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Factors Influencing the Present Distribution of the Spanish Imperial Eagle *Aquila adalberti*

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ABSTRACT

In this paper we analyse the status of the Spanish imperial eagle Aquila adalberti *in relation to its historic range in Spain, and try to determine geographic, climatic and land-use factors which may favour or limit its distribution.*

Fourteen of the 32 variables studied showed statistical differences between the grid squares where the eagle breeds and those grid squares sampled at random where it does not breed. The eagle remains in more forested areas, with lower levels of human land use and with a higher density of rabbits, but no clear topographic differences were observed. The eagle is associated with areas having a typical mediterranean climate—relatively warm dry summers and temperate rainy winters. A stepwise discriminant function analysis showed that it was possible to classify correctly more than 80% of the squares. A low incidence or absence of irrigated farmlands was the best predictor of the eagle's presence. The rapid increase of people in areas previously depopulated, and human presence in fields where irrigated cultures have been developed, had a negative effect on the eagle's distribution.

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INTRODUCTION

The Spanish imperial eagle *Aquila adalberti* Brehm 1861 is one of the rarest raptors in the world and recorded as endangered in the IUCN Red Data Book (King, 1981). This eagle is now considered a different species from its Eastern congener, *Aquila heliaca* Savigny 1809 (Hiraldo *et al.*, 1976; Collar & Andrews, 1988; González *et al.*, 1989*a*). During the last century its area of distribution has been considerably reduced (González *et al.*, 1989*b*). In Morocco it has disappeared as a breeding species (Mills, 1976; Bergier, 1987) and has become very rare in Portugal, where individuals have been observed but no breeding has been recorded in recent years (Palma, 1986). In Spain, the only country where the species still breeds, it has disappeared from the edges of its distribution range of the last century (Penibetic Mountains, Levant and north of the Guadarrama Mountains). At least 100 breeding pairs still remain in central, west and south-west Spain (González *et al.*, 1987).

The decline of this species in Spain has been attributed mainly to human persecution and habitat alterations due to changes in land use (Verner, 1909; Valverde, 1959; Garzón, 1974). In this paper we analyse the present distribution of the species in relation to its historic range in Spain and try to determine geographic, climatic and land-use factors which may favour or limit its distribution.

MATERIAL AND METHODS

The grid formed by the 'L' series of the 1:50 000 topographic map of Spain (Servicio Cartográfico del Ejército) was used to determine presence or absence of breeding eagles in the 18 × 28 km square of each sheet. Information from the second national census of the species was used (González *et al.*, 1987). Thirty-seven squares of the 53 where the species was located were used for this study. These included 91 breeding pairs (87·5% of the total population), and were considered to be representative of the breeding habitat. To compare the present breeding areas with the historic range of the species in Spain, another 37 squares from the national grid were randomly selected as controls (Fig. 1). Control squares containing breeding eagles, or which were outside the known breeding range in 1900 (González *et al.*, 1989*b*), were rejected as controls.

A total of 32 variables for each square (Table 1) were measured on the 1:50 000 topographic maps and on farming and land-use maps (Mapa de Cultivos y Aprovechamientos) of the same scale. Two other variables, the areas of small-game reserves for hunting purposes (HACO) and the density

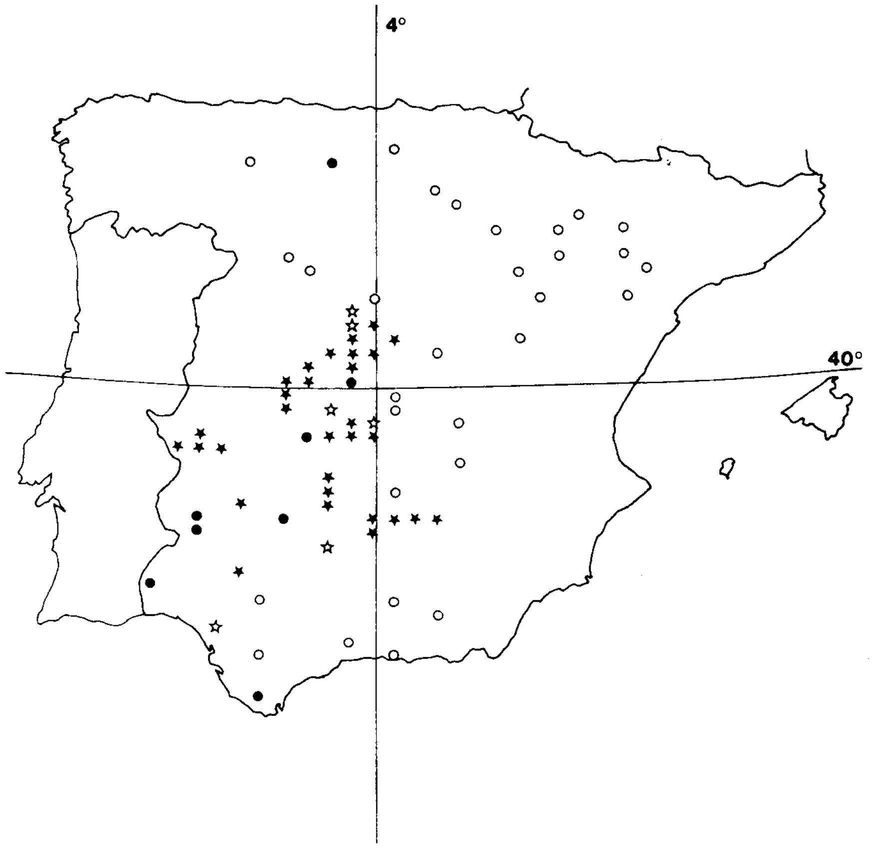

Fig. 1. Map of the study area. (★), 'eagle' square classified as 'eagle' square; (☆) 'eagle' square misclassified as 'control' square; (●) 'control' square misclassified as 'eagle' square; (○) 'control' square classified as 'control' square (see details in text). For obvious security reasons, the 'eagle' squares have been moved with respect to their actual situation.

of rabbits *Oryctolagus cuniculus* (DECO), were calculated on a provincial basis from the National Game Statistics (ICONA, 1985).

The values of the variables in squares containing eagles and those in control squares were compared by Student t-tests to find differences between the present and historical breeding ranges. Several stepwise discriminant function analyses were made with the BMDP Statistical Package (Dixon & Brown, 1983) to identify sets of variables which best differentiated between the present breeding range and areas from which the species has disappeared this century. As sample sizes could not be increased to three times the number of variables measured (Williams & Titus, 1988) a jack-knifed classification was obtained for each analysis. There was never a significant reduction in the percentage of correct classifications.

TABLE 1
List of Variables

Mnemonic code	*Description*
TOP	Relief index[a]
CMAX	Highest elevation above sea level (m)
CMIN	Lowest elevation above sea level (m)
LABS	Extensive non-forested cultivation (ha)
REG	Irrigated farmland (ha)
LABC	Cultivated areas with scattered trees (ha)
MATS	Mediterranean maquis, non-forested (ha)
MATC	Mediterranean maquis, forested (ha)
REP	Conifer forest (ha)
IMP	Unproductive land (ha)
TMED	Annual mean temperature (°C)
TFRI	Mean temperature of coldest month (°C)
TCAL	Mean temperature of hottest month (°C)
HEL	Number of days with frost
ETP	Potential evapotranspiration (mm)
PMA	Annual mean rainfall (mm)
DEFHID	Annual mean water deficit (mm)
DSEQ	Number of months with drought
HAB	Number of inhabitants per km^2
AHA	% of farms with <5 ha
AAHA	% of farms with 5–50 ha
AAAHA	% of farms with 50–100 ha
AABHA	% of farms with >500 ha
HACO	% of provincial area dedicated to rabbit game reserves
DECO	Mean annual number of rabbits hunted in the province
CONT	Continentality index: TCAL–TFRI
PAST	Non-forested cultivated land: LABS + REG (ha)
INTRA	Inaccessibility index: (MATS + MATC/1000) + AABHA + TOP[b]
VER	Summer mean rainfall (mm)
INV	Winter mean rainfall (mm)
OT	Autumn mean rainfall (mm)
PRI	Spring mean rainfall (mm)

[a] Number of 100 m contours crossed by the perpendicular transects N–S and E–W radiating from the centre of the square.
[b] Index which measures the degree of difficulty of human access.

RESULTS

Fourteen of the 32 variables studied showed statistically significant differences between the squares where the Spanish imperial eagle actually breeds and those chosen as controls (Table 2). It breeds in significantly more continental areas (CONT), with higher summer temperatures (TCAL), higher rainfall in spring (PRI), autumn (OT) and winter (INV) and lower

TABLE 2
Mean and Standard Deviation of the Variables for 'Control' Squares and 'Eagle' Squares and Level of Significance of the Difference of Means (Student t-test)

Variable	*'Control' squares*		*'Eagle' squares*	
	$\bar{x}$	$\pm sd$	$\bar{x}$	$\pm sd$
TOP	35·24	20·76	38·08	21·21
CMAX	1 105·83	494·29	1 043·86	536·41
CMIN	496·48	318·69	451·40	240·54
LABS**	18 718·43	9 644·67	12 152·32	9 413·55
REG***	7 904·75	6 964·53	2 568·02	3 959·58
LABC*	3 308·56	7 240·01	9 268·73	9 191·25
MATS*	7 754·86	6 194·78	12 213·94	8 493·66
MATC	5 516·10	6 590·38	6 913·24	6 422·86
REP	5 491·16	6 079·81	6 029·10	6 308·39
IMP*	1 427·78	1 269·33	2 370·97	1 869·20
TMED	13·74	2·61	14·41	2·34
TFRI	5·48	2·70	5·86	1·89
TCAL*	23·05	2·91	24·58	2·52
HEL	5·74	1·95	5·43	1·53
ETP	846·35	113·12	880·54	105·65
PMA	602·70	193·71	683·37	165·36
DEFHID	413·37	142·07	451·35	112·85
DSEQ	4·14	1·15	4·08	0·83
HAB	25·75	25·85	18·56	20·09
AHA	44·23	17·79	44·76	20·63
AAHA*	40·10	15·20	31·72	14·00
AAAHA	10·31	8·63	10·70	8·39
AABHA	4·89	7·06	12·25	22·04
HACO	8·56	12·69	14·08	14·78
DECO	1·11	1·16	1·35	0·63
CONT**	17·56	2·10	18·71	1·52
PAST***	26 623·19	12 131·50	14 720·34	10 175·34
INTRA*	53·43	29·98	69·46	35·34
VER*	6 681·75	4 207·96	4 628·10	2 382·76
INV*	19 857·43	9 902·91	24 818·78	6 539·29
OT*	17 017·56	5 253·89	19 584·19	5 284·43
PRI*	16 713·51	4 829·79	19 306·75	4 596·26

*$p < 0·05$.
**$p < 0·01$.
***$p < 0·001$.

rainfall in summer (VER). From a land-use point of view the areas where the eagle breeds have significantly less cultivated land (PAST)—either irrigated farmland (REG) or other extensive non-forested cultivations (LABS)—and a greater extension of cultivated areas with scattered trees (LABC), mediterranean maquis (MATS) and unproductive land (IMP). No clear topographic differences were observed between the squares (TOP, CMAX, CMIN).

The stepwise discriminant function analysis showed that it was possible to classify correctly more than 80% of the squares as 'eagle' or 'control' squares with different sets of variables. Low incidence or absence of irrigated farmland (REG) was the best predictor of squares suitable for eagles. A discriminant function constructed for this variable alone correctly classified 89·2% of the 'eagle' squares, although 'control' squares with a low incidence of irrigated farmland (43·2%) were incorrectly classified as 'eagle' squares by the function. The best discriminant function obtained was constructed with

TABLE 3
Classification Matrix and Functions of Stepwise Discriminant Analysis

Actual group	*Predicted group*		
	'Control' squares	*'Eagle' squares*	$\sum$
'Control' squares	31	6	37
'Eagle' squares	5	32	37
$\sum$	36	38	
REG	0·000 15	−0·000 15	
VER	0·002 14	0·001 45	
CONT	4·552 84	5·284 78	
DSEQ	6·220 13	4·301 52	
HACO	−0·214 21	−0·155 24	
Constant	−60·380 68	−60·988 67	

5 variables (REG, VER, CONT, DSEQ, HACO) which classified correctly 83·8% of the 'eagle' squares and 86·5% of the 'control' squares (Table 3). The 85·1% correct classification was only reduced to 70·2% ($\kappa = 0{\cdot}702$, SE $= 0{\cdot}116$, $Z = 6{\cdot}05$; $p < 0{\cdot}001$) when the effect of chance was removed (Titus *et al.*, 1984). The jack-knife classification procedure showed the robustness of the test as percentages of correct classification only decreased to 75·7% for 'eagle' squares and 83·8% for 'control' squares. In 3 out of 5 'eagle' squares incorrectly classified by the function, the misclassification was due to a great extension of irrigated farmland (Fig. 1). In fact these squares do not represent the eagles' habitat as these three pairs bred in the borders and have most of their home ranges in neighbouring squares with more suitable habitats.

DISCUSSION

Direct persecution has been quoted as one of the main factors causing a reduction in population and distribution of avian predators (Bijleveld, 1979; Newton, 1979). During the last century the Spanish imperial eagle has been subjected to persistent persecution which has contributed to its decline (González *et al.*, 1989*b*). Although this persecution was generally throughout its old distribution range, it caused extinction only in certain areas while in others the population was greatly reduced. It has begun to recover in the last decade (González *et al.*, 1987). As probably not all the areas enclosed in the old distribution range had breeding eagles, the 'control' squares represent those areas where the eagles have disappeared and in addition those where it probably has never bred.

Climate appears to have an indirect effect on the eagle. In mediterranean Spain lower winter rainfall—and therefore lower total annual rainfall ($r = 0{\cdot}9$; $p < 0{\cdot}001$; d.f. = 72)—gives rise to more arid conditions with lower tree cover (Rivas-Martínez & Arnaiz, 1985). Lack of trees can be a limiting factor for the eagle as this species seems to prefer forested plains. There is a positive correlation between summer rainfall and altitude ($r = 0{\cdot}52$; $p < 0{\cdot}001$; d.f. = 72), which is a characteristic of mountainous areas avoided by the eagle (González *et al.*, 1987). On the other hand the climate influences the distribution and abundance of rabbits—the main prey of the eagle (Delibes, 1978; Amores, 1980)—the most productive populations of rabbits occurring in areas with a mediterranean climate (Myers, 1970; Soriguer, 1981, 1983). The discriminant analysis (Table 3) confirms that the eagle prefers areas with high rabbit densities (HACO), and often coexists with Bonelli's *Hieraetus fasciatus* and golden *Aquila chrysaetos* eagles, which also feed mainly on rabbits (Delibes *et al.*, 1975; Arroyo *et al.*, 1976, 1986; Jordano, 1981), for example in the Sierra Morena and Extremadura in south-west Spain. In the north where the climate is colder, the golden eagle predominates (Arroyo *et al.*, 1988) and the imperial eagle disappears. To the east, where it is drier, Bonelli's is more common (B. Arroyo, pers. comm.) and the imperial eagle is absent. The Spanish imperial eagle seems to be the most specialized of the three and this may be why it is so local (Brown & Amadon, 1968). As the climate has not varied very much during the last century (INM, 1985) we suppose that the eagle never bred outside its present climatic range, or if it did breed numbers were so low that it was easily exterminated by human persecution.

Habitat changes resulting from the development of irrigated cultivation are similar to those caused by other agricultural activities which remove tree cover. However, it is not only the reduction of tree cover, but the rapid increase of inhabitants in areas previously depopulated and the higher numbers of people working in the fields which have caused the eagles to avoid these areas. There has also been a sharp reduction in the number of rabbits by direct persecution and reduction of scrub cover (Jaksic & Soriguer, 1981; R. C. Soriguer, pers. comm.). The increase in power lines that irrigated cultivation needs may be an important negative factor for eagle distribution, as electrocution is the main cause of mortality for eagle juveniles in some areas (Calderón *et al.*, 1988).

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