearer and easier to interpret. The conclusions particular to the Bearded Vulture nest-site selection model is that the spatial predictions

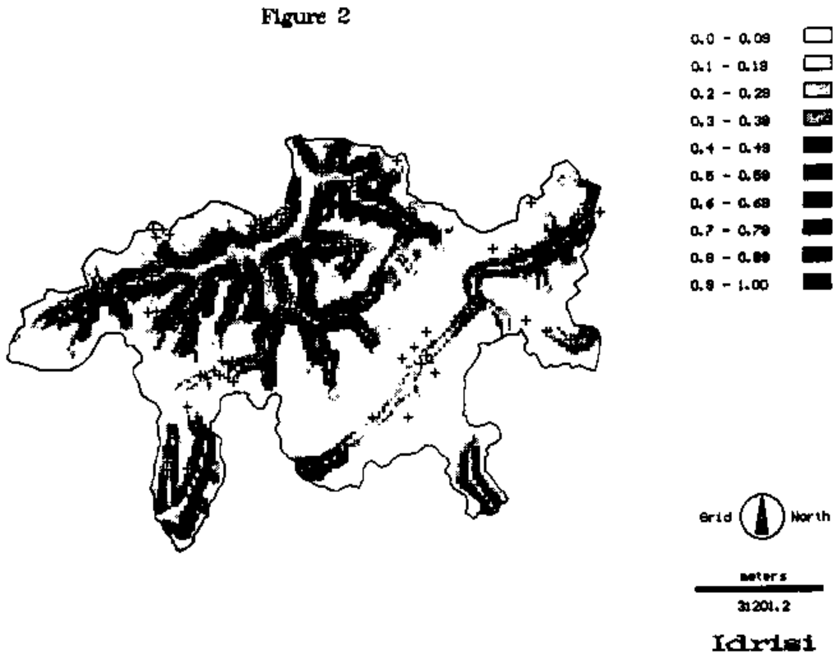

FIGURE 2.- Probability map of the distribution of adequate nesting sites for the Bearded Vulture in the canton of Grisons (Switzerland). The estimates are for 1-km grid cells and the model assumes that availability of cliffs and proximity to other breeding pairs are not limiting factors. Overlayed -red crosses-are historical Bearded Vulture records (1800-1884) for the area according to O. Lardi ("unpub. data").
[Mapa de probabilidad de la distribución de lugares adecuados para la nificación del Quebrantahuesos en el cantón de Grisons (Suiza). Las estimas son para cuadrículas de 1 km de lado, y el modelo asume que la disponibilidad de cortados y la proximidad a otras parejas reproductoras no actuan como factores limitantes. Las cruces rojas indican la localización de citas históricas para la especie en el área entre 1800 y 1884 (O. Lardi, datos sin publicar)].

obtained from a model at a 1:1,000,000 scale are still very rough to be used for management purposes. The next step would be to obtain digital information at smaller scales, refit the models and test the predictions. It is dificult to answer if the models could be extrapolated to other areas. Unfortunately the information of old nesting sites in the Alps is not detailed enough. Probably an alternative would be to test the predictions of the models with information of nest sites in other mountain ranges where the species still breeds and it is possible to obtain bigger samples of nest sites.

AKNOWLEDGMENTS: J. P. Müller kindly provided an unpublished study (O. Lardi "unpub. data") of historical records of Bearded Vultures in the canton of Grisons, and gave extra information on the reliability of the geographical locations of the records. R. Bögel and W. D'Oleire-Oltmanns provided the clips of the Pyrenees and the Alps from the DCW and helped in the difficult task of exporting them to IDRISI. Y. Menor de Gaspar measured UTM coordinates for nest sites and random points from the maps.

BIBLIOGRAPHY

BAKER, R.J. 1987. *GLIM 3.77 reference manual*. Numerical Algorithms Group. Oxford.

BROWN, C.J. 1988. *A study of the Bearded Vulture* Gypaetus barbatus *in southern Africa*. Ph.D. Thesis, Universidad de Natal. Pietermaritzburg.

BROWN, C.J. & PLUG, I. 1990. Food choice and diet of the Bearded Vulture *Gypaetus barbatus* in southern Africa. *South African Journal of Zoology*, 25: 169-177.

DONÁZAR, J.A., HIRALDO, F. & BUSTAMANTE, J. 1993. Factors influencing nest site selection, breeding density and breeding success in the Bearded Vulture (*Gypaetus barbatus*). *Journal of Applied Ecology*, 30: 504-514.

HIRALDO, F., DELIBES, M. & CALDERÓN, J. 1979. *El Quebrantahuesos* Gypaetus barbatus *(L.)*. Monografías. 22. ICONA. Madrid.

TITUS, K., MOSHER, J.A. & WILLIAMS, B.K. 1984. Chance-corrected classification for use in discriminant analysis: ecological applications. *American Midland Naturalist*, 111: 1-7.