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ORIGINAL ARTICLE

G. Urios · A. Martínez-Abraín

The study of nest-site preferences in Eleonora's falcon *Falco eleonorae* through digital terrain models on a western Mediterranean island

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Abstract This study addresses nesting-site preferences in Eleonora's falcon *Falco eleonorae* by means of geographic information systems and high-quality high-resolution digital terrain models (DTMs). A small western Mediterranean archipelago (Columbretes Islands) with a colony of 34 pairs was chosen as a case study. Overall, 21 grid variables obtained from DTM were considered of which 12 showed a significant effect. Four of them were topographic (i.e. elevation, X-axis aspect, slope and curvature), four climatic (i.e. wind exposure, solar insolation, solar radiation and radiation index), three anthropogne (visibility of lighthouse beam, visibility of antropic zones and distance to antropic zones) and one biotic (vegetation cover). Falcon nests were placed on pixel cells with lower average insolation and radiation than cells without nests, but had higher values of wind exposure. Nests were built on concave sites mainly with an easterly facing aspect and steep slopes. Falcons were shown to respond to human presence as all antropic variables considered had a significant effect. The results have a number of management and conservation implications, because the knowledge of nesting preferences of the species allows the proper design of sanctuaries and an appropriate human use of these areas.

Keywords Conservation · DTM · *Falco eleonorae* · Nest-site preferences · Western Mediterranean

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G. Urios
Departament de Biología Vegetal,
Universitat de València, C/Dr. Moliner 50,
46100 Burjassot, Valencia, Spain

A. Martínez-Abraín
IMEDEA (CSIC-UIB),
C/Miquel Marqués 21 Majorca,
07190 Esporles, Spain

Present address: G. Urios (✉)
Plaza del Carmen 6-3°, 46003 Valencia, Spain
E-mail: guriol01@tiscali.es
Tel.: +34-96-5567232

Introduction

Many studies dealing with the management and conservation of threatened species have studied and quantified nesting-site variables (Bednarz and Dinsmore 1981; Newton et al. 1981; Reynolds et al. 1982; Rich 1986). Recently, quantitative studies of habitat preferences, as a way of defining the ecological requirements of species and their conservation needs, are becoming more common (Bustamante and Seoane 2004; Clark and Shutler 1999; Mezquita 2004). In this study, we emphasise the usefulness of digital stereo pairs, geographic information systems (GIS) and high-quality high-resolution digital terrain models (DTMs) to quantify nest-site preferences in Eleonora's falcon *Falco eleonorae*, a rare Mediterranean raptor species.

Eleonora's falcon is a migrant social raptor species that breeds on Mediterranean islands and winters on islands of the Indian Ocean and along the eastern African coast. Its western range extends to the Atlantic coasts of Morocco and the Canary Islands (Cramp and Simmons 1980). A large part of the world population ca. 4,500 pairs (Hagemeijer and Blair 1997) concentrates in the Aegean Sea and on a small number of islands (Wink et al. 1990). In Europe, the species is considered as rare and hence conservation dependent because, although it is not globally threatened, its world population is below 10,000 breeding pairs and is not marginal to a larger non-European population (Tucker and Heath 1994). In addition, Eleonora's falcon may suffer from human disturbance as its breeding calendar overlaps with the summer months, when tourisism peaks in most Mediterranean islands (Martínez-Abraín et al. 2002).

The Action Plan for the species (Ristow 1999) suggested the need for studying its ecological requirements among the main conservation targets, although little has been advanced so far. More specifically, studies of nesting habitat selection or nest-site preferences in Eleonora's falcon are virtually non-existent. Studies available deal with the possible relationship between temperature and reproductive success (Wink et al. 1982) or just point out the implications of some climatic variables, such as solar radiation, in the process of nest-site selection (Walter 1979), but quantitative analyses are scarce.

We analyse quantitatively nesting-site preferences in this falcon species by means of GIS and DTMs because these tools allow a powerful compilation, analysis and simulation of biotic and abiotic information (Miller 1994; Wilson and Gallant 2000). Specifically, DTMs are necessary for an adequate spatial modelling (Guisan and Zimmerman 2000) and have been employed here to model several topographic, climatic, antropic and biotic variables in the study of nesting site preferences in Eleonora's falcon in a small western Mediterranean archipelago.

Methods

Study area and monitoring of colonies

The study took place on the Columbretes archipelago (39°51′N, 0°40′E), a 19-ha volcanic outcrop located close to the edge of the wide continental shelf of Castellón, E Spain, comprising four major islet groups (Fig. 1). The Columbretes archipelago was protected as a nature reserve in 1988 and as a marine reserve

Fig. 1 *Map* showing the location of the study site (Columbretes Islands) within the western Mediterranean

(4,400 ha) in 1990. Falcons presently nest in each of the four groups of islets, although the study on nesting site preferences was conducted only on the largest island (Columbrete Grande Is., including the three minor islets contiguous to it, see Fig. 1) because digital cartography was only available for this islet, which also held the largest subcolony. Falcon numbers have grown steadily since the protection of the archipelago, from 16 pairs in 1985 to 34 pairs in 2003 (Martínez-Abraín et al. 2002). During the 19th century, falcons did not breed on Columbrete Grande Is. (Salvator 1895) probably because of the permanent presence of lighthouse keepers on the island and their hunting activity. However, falcons were already present as breeders on Columbrete Grande Is. in the 1960s and 1970s.

Breeding colonies were monitored extensively during the period 1996–2000. Location of nests and main breeding parameters (i.e. clutch size, hatching success and productivity) were obtained annually. Fledglings were also metal and colour-ringed. Nests were located from a boat by touring the 13-ha islet from mid to late July, with the help of the knowledgeable wardens of the islands. Precise location of all nests was determined from land visits and nests were individually numbered. The small surface area of the major islet probably allowed detection of all nests.

Digital terrain models

The DTMs for the area are not presently available in local environmental or cartographic agencies and hence must be generated. Models available for almost the entire earth suface (mainly Shuttle Radar Topography Mission) are of a very low resolution and accuracy and were not used, although they can be appropiate for most large-scale studies.

We employed the most usual technique for the generation of DTMs (Moore et al. 1991). Specifically, we used photogrammetrically derived data, based on the stereoscopic interpretation of aerial photographs, which covered the whole study area, and field GPS measurements (ASTEC Z-Surveyor) to obtain ground control points. Once obtained the cloud of points with UTM coordinates X, Y, Z, we proceeded to interpolate them by kriging (Lam 1983; Oliver and Webster 1990), using ARC/INFO 7.1. algorithms (ESRI 1998). The same software package was used to develop a spatial database, which included all factors described below.

The result was a high resolution model (pixel size = 6 m) of the Columbrete Grande Is. To validate the DTM, we first visualised the model tridimensionally and observed the frequency histogram, to verify the absence of biases in the distribution of elevation frequencies. Second, we compared interpolated values with field measurements obtained by land surveying (Sokkia SET-5). Both variables (i.e. interpolated and measured) were then analysed to discard the existence of systematic biases in the deviations by means of a paired-sample Student t-test. Positioning of nests in the field was done by means of a GPS with sub-metric precision (Leica GS-50). Field work was carried out on a sample of 20 different nesting locations, during the period 1996–2000. Once obtained and validated the DTM, 21 derived grid variables were obtained, all of them factors that have been previously reported as influencing nest-site preferences in birds (Table 1). Differences between average values of cells with nest and cells available were analysed by means of the non-parametric Mann–Whitney U statistic because of the large difference between cells with nests ($n = 20$) and cells available ($n = 4{,}031$). Significance level was established at $p = 0.05$.

The wind exposure grid was built combining data on wind speed and frequency for a rose of 16 basic

Table 1 Mann–Whitney U statistic applied to variables considered to evaluate nest-site preferences in Eleonora's falcon *Falco eleonorae*. Wind exposure, solar insolation and solar radiation were obtained for three different periods but only one was selected from PCA

Name	Description	U	p-value
Topographic			
Elevation:	Elevation in meters	25,732.5	0.006
Aspect (X)	Aspect in X-axis	24,001.0	0.002
Aspect (Y)	Aspect in Y-axis	39,825.0	> 0.05
Slope (%)	Slope in degrees	17,481.0	< 0.001
Curvature	Second derivative of the slope	27,484.0	0.015
Rugosity	Rate of change of slope and aspect	39,135.5	> 0.05
Climatic			
Wind exposure (smoothing filter)	Smoothed values (mean) of wind exposure	25,460.5	0.005
Wind exposure (unfiltered)	Interaction between wind speed and frequency	40,055.5	> 0.05
Solar insolation	solar insolation in hours	15,056.0	< 0.001
Solar radiation	Solar radiation in Joules/m^2	26,527.0	0010
Radiation index	Ratio between incident radiation and a horizontal surface for reference	23,671.5	0.002
Antropic			
Visibility of lighthouse beam	Visibility of the lighthouse beam	23,032.0	< 0.001
Visibility of antropic zones	Visibility of zones of intensive antropic use	21,516.5	< 0.001
Distance to antropic zones	Distance to zones of intensive antropic use	16,865.0	< 0.001
Biotic			
Vegetation cover	Binary map of presence–absence of vegetation	25686.0	0.001

directions. Three models were generated for solar insolation, incident solar radiation (see Table 1 for further explanations) and wind exposure, corresponding to three different periods: (1) arrival of falcons to the archipelago (10 April as an average) when territories are occupied, (2) beginning of the laying period and incubation (26 July as an average), and (3) hatching of eggs (4 September).

Once grids for wind exposure, insolation and radiation were obtained for each of these periods (nine grid variables) three PCAs were performed on the original three variables and eigenvectors as well as the variance-covariance matrix were analysed. Large values of original variance ($V=90$, 95 and 95), calculated as the ratio between its eigenvalue and the summatory of all eigenvalues, showed that a large part of the variance was contained in each first component. Hence only one digital model for each original variable was included in the analysis, the one corresponding to the date best correlated with the first component of the PCA. The best correlated insolation and radiation grid were those obtained for the day 100 of the year, corresponding to the arrival of falcons to the breeding territories ($r=0.95$). The best correlated digital model of wind exposure was that of July. However, that particular grid was not significant ($r=0.99$; $p=0.991$) and presented strong contrasts and gradients at short distances. To reduce the back noise we filtered it by means of an average filter that assigns to each cell the average value of the nine neighbouring cells, after Hutchinson and Gallant (2000). Average facing aspect of nests was obtained from ad hoc equations for circular variables. Visibility models were constructed by means of ARC/INFO algorithms, which take into consideration the screening effect of shrub-dominated areas.

Solar insolation and incident solar radiation were calculated using SOLARFLUX model (Hetrick et al. 1993). The radiation index was built after Fernández-Cepedal and Felicísimo (1987). Rugosity was obtained after algorithms developed by Felicísimo (1994) and is a mesure of vector dispersion, which takes into account changes in slope and aspect around a 3×3 moving window. Both variables need to be implemented in C++ code as they are not available in commercial packages.

The vegetation digital model was obtained by visual interpretation and later rasterisation of digital geometrically corrected stereo pairs. Finally, curvature corresponds to total curvature as a measure of the curvature of the surface itself (Gallant and Wilson 2000) as defined in ARC-INFO algorihms.

All data analysis were performed using the SPSS, v.10.0 package.

Results

The comparison between interpolated and mesured elevation values (t-test) showed that there was no evidence of biases in the former ($p=0.38$) at a 95% confidence interval. Furthermore the root mean square errors are between the standards for first-class accuracy models (Shearer 1990; Ley 1986), that means under one-third of the grid node separation.

We found that the average value of 12 of the 21 variables considered was significantly different in cells with nests compared to cells available (see Mann-Whitney U-tests and corresponding p-values in Table 1). In Table 2, we show the main descriptive statistics (mean and 95% CI) of each variable with a significant effect for pixels with and without nests. Facing aspect (Y-axis), rugosity and wind exposure (unfiltered values) did not show to have any significant effect.

Topographical variables: elevation, slope, curvature and facing aspect

Data showed that mean elevation above sea level of cells with nests was lower than mean elevation of cells

Table 2 Mean values and 95% confidence interval for variables found to have a significant effect

Variable	Cells without nests			Cells with nests		
	Mean	Lower 95% CI	Upper 95% CI	Mean	Lower 95% CI	Upper 95% CI
Topographic						
Elevation	26.4	26.00	26.92	17.4	14.90	19.93
Aspect (X)	−0.02	−0.041	−0.001	0.39	0.041	0.747
Slope (%)	25.5	25.07	25.93	41.9	34.72	49.16
Curvature	0.3	−0.30	0.88	−7.4	−27.9	13.1
Climatic						
Wind exposure (smoothing filtered)	34.4	33.04	35.67	56.1	35.51	76.63
Solar insolation	9.9	9.87	9.95	7.6	6.54	8.56
Solar radiation	12,663,716.0	12,554,694.2	12,772,739.4	10,586,121.9	8,739,323.4	12,432,920.5
Radiation index	75.6	74.92	76.21	53.9	40.55	67.25
Antrophic						
Visibility of lighthouse beam	0.6	0.62	0.65	0.20	0.01	0.39
Visibility of antrophic zones	0.6	0.61	0.64	0.15	-0.02	0.32
Distance to antrophic zones	145.5	140.80	150.17	323.45	222.50	424.40
Biotic						
Vegetation cover	0.5	0.46	0.49	0.1	-0.04	0.24

available. Only 3 out of 20 nests were placed at an elevation lower than 10 m asl (Fig. 2). Cells with nests had on average steeper slopes than cells available (Fig. 3). The average curvature of the island was negative (-0.02 ± 19.2, mean ± SD) but cells with nests showed a more negative tendency (-7.42 ± 42.8, mean ± SD) suggesting that nests were placed mainly in concave zones, although the variance was very high. After transforming the original circular variable into two Cartesian variables we found that the X-axis (East-West aspect) but not the Y-axis (North-South aspect) had a significant effect on nesting site preferences. Nests had preferentially an easterly facing aspect (positive values).

Climatic variables: solar insolation, incident solar radiation and wind

Mean solar insolation of cells with nests was lower than that of cells available, during the period analysed (day 100). Similarly, mean incident solar radiation and radiation index were higher in pixels available than in pixels containing nests (Fig. 4). Wind exposure (smoothing filter) was on average higher in cells with nests than in cells available, considering wind values from end of July when falcons start laying according to PCA results (Fig. 5).

Antropic factors: visibility of antropic zones, visibility of the lighthouse beam and distance to antropic zones

Eighty per cent of the nests were located in pixel cells from which the light beam of the lighthouse could not be seen, whereas only 37% of pixels available were out of the reach of the beam (Fig. 6). Nests were also placed preferentially (85%) out of sight of the zones with intensive human use versus only 39% in cells available. Similarly, mean distance of cells with nests to zones with human use was longer than mean distance of pixels available. However, nests occurred at any distance between the minimum and maximum values observed. This could be explained by an interaction between distance and visibility to be further explored. Distance to antropic zones can be short provided that the nest is not

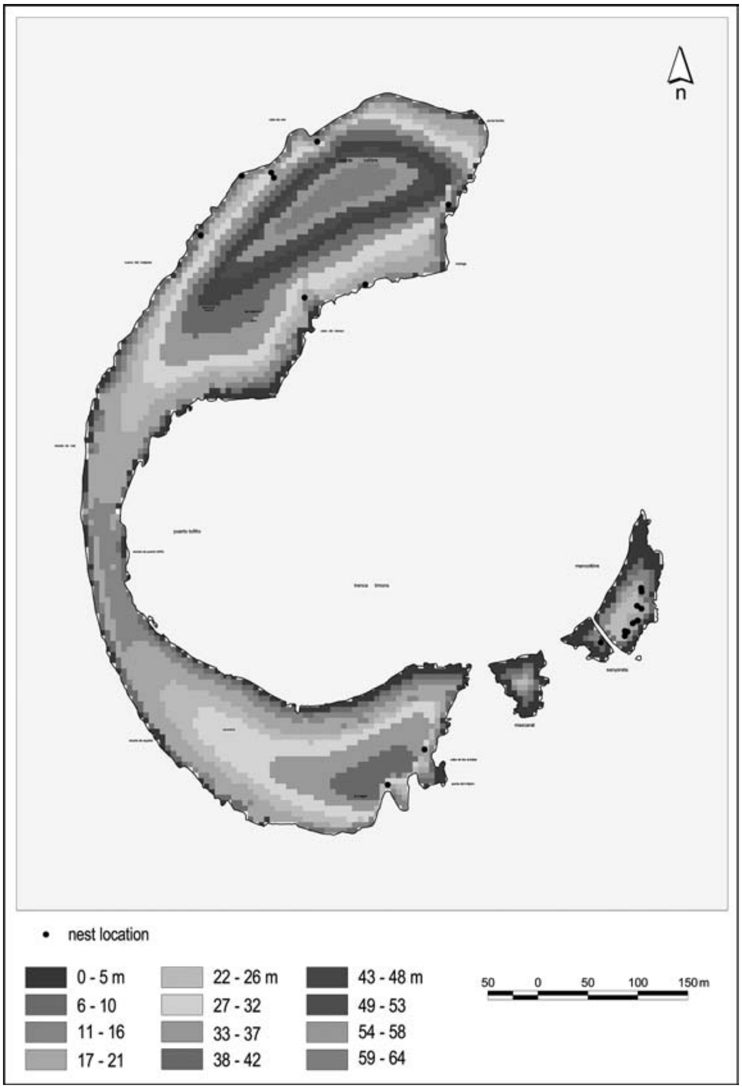
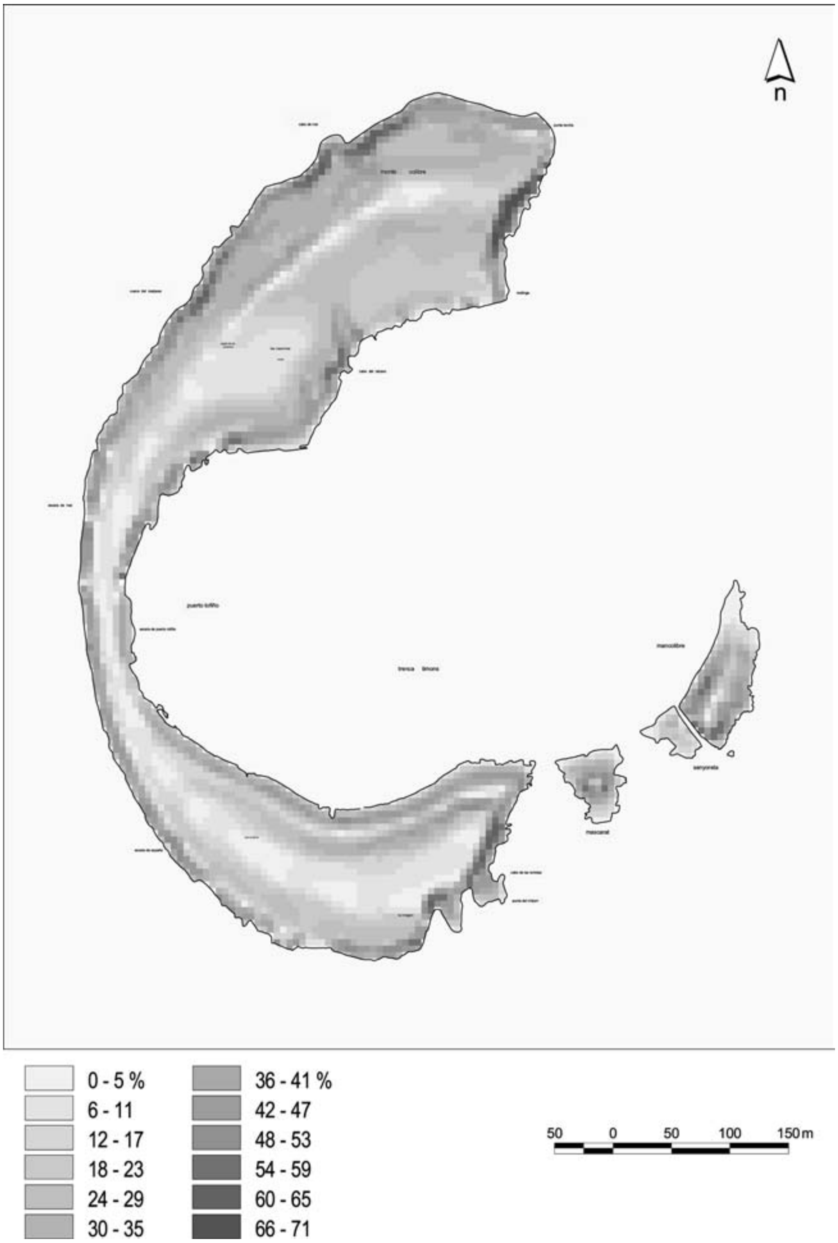


Fig. 2 Median (*middle line*), interquartilic range and 50% confidence interval of significant variables in zone pixels without (*left*) and with (*right*) nests. **a** Direct insolation, **b** solar radiation, **c** radiation index, **d** wind exposure (smoothing filter), **e** elevation, **f** aspect (X-axis), **g** slope (%) and **h** distance to antropic zones

Fig. 3 Slope



visible. In fact, only one nest was placed at a short distance in an area visible by humans.

Biological variables: vegetation cover

Nests were placed preferentially in cells without vegetation cover (90%) whereas only 54% of cells available were free of vegetation.

Discussion

Topographical, climatic and biotic variables

Elevation above ground level has been identified previously as a significant variable in studies of nesting habitat selection dealing with other raptor species such as the Lammergeier *Gypaetus barbatus* and the lesser kestrel *Falco naumanni* (Donázar et al. 1993; Bustamante 1997) or in predictive presence/absence models developed for the red kite *Milvus milvus* (Seoane et al. 2003). Elevation above sea level of nests of the Eleonora's Falcon is probably influenced by wave action during storms. Falcons seem to prefer nest sites located above an elevation threshold that prevents damage to nestlings during the last stages of development, when storms are more common in the study area.

The preference for steep slopes by the species at Columbretes Is. is probably related to the defence against terrestrial intruders, either man or terrestrial mammals. Although no mammal, other than humans, is now present on the archipelago, domestic rabbits were

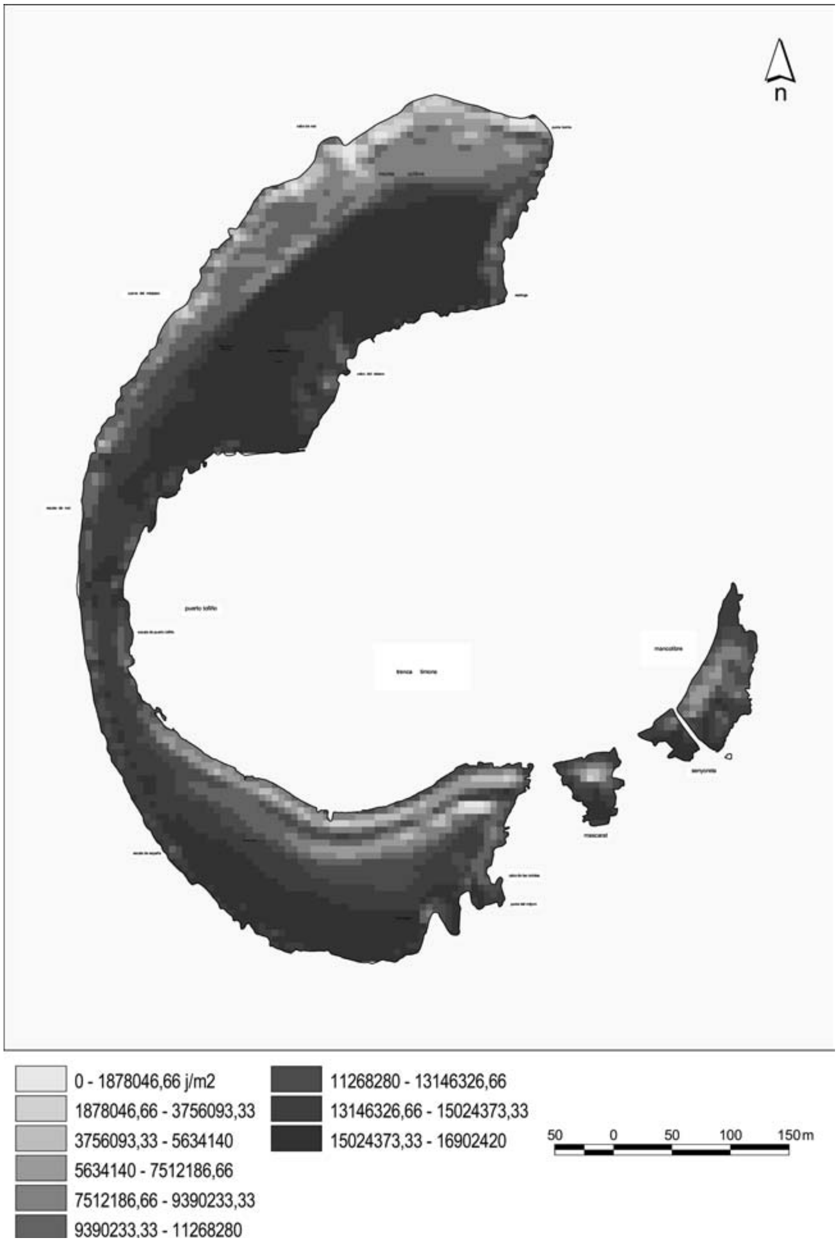


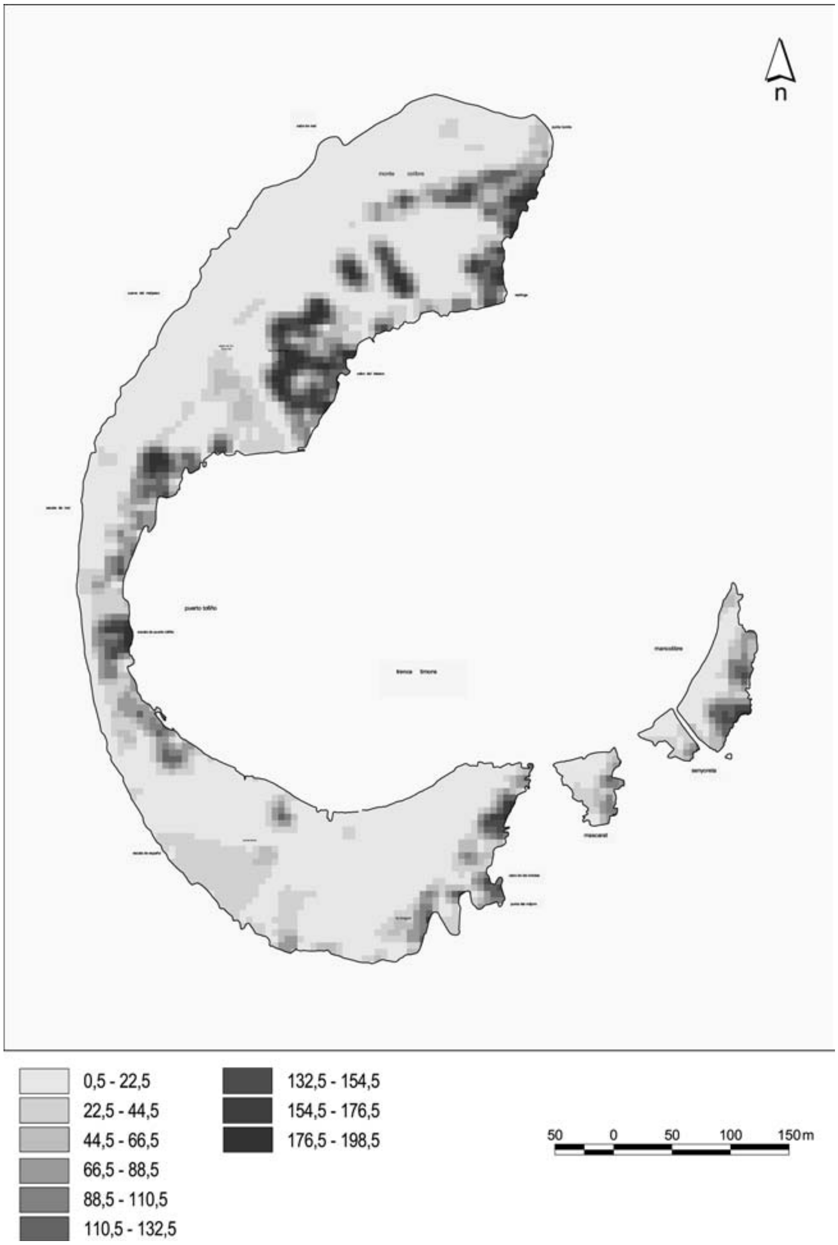
Fig. 4 Solar radiation

present in large numbers until the mid 1980s, which could cause some loss of eggs and nestlings. Domestic mice (*Mus* sp.) were also abundant at the end of the 19th century (Salvator 1895) and large densities are known to have caused loss of eggs and nestlings in island species (Orueta, personal communication). Terrestrial predators, however, are now present in other colonies of the species (Ristow and Wink 1985) where this factor could play a more relevant role.

Preference for nesting places with a negative curvature (concave zones) could reflect the need for some visual protection against would-be aerial predators such as the abundant yellow-legged gull *Larus michahellis* as well as visual avoidance of other falcon pairs nesting in the vicinity to prevent conflicts in this social raptor.

Nests had a preferential easterly facing aspect. Preference for easterly-facing nesting sites does not seem to be linked with the direction of arrival of their main prey (i.e. migrant passerines), contrary to that suggested by Mayol (1977) for colonies in the Balearic Islands, as migrants come mainly from the northern quadrant during the autumn. Considering that insolation and radiation SOLARFLUX models used take into account topographic shading, and that counter intuitively they gave low average values for south-east facing cells, this preference is most likely related to a nesting strategy aimed at avoiding areas with a high degree of sun exposure. This strategy is probably adopted to minimise physiological stress during incubation and chick rearing as well as damage by overheating of clutches during

Fig. 5 Wind exposure (smoothing filter)



periods in which adults are absent from nests. This last factor is especially important in colonies with high human frequentation, such as Columbretes, where peaks of presence of visitors overlap with the incubation and chick-rearing periods, which in turn coincide with the high mean temperatures of the summer (Urios 2003). Previous studies have already highlighted the importance of this variable for Eleonora's falcon. For instance, according to Wink et al. (1982), nests directly exposed to sun have the lowest reproductive success. The use of DTMs to model solar insolation and radiation brings new possibilities for the study of nesting-site preferences and predictive cartography for this species and for many other animal or plant species (Austin et al. 1984; Franklin et al. 2000).

Contrary to that stated by other authors for colonies in the Aegean Sea (Wink et al. 1982; Walter 1979), Columbretes Eleonora's falcons preferred nesting sites at the Columbretes Is. with a high value of mean wind exposure. This might be another way of reducing the thermal stress of birds by facilitating evapotranspiration during incubation. Additionally, wind could facilitate a rapid and economic flight out of the nest. Wind has been found to be a relevant factor for nesting site selection in other cliff-dwelling raptor species (Donázar et al. 1993). Interestingly, nests were more likely to be located in areas without vegetation cover, also a likely nesting strategy which favours a rapid and safe flight when entering or leaving nests, owing to the absence of obstacles. The modelling of the wind variable as well as

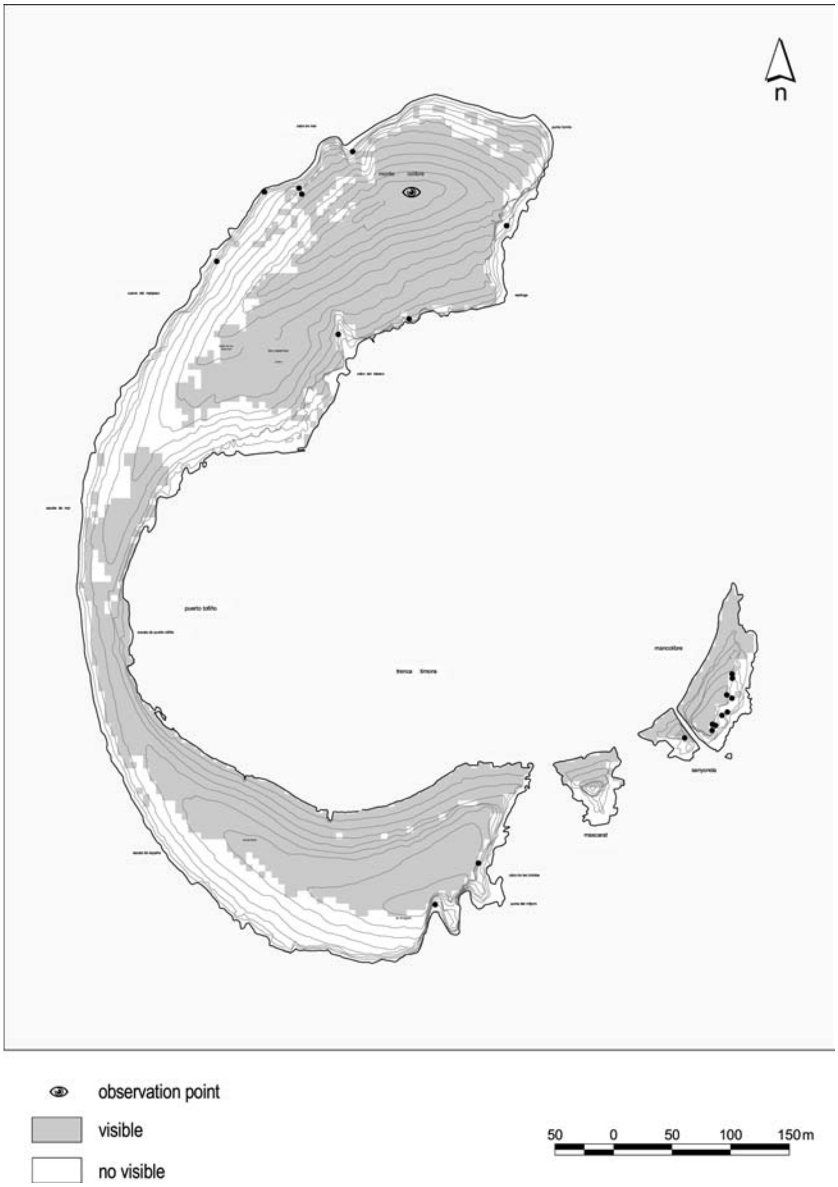


Fig. 6 Visibility of lighthouse beam

of all other variables at the microscale are the main achievements of this study and have seldom been implemented.

Antropic effects

Falcons seemingly avoid a direct sight of the light beam from the lighthouse. In fact, light contamination is known to disturb seabird species either attracting them or decreasing reproductive success by increased predation (Nelson 1989; Reed et al. 1985; Oro et al. 2005). At the Columbretes Is., light could reveal falcon nests to predatory yellow-legged gulls which have a colony of ca. 500 pairs. Falcons seemingly also avoided direct visibility from zones of intensive human use. Some nests, however, were located close to areas used by human visitors, although they were placed out of the sight of humans. Although in a previous study we did not find any effect of human disturbance on reproductive success of Eleonora's falcons (Martínez-Abraín et al. 2002), it is known that it has affected the reproductive output of other raptor species such as the lammergeyer (Donázar et al. 1993) and the Spanish imperial eagle *Aquila adalberti*, as subadults or young adults are known to establish territories in areas of higher human disturbance than experienced adults (González et al. 1992). Importantly, DTMs have proved to be a powerful tool for the study of human disturbance on birds.

Our results have practical conservation applications as the knowledge of the nesting site preferences in Eleonora's falcon can be taken into account by managers when designing conservation actions such as reserve design or when planning public use of sanctuaries. Similarly, our methodological approach could be exported to other raptor species to model their nest-site preferences, especially in landscapes where human effects have to be measured with accuracy.

Zusammenfassung

Untersuchungen zur nistplatzwahl bei eleonorenfalken *Falco eleonorae* auf einer Insel des westlichen mittelmeers mit hilfe von digitalen geländemodellen

Mit Hilfe von Geographischen Informationssystemen und hochauflösenden digitalen Geländemodellen (digital terrain models, DTM) wurde die Nistplatzwahl von Eleonorenfalken auf der Inselgruppe Columbretes im westlichen Mittelmeer untersucht, wo eine kleine Kolonie von 34 Paaren besteht. Insgesamt wurden 21 aus dem DTM gewonnene Rastervariablen berücksichtigt, von denen 12 einen signifikanten Effekt zeigten. Vier von ihnen waren topographischer Natur (Höhe, Ausrichtung, Neigung und Wölbung), vier klimatische Faktoren (Exposition gegenüber Wind, Sonneneinstrahlung, Stärke der Sonnenstrahlung und Strahlungsindex) und drei anthropogener Art (Sichtbarkeit des Lichtstrahls eines Leuchtturms, Sichtbarkeit von und Abstand zu von Menschen benutzten Gebieten). Als biotische Variable stellte sich nur die Vegetationsdecke als bedeutsam heraus. Die Nester befanden sich an Stellen mit geringerer durchschnittlicher Sonneneinstrahlung und Strahlungsstärke bei gleichzeitig höherer Windexposition. Die Nester wurden meist in Mulden gebaut mit östlicher Ausrichtung und steilen Böschungen. Es zeigte sich, dass die Falken auf die Anwesenheit von Menschen reagierten, da alle in Betracht gezogenen anthropogenen Variablen einen signifikanten Effekt aufwiesen. Die Ergebnisse haben Auswirkungen auf Management und Naturschutz, da das Wissen über die Nistpräferenzen der Art eine angemessene Gestaltung von Schutzgebieten und eine geeignete Nutzung dieser Gebiete durch Menschen ermöglicht.

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References

Austin MP, Cunningham RB, Fleming PM (1984) New approaches to direct gradient analysis using environmental scalars and statistical curve-fitting procedures. Vegetatio 55:11–27

Bednarz JC, Dinsmore JJ (1981) Status, habitat use and managemet of red-shouldered hawks in Iowa. J Wildl Manag 45:236–241

Bustamante J (1997) Predictive models for lesser kestrel *Falco naumanni* distribution, abundance and extinction in southern Spain. Biol Conserv 80:153–160

Bustamante J, Seoane J (2004) Predicting the distribution of four species of raptors (Aves: Accipitridae) in southern Spain: statistical models work better than existing maps. J Biogeogr 31:295–306

Clark RG, Shutler D (1999) Avian habitat selection: pattern from process in nest-site use by ducks? Ecol SocAm80(1):272–287

Cramp S, Simmons KE (1980) The birds of the western palearctic, vol 2. Oxford University Press, Oxford

Donázar JA, Hiraldo F, Bustamante J (1993) Factors influencing nest site selection, breeding density and breeding success in the bearded vulture (*Gypaetus barbatus*). J Appl Ecol 30:504–514

ESRI (1998) Grid command references. Enviromental systems research institute. Redlands, Calif.

Felicísimo AM (1994) Modelos digitales del terreno. Introducción y aplicaciones en las ciencias ambientales. Universidad de Oviedo, Oviedo

Fernández-Cepedal G, Felicísimo AM (1987) Método de cálculo de la radiación solar incidente en áreas con apantallamiento topográfico. Biología 5:109–119

Franklin J, McCullough P, Gray C (2000) Terrain variables used for predictive mapping of vegetation communities in Southern California. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and applications. Wiley, New York, pp 331–353

Gallant J C and Wilson J P 2000 Primary topographic attributes. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and applications. Wiley, New York, pp 51-85

González LM, Bustamante J, Hiraldo F (1992) Nesting habitat selection by the Spanish imperial eagle *Aquila adalberti*. Biol Conserv 59:45–50

Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecol Model 135:147–186

Hagemeijer EM, Blair MJ (eds) (1997) The EBBC Atlas of European breeding birds: their distribution and abundance. Poyser, London

Hetrick WA, Rich PM, Weiss SB (1993) GIS-based solar radiation flux models. Proceedings of the ASPRS-ACSM. Am Soc Photogr Remote Sensing 3:132–143

Hutchinson MF, Gallant JC (2000) Digital elevation models and representation of terrain shape. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and applications. Wiley, New York, pp 29–50

Lam N (1983) Spatial interpolation methods: a review. Am Cartographer 10:129–149

Ley RG (1986) Accuracy assessment of digital terrain models. Autocarto London, 1:455–464

Martínez-Abraín A, Oro D, Ferrís V, Belenguer R (2002) Is growing tourist activity affecting the distribution or number of breeding pairs in a small colony of the Eleonora's Falcon? An Biodiv Conserv 25:47–51

Mayol J (1977) Estudios sobre el halcón de eleonor (*Falco eleonorae*) en las Islas Baleares. Ardeola 23

Mezquita ET (2004) Nest site selection and nesting success of five species of passerines in a South American open *Prosopis* woodland. J Ornithol 145:16–22

Miller RI (1994) Mapping the diversity of nature. Chapman & Hall, London

Moore ID, Grayson RB, Ladson AR (1991) Digital terrain modelling: a review of hydrological, geomorphological and biological applications. Hydrol Processes 5:3–30

Nelson DA (1989) Gull predation on Cassin's Auklet varies with the lunar cycle. Auk 106:495–497

Newton I, Davis PE, Moss D (1981) Distribution and breeding of red kites in relation to land-use in wales. J Appl Ecol 18:173–186

Oliver MA, Webster R (1990) Kriging: a method of interpolation for geographical information systems. J Geographical Inf Syst 4:313–332

Oro D, de León A, Minués E, Furness RW (2005) Estimating predation on breeding European storm-petrels by yellow-leged gulls. J Zool (in press)

Reed JR, Sincock JL, Hailman JP (1985) Light attraction in endangered procellariiform birds: reduction by shielding. Auk 102:377–383

Reynolds RT, Meslow EC, Wright HM (1982) Nesting habitat of coexisting accipiter in oregon. J Wildl Manag 46:123–138

Rich E (1986) Habitat and nest site selection by burrowing owls in the sage brush steppe of Idaho. J Wildl Manag 50:548–555

Ristow D (1999) International species action plan for Eleonora's Falcon (*Falco eleonorae*). BirdLife International, Cambridge

Ristow D, Wink M (1985) Breeding success and conservation management of Eleonora's Falcon. ICBP Tech Publ 5:147–152

Salvator LV (1895) Columbretes. Mercy und Druck, Praga

Seoane J, Viñuela R, Díaz-Delgado R, Bustamante J (2003) The effects of land use and climate on red kite distribution in the Iberian Peninsula. Biol Conserv 111:401–414

Shearer JW (1990) The accuracy of digital terrain models. In: Petrie G, Kennie TJM (eds) Terrain modelling in surveying and civil engineering. Whitless, New York

Tucker GM, Heath MF (1994) Birds in Europe: their conservation status. BirdLife International, Cambridge

Urios G (2003) Application of geographic information systems and digital terrain models to the environmental cartography of the Columbretes Islands. PhD Thesis, Universitat de València, Valencia

Walter H (1979) Eleonora's falcon. Adaptations to prey and habitat in a social raptor. University of Chicago Press, Chicago, Ill.

Wilson JP, Gallant JC (eds) (2000) Terrain analysis: principles and applications. Wiley, NY

Wink M, Wink C, Ristow D (1982) Biologie des eleonorenfalken (*Falco eleonorae*). Der enlfluss der hortslage auf den bruterfolg. J Ornithol 123:401–408

Wink M, Swatschek L, Feldmann F, Scharlau W, Ristow D (1990) Untersuchungen von verwandtschaftsbeziehungen in vogelpopulationen mittels DNA-fingerprint. Die Vogelwelt 111:86–95