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MODELING HABITAT USE AND DISTRIBUTION OF HEN HARRIERS (*CIRCUS CYANEUS*) AND MONTAGU'S HARRIER (*CIRCUS PYGARGUS*) IN A MOUNTAINOUS AREA IN GALICIA, NORTHWESTERN SPAIN

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ABSTRACT.—To evaluate the effect of habitat characteristics on the sympatric populations of Hen Harriers (*Circus cyaneus*) and Montagu's Harriers (*Circus pygargus*), we have developed predictive models (logistic regression) for the presence/absence and distribution of harriers in the Site of Community Importance Baixa-Limia, northwestern Spain. We have used habitat and topographical variables measured on digital 1:50 000-scale cartography. We have developed spatial prediction on suitable habitat availability for harriers by means of Geographical Information System Analysis of 2 × 2 km plots. The final models explained 11% of the variance for Hen Harrier, 18% of the variance for the Montagu's Harrier, and 12% of the variance for both species simultaneously. Altitude was a variable that influenced the presence of both harrier species, which were more common over 800 m. The presence of Montagu's Harrier in a plot was positively associated with the presence of gradual relief of Atlantic heathland. The most important threats to harrier populations are human infrastructures (e.g., roads, tracks), proliferation of human activities such as afforestation and intense deliberate wild-fires that change the habitat conditions for both species.

KEY WORDS: *Hen Harrier*, Circus cyaneus; *Montagu's Harrier*, Circus pygargus; *habitat use*, *modeling*, *Spain.*

MODELIZACIÓN DEL USO DEL HÁBITAT Y DISTRIBUCIÓN DEL AGUILUCHO PÁLIDO (*CIRCUS CYANEUS*) Y AGUILUCHO CENIZO (*CIRCUS PYGARGUS*) EN UN ÁREA MONTAÑOSA DE GALICIA (NO ESPAÑA)

RESUMEN.—Con el objetivo de evaluar el efecto de las características del hábitat sobre poblaciones simpátridas de aguilucho pálido (*Circus cyaneus*) y aguilucho cenizo (*Circus pygargus*), desarrollamos modelos estadísticos predictivos (Análisis de Regresión Logística) para la presencia/ausencia y distribución de los aguiluchos en el LIC (Lugar de Interés Comunitario) Baixa-Limia (NO España). Usamos variables ambientales medidas sobre cartografía digital a escala 1:50 000, utilizando un Sistema de Información Geográfica con la retícula de 2 × 2 km. Los modelos finales explicaron un 11% de la varianza para el aguilucho pálido, un 18% para el aguilucho cenizo y un 12% para ambas especies simultáneamente. La altitud fue un factor que influyó en la presencia de ambas especies, siempre por encima de 800 m. La presencia de aguilucho cenizo en una cuadrícula se relacionó positivamente con la presencia de áreas con relieve suave de brezal atlántico. Las amenazas más importantes son infraestructuras como carreteras y pistas de tierra, repoblaciones y grandes incendios forestales intencionados, modificadores de las condiciones del hábitat de ambas especies.

[Traducción de los autores]

Determination of the variables that influence the distribution of species has been one of the most important objectives of ecology (Cody 1985, Wiens 1989). Studies of habitat selection have traditionally analyzed the relations of one species relative to the characteristics of its habitat; often leading to the development of predictive models

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(Morrison et al. 1998). These models are particularly important in efforts to preserve threatened species, as for example in the case of some Iberian raptor species (e.g., Donázar et al. 1993, Gil-Sánchez et al. 1996, Bustamante 1997, Sánchez-Zapata and Calvo 1999), even though they are not exempt from severe limitations (Fielding and Haworth 1995, Beutel et al. 1999, Seoane and Bustamante 2001). Raptors are usually highly selective with regard to their habitat, especially regarding the availability of suitable areas for breeding and hunting (Janes 1985).

The spatial scale involved is important to understanding the implications and limitations of predictive models (e.g., Litvaitis et al. 1994, Pribil and Picman 1997, Rotenberry and Knick 1999, Mitchell et al. 2001). In this respect, the models on scales similar to or greater than the home range seem to establish relations amongst raptors with regard to the selection of macrohabitat and associations with ecosystem mosaics (Sánchez-Zapata and Calvo 1999, Rico-Alcázar et al. 2001).

The Hen Harrier (*Circus cyaneus*) and the Montagu's Harrier (*Circus pygargus*) have declining populations in Europe (Tucker and Evans 1997). On the Iberian peninsula, these harriers usually use cereal crop lands as nesting habitat (Ferrero 1996), even though in the northwestern part of the peninsula they usually breed in areas of natural vegetation (Pinilla et al. 1994, Vázquez-Pumariño 1995, Ferrero 1996). Studies of habitat selection and predictive modeling for these species are scarce, both for the European continent and in the Iberian peninsula (Salamolard 1997, Martínez et al. 1999, Madders 2000). In Galicia (northwestern Spain), both harrier species are sympatric, occurring in an area dominated by Atlantic-heathland shrubs.

The objective of the present study was to establish models of habitat selection using the information obtained from an atlas of nesting birds. The atlases of the distribution of species are very limited with respect to the information they provide (Donald and Fuller 1998, Sutherland 2000), but they may be used as a very important source of information to create predictive models of distribution for different species of vertebrates (e.g., Osborne and Tigar 1992, Jaber and Guisan 2001, Rojas et al. 2001). These models will become a tool which will contribute to the management of a protected area relating to two high priority species included in Annex I of the Birds Directive 79/409/79 European Economic Community. Annex I lists species of birds in Europe which are of priority for habitat conservation (Tucker and Evans 1997).

STUDY AREA AND METHODS

The study area is 40 000 ha, the majority of which (34 627 ha) is the Site of Community Importance (SCI) Baixa Limia. It extends along the southwestern sierras of the province of Ourense, bordering the National Portuguese Park of Peneda-Gerês (Fig. 1). Both protected areas, the Spanish and the Portuguese, cover in total an area of 106 627 ha.

It is a mountain range of medium altitude, with summits of up to 1500 m, comprised predominantly of granite rocks. Currently, human population in the area is quite low, even though the landscape has been intensely affected by human actions. From the climatic point of view, this area has a temperate sub-Mediterranean oceanic climate of 8–12°C, with an annual precipitation of 1200–1600 mm, and a significant water shortage in the summer (Martínez- Cortizas and Pérez-Alberti 1999). The most common types of vegetation are the shrub communities (*Ulex* sp., *Chamaespartium tridentatum, Erica* sp., *Genista* sp., and *Cytisus* sp.), which constitute the greatest percentage of vegetation. Woods are very fragmented, and are dominated by oaks (*Quercus robur, Q. pyrenaica*) and pines (*Pinus pinaster, P. sylvestris*). All plant communities in the study area are impacted by frequent deliberate fires, sometimes affecting large areas.

The harrier's distribution in the study area was obtained from field work carried out in the spring seasons, 1997–2000. This work consisted of systematic surveys throughout the study area, although the entire study area was only covered in spring 2000 considering the sampling effort necessary for the detection of harrier species (Pinilla and Arroyo 1995). Evidence of occupancy by a nesting harrier included: a nest containing eggs or young, adults seen carrying food, and hearing the begging calls of young birds (Bibby et al. 1992). With the help of Global Positioning System (GPS), all the observations were located in the corresponding 1 × 1 km square (maps 1: 25 000). This sampling was carried out with the aim of completing an atlas for breeding harriers.

Harrier's presence for any breeding category was the dependent variable used in the analysis (Hagemeijer and Blair 1997). Breeding categories included: possible breeding (harriers observed in potential nesting habitat), probable nesting (pair observed in suitable nesting habitat, courtship, display, or nest building) and confirmed breeding (nest contained eggs or young) (Hagemeijer and Blair 1997). Presence was obtained from the final distribution atlas, derived from cumulative observed data for the 1997–2000 period. Atlas data indicated that the local Montagu's Harrier population in Baixa-Limia was 15–20 pairs, and the Hen Harrier population was 8–10 pairs.

For the analysis of habitat selection a 2 × 2 km grid was used, integrating the information obtained in the 1 × 1 km squares. The 2 × 2 km squares which had less than 50% of their surfaces within the limits of the SCI or more than 50% in Portugal were discounted. For analysis we used the 2 × 2 km grid, due to the low proportion of grid squares in which harriers were present based on a 1 × 1 km grid, and also because the cartography used

Figure 1. Study site (*Baixa Limia*) in Galicia (northwestern Iberian peninsula).

lost resolution at small scales (Sánchez-Zapata 1999, Zuberogoitia 2002).

The independent variables were selected because they represented different uses of the land, degree of humanization, topographic irregularity, and habitat heterogeneity (Table 1), and values for each variable were assumed for each 2 × 2 plot studied. The information relating to the different environmental variables was taken from 1:50 000 digital cartography via a Geographic Information System (GIS-ArcView 3.1, Environmental Systems Research Institute, Inc., Redlands, CA U.S.A.). The digital cartography used had a resolution of 250 × 250 m.

Continuous variables (i.e., slope and altitude) were obtained from analysis of the variable of each square using a digital elevation model with a resolution of 250 ×

Table 1. Independent variables included in the logistic regression for the habitat models of Hen Harrier and Montagu's Harrier in the Site of Community Importance Baixa-Limia.

LABEL	DESCRIPTION OF THE VARIABLE
No. settlements	Number of human settlements
Area of settlements	Area of human settlements
Road length (m)	Length of paved roads
Min. altitude (m)	Minimum altitude
Max. altitude (m)	Maximum altitude
Max.-min. altitude (m)	Maximum altitude-minimum altitude
Mean altitude (m)	Average altitude
Min. slope (grades)	Minimum slope
Max. slope (grades)	Maximum slope
Max.-min. slope (grades)	Maximum slope-minimum slope
Mean slope (grades)	Average slope
Scrub-pasture area (km^2)	Area of scrubland and pastureland
Forest area (km^2)	Area of forests
Dam area (km^2)	Area of dams
Scrub-forest edge (m)	Meters of edge between scrubland-forests
Scrub-dam edge (m)	Meters of edge between scrubland-dam
Forest-dam edge (m)	Meters of edge between forest-dam

250 m. The remaining variables were obtained directly with GIS using vectorial data. Scrubland and pasture surfaces are often intermixed. They were treated as one cover type because they could not be distinguished at the spatial resolution used. All forest types were also treated as the same variable independent of their tree species composition. Forests and scrubland-pastures represented close to 90% of the total study area.

A Mann-Whitney *U*-test was used to establish which variables were significantly different between plots in which both species (independently) were present or absent. Those variables that showed significant differences were included in the stepwise-logistic regression analysis (Jovell 1995). The significance of the variables included in the final regression model was determined by the Wald test (Jovell 1995). The level of significance used was $P < 0.05$. We used SPSS package (SPSS 11, McGraw-Hill, Madrid, Spain) for statistical analysis.

RESULTS

Within the study area, the Hen Harrier was detected in 62 1-km^2 plots of 397 (15.6%) and in 32 4-km^2 squares of 93 (34.4%). With regard to the Montagu's Harrier, its presence was detected in 123 1-km^2 plots (31%), and in 60 4-km^2 plots of 2 × 2 km (64%). Both species were detected in 31 1-km^2 (7.8%), and in 27 4-km^2 plots (29%).

At the 4-km^2 plot scale, the areas occupied by the Hen Harrier differed from the unoccupied ones in that the former had fewer human settlements. Hen Harrier plots were located at higher altitudes and on more gradual slopes than unoccupied squares (Table 2). For the Montagu's Harrier, occupied plots had a greater extent of scrubland and were located significantly higher than unoccupied squares (Table 3), although they were rarely present above 1000 m above sea level.

Considering both species simultaneously, the areas occupied differed from the unoccupied ones in that the former had fewer human settlements. Also, occupied plots were located at greater altitude and more gradual slopes than the unoccupied squares (Table 4).

The analysis of logistic regression only included the variables of minimum altitude for both species and scrubland and pastureland area for the Montagu's Harrier; both related positively to occupancy. For both species simultaneously, the model included minimum altitude related positively to occupancy (Table 5).

The final model developed for the Hen Harrier was: occupancy $= 1/1 + e^{2.812-0.003(\text{min altitude})}$, and explained 11% of the variance. The overall correct classification was 65.6%. The final model developed for the Montagu's Harrier was: occupancy $= 1/1 + e^{2.818-4.96\times10-7(\text{Scrub and pasture area})-0.003(\text{min altitude})}$, explained 18% of the variance. The overall correct classification was 64.5%.

The final model developed for both species simultaneously was: occupancy $= 1/1 + e^{3.359-0.003(\text{min altitude})}$, explained 12% of the variance. The overall correct classification was 71%.

Table 2. Comparison of mean values of variables, using Mann-Whitney tests, in 2 × 2 km plots occupied and unoccupied by Hen Harrier in the Site of Community Importance Baixa-Limia (Mean ± SD).

LABEL	OCCUPIED SQUARES 2 × 2 km ($N = 32$)	UNOCCUPIED SQUARES 2 × 2 km ($N = 61$)	U	P
No. settlements	0.1563 ± 0.5741	0.4262 ± 0.8054	782.0	0.031*
Area of settlements	6073 ± 26 763	24 440 ± 52 130	774.5	0.026*
Road length (m)	374 ± 737	887 ± 1314	812.0	0.131
Min. altitude (m)	831 ± 176	695 ± 244	606.0	0.003**
Max. altitude (m)	1165 ± 131	1077 ± 228	707.0	0.030*
Max.-min. altitude (m)	334 ± 120	381 ± 138	732.0	0.048*
Mean altitude (m)	1009 ± 151	889 ± 243	651.0	0.009**
Min. slope (grades)	0.24 ± 0.17	0.31 ± 0.23	826.5	0.227
Max. slope (grades)	32.36 ± 7.47	35.27 ± 9.94	756.5	0.076
Max.-min. slope (grades)	33.11 ± 7.38	34.95 ± 9.9	768.0	0.093
Mean slope (grades)	9.47 ± 3.31	10.93 ± 3.67	681.5	0.017*
Scrub-pasture area (km^2)	2.94 ± 0.92	2.63 ± 0.95	785.5	0.131
Forest area (km^2)	0.75 ± 0.80	0.92 ± 0.87	876.0	0.419
Dam area (km^2)	0.03 ± 0.13	0.12 ± 0.42	909.0	0.314
Scrub-forest edge (m)	10 978 ± 7518	11 731 ± 9073	953.5	0.856
Scrub-dam edge (m)	110 ± 538	488 ± 1496	919.0	0.369
Forest-dam edge (m)	37 ± 212	123 ± 447	895.0	0.178

* Significantly different at $P < 0.05$.
** Significantly different at $P < 0.01$.

Table 3. Comparison of mean values of variables, using Mann-Whitney tests, in 2 × 2 km plots occupied and unoccupied by Montagu's Harrier in the Site of Community Importance Baixa-Limia (Mean ± SD).

LABEL	OCCUPIED SQUARES 2 × 2 ($N = 60$)	UNOCCUPIED SQUARES 2 × 2 ($N = 33$)	U	P
No. settlements	0.2667 ± 0.7334	0.4545 ± 0.7538	828.5	0.075
Area of settlements	14 055 ± 39 823	25 510 ± 54 765	827.0	0.074
Road length (m)	571 ± 1056	964 ± 1334	844.0	0.181
Min. altitude (m)	793 ± 212	650 ± 238	654.0	0.007**
Max. altitude (m)	1145 ± 176	1039 ± 234	746.0	0.050*
Max.-min. altitude (m)	352 ± 134	389 ± 130	820.0	0.172
Mean altitude (m)	978 ± 198	844 ± 241	683.0	0.014*
Min. slope (grades)	0.28 ± 0.22	0.31 ± 0.21	880.5	0.379
Max. slope (grades)	33.33 ± 10.04	35.97 ± 7.35	799.0	0.125
Max.-min. slope (grades)	33.05 ± 9.98	35.66 ± 7.33	802.5	0.132
Mean slope (grades)	10.02 ± 3.70	11.17 ± 3.34	803.5	0.134
Scrub-pasture area (km^2)	2.89 ± 0.90	2.46 ± 0.99	701.0	0.020*
Forest area (km^2)	0.79 ± 0.79	1.0 ± 0.94	836.0	0.216
Dam area (km^2)	0.08 ± 0.33	0.11 ± 0.4	969.0	0.754
Scrub-forest edge (m)	11 002 ± 8227	12 326 ± 9139	908.0	0.510
Scrub-dam edge (m)	296 ± 1122	471 ± 1494	951.0	0.547
Forest-dam edge (m)	69 ± 271	139 ± 534	979.0	0.856

* Significantly different at $P < 0.05$.
** Significantly different at $P < 0.01$.

Table 4. Comparison of mean values of variables, using Mann-Whitney test, in 2 × 2 km plots occupied and unoccupied by both species simultaneously in the Site of Community Importance Baixa-Limia (Mean ± SD).

LABEL	OCCUPIED SQUARES 2 × 2 ($N = 27$)	UNOCCUPIED SQUARES 2 × 2 ($N = 66$)	U	P
No. settlements	0.1481 ± 0.6015	0.4091 ± 0.7840	706.0	0.032*
Area of settlements	7074 ± 29 103	22 639 ± 50 485	703.5	0.030*
Road length (m)	432 ± 790	825 ± 1282	785.0	0.307
Min. altitude (m)	847 ± 178	699 ± 237	515.0	0.001**
Max. altitude (m)	1164 ± 139	1084 ± 222	660.0	0.051
Max.-min. altitude (m)	317 ± 118	384 ± 135	581.0	0.009**
Mean altitude (m)	1016 ± 155	895 ± 236	582.0	0.009**
Min. slope (grades)	0.22 ± 0.16	0.32 ± 0.23	664.5	0.055
Max. slope (grades)	31.19 ± 7.21	35.53 ± 9.7	600.5	0.014*
Max.-min. slope (grades)	30.97 ± 7.15	35.20 ± 9.66	613.0	0.019*
Mean slope (grades)	9 ± 3.25	11.01 ± 3.60	531.5	0.002**
Scrub-pasture area (km^2)	2.74 ± 0.95	2.67 ± 0.96	751.5	0.238
Forest area (km^2)	0.80 ± 0.85	0.89 ± 0.85	825.0	0.576
Dam area (km^2)	0.04 ± 0.15	0.11 ± 0.41	849.0	0.509
Scrub-forest edge (m)	11 508 ± 7863	11 457 ± 8854	863.5	0.816
Scrub-dam edge (m)	130 ± 585	451 ± 1443	856.5	0.569
Forest-dam edge (m)	44 ± 230	113 ± 431	830.0	0.288

* Significantly different at $P < 0.05$.
** Significantly different at $P < 0.01$.

DISCUSSION

The Hen Harrier had a strong tendency to occupy relatively-level areas in higher altitude of the study area, dominated by Atlantic-heathland vegetation with scarce human presence. These harriers did not have a tendency to occupy heterogeneous habitats at the scale examined. At finer scales, individuals may be influenced by the structure of shrub formations within their home ranges, when exploiting different trophic resources (Preston 1990, Madders 2000).

The Montagu's Harrier seemed to show a preference for natural shrub formations (e.g., *Erica* sp., *Ulex* sp., *Cytisus* sp. and pasture), just as in other areas of the northwestern Iberian peninsula (Vázquez-Pumariño 1995), where there was a lack of large areas of cereal cultivation. Our data also indicated a tendency for Montagu's Harriers to occur in zones of higher altitude.

For both species simultaneously, the final logistic model included only one variable, minimum altitude. This result suggests that preserving the natural Atlantic-heathland vegetation above 800 m may aid in the conservation of the harrier populations of the Baixa-Limia, as well as those in other mountain range areas in Galicia. A greater part of the harrier population in northwestern Spain depends on this habitat, which together with the decline of many European populations (Etheridge and Hustings 1997, Krogulec 1997), justifies the need for habitat management to improve species viability.

The frequency of deliberate small fires in the heathland areas studied, particularly during winter, may favor the creation of a mosaic of scrub types, with bordering areas which might provide suitable habitat for these and other raptors (Dodd 1988, Kochert et al. 1999). On the other hand, the proliferation of intense fires, particularly in spring and summer, may endanger nesting and cause declines of some prey species (Camprodon and Plana 2001).

The abundant presence of livestock grazing in some of these mountain zones reduces the development of shrub vegetation, potentially influencing the abundance of some prey and their vulnerability to capture by raptors (Kochert et al. 1988, Thirgood et al. 2002). The maintenance of traditional agricultural practices such as extensive grazing, and heterogeneous cultivation, are key to the maintenance of the fauna in some European habitats (Tucker and Evans 1997).

Table 5. Logistic regression models for the probability of finding Montagu's Harrier, Hen Harrier and both species simultaneously in the Site of Community Importance Baixa-Limia.

	B	SE	WALD	*P*
Hen Harrier				
Intercept	−2.812	0.888		
Min. altitude	0.003	0.001	6.749	0.009
Montagu's Harrier				
Intercept	−2.818	1.054		
Scrub-pasture area	4.96×10^{-7}	0.000	4.174	0.041
Min. altitude	0.003	0.001	7.391	0.007
Both species simultaneously				
Intercept	−3.359	0.981		
Min. altitude	0.003	0.001	7.264	0.007

The most significant threats for the mountainous habitats observed in the study area are the proliferation of roads and the massive afforestation of zones of scrub-pasture land. These changes result in the progressive destruction of suitable hunting and nesting habitats for harriers and other species of raptors adapted to open habitats (Tucker and Evans 1997, Petty 1998, Madders 2000). To conserve harriers effectively, we recommend restrictions on the proliferation of roads and managing to improve scrubland habitats.

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