Ecological Modelling of the Distribution of the Lanner Falcon Falco biarmicus feldeggii in Sicily at Two Spatial Scales

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Massimiliano Di Vittorio
Ecologia Applicata Italia srl

Luca Luiselli
Rivers State University of Science and Techn…

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ECOLOGICAL MODELLING OF THE DISTRIBUTION OF THE LANNER FALCON *FALCO BIARMICUS FELDEGGII* IN SICILY AT TWO SPATIAL SCALES

MODELOS ECOLÓGICOS DE LA DISTRIBUCIÓN DEL HALCÓN BORNÍ *FALCO BIARMICUS FELDEGGII* EN SICILIA A DOS ESCALAS ESPACIALES

Massimiliano Di Vittorio[1, 2 *], Andrea Ciaccio[2], Salvatore Grenci[2] and Luca Luiselli[3]

Summary.—The presence of the lanner falcon *Falco biarmicus feldeggi* in Sicily was modelled by generalized linear models using climatic, topographic, ecological and land-use variables at both the landscape (UTM cells of 10 × 10 km) and the home range (12.56 km^2) spatial scales. At the landscape scale, a significant spatial autocorrelation of the lanner population, corresponding to the longitudinal distribution of sites, was found, with the species occurring within the most xeric UTM cells. There was also a negative relationship between falcon presence and potential evapo-transpiration values, either in the coldest months or throughout the year. The same negative relationship was also seen with the surfaces of CORINE artificial areas, thus showing that the species has a low tolerance to any anthropogenic landscape. At home range scale, our predictive models revealed a preference for territories with steep slopes surrounded by natural grassland, sclerophyll vegetation, arable land and agricultural land. The lack of spatial correlation and the identification of specific preferred land use classes, suggests that the home range scale is more appropriate than the landscape scale for predicting the occurrence of lanner falcons. The maintenance of a stable lanner falcon population in Sicily should be addressed at both small and large scales.

Key words: habitat preference, lanner falcon, Sicily, spatial scales.

Resumen.—Se estimó la presencia del halcón borní *Falco biarmicus feldeggi* en Sicilia mediante modelos lineales generalizados utilizando variables climáticas, topográficas, ecológicas y de uso del suelo a escalas tanto del paisaje (cuadrículas UTM de 10 × 10 km) como de áreas de campeo (12,56 km^2).

[1] Ecologia Applicata Italia srl, Via Jenner 70-00151 Roma.

[2] Coordinamento Tutela Rapaci Sicilia.

[3] Environmental Studies Centre Demetra, via Olona 7, 00198 Rome, Italy; and Niger Delta Ecology and Biodiversity Conservation Unit, Department of Applied and Environmental Biology, Rivers State University of Science and Technology, PMB 5080, Port Harcourt, Rivers State, Nigeria.

* Corresponding author: divittoriomassimiliano@gmail.com

A escala paisajística se encontró una autocorrelación espacial significativa en la población de halcones, que correspondió a una distribución longitudinal de los sitios, presentándose la especie en las cuadrículas UTM más áridas. También hubo una relación negativa entre la presencia del halcón y los valores de evapo-transpiración, tanto en los meses más fríos como durante todo el año. Esa misma correlación también se obtuvo con las superficies de áreas artificiales CORINE, lo que muestra la baja tolerancia de la especie a paisajes transformados por el hombre. A escala de áreas de campeo los modelos revelaron preferencias por territorios con pendientes empinadas rodeadas por pastizales naturales, vegetación esclerófila y campos agrícolas. La falta de correlación espacial y la individualización de usos específicos de la tierra sugiere que la escala de área de campeo es más apta que la de paisaje para predecir la presencia de los halcones borní. Debería mantenerse una población estable de halcones borní en Sicilia tanto a pequeña como a gran escala.

Palabras clave: escalas espaciales, halcón borní, preferencia de hábitat, Sicilia.

Introduction

Statistical predictive models based on species distribution and devoted to the identification of conservation priorities have greatly benefited in recent years from the development of geographic information systems (GIS) and the growing availability of digital landscape data (e.g. Mladenoff and Sickley, 1998; Schadt *et al*., 2002; Guisan and Thuiller, 2005; Muñoz *et al.,* 2005). These tools have become particularly promising for those species that are still little known, despite probably being under threat (e.g., Guisan and Thuiller, 2005).

Ecological patterns depend on the spatial scale at which they are analysed (Wiens, 1989; Levin, 1992; Graf *et al*., 2005). A species' choice of suitable habitat is usually a byproduct of a process of integration of different spatial scales (Martínez *et al*., 2003; López-López *et al*., 2007). For these reasons, a multi-scale approach has often been proposed to identify different factors affecting a species' habitat preferences (Johnson, 1980; Store and Jokimäki, 2003; López-López *et al*., 2007).

The lanner falcon *Falco biarmicus* is a large falcon distributed across Africa, the Middle East and south-eastern Europe, with the European subspecies *F. b. feldeggii* being included in Annex I of the Bird Directive 79/409/CEE. In Italy, this species is listed as vulnerable (BirdLife International, 2004), with a population of about 70-100 breeding pairs (Di Vittorio, 2007; Andreotti *et al*., 2008; AA. VV., 2008; Amato *et al*., 2014). Sicily hosts the largest Italian (and also European) population of *F. b. feldeggi*, which still remains one of the ecologically less-known of European falcon species.

The aim of this study was to model the occurrence of lanner falcons in Sicily at two different spatial scales in order to classify the environmental features determining their habitat preferences, and hence to (1) identify the correct scale on which to plan conservation projects and (2) to highlight the explanatory variables necessary to maintain the Sicilian population.

Materials and methods

A total of 65 occupied lanner territories in Sicily (Di Vittorio, 2007) was used in order to analyze this species' habitat choices (fig. 1). We used two different spatial scales to model the ecological distribution of the lanner falcon in Sicily: a) the 'landscape' scale, by comparing the bioclimatic, ecological and land use characteristics of 279 10 × 10 km UTM cells in Sicily where the lanner falcon is present or absent; b) the 'home range' scale,

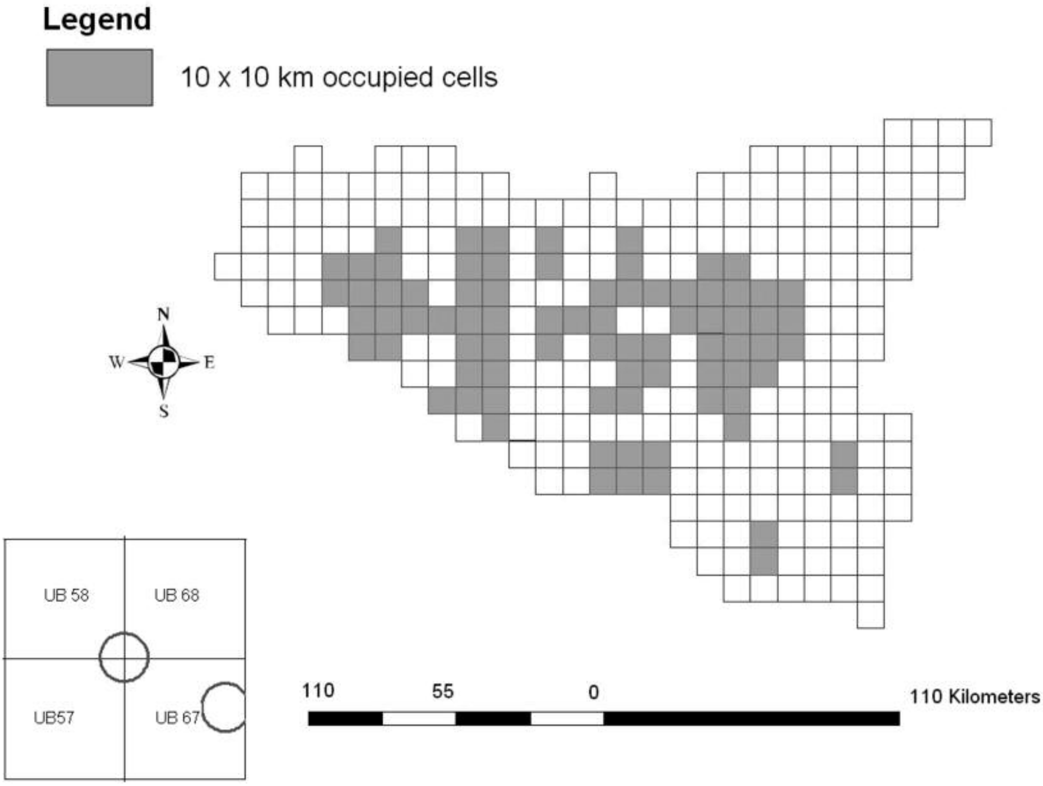

FIG. 1.—Distribution of the lanner falcon in Sicily, southern Italy. Occupied 10 × 10 km UTM cells are shaded in grey. In the insert, four UTM cells with home ranges of two pairs have been reported as example.
[Distribución del halcón borní en Sicilia, sur de Italia. Las cuadrículas UTM de 10 × 10 km aparecen en gris. En el recuadro insertado se muestran como ejemplo cuatro cuadrículas UTM con las áreas de campeo de dos parejas.]

based on the spatial distribution of territories centred on nest-sites and comparing the specific habitat composition of 65 stable nest sites and 65 unoccupied control points.

Measuring habitat variables at the landscape scale

The territory of Sicily was included into 289 10 × 10 km UTM cells best approximating the irregular contour of Sicily (fig. 1). Ten of these UTM cells were situated along the coast, and were characterised by less than 2 km^2 of land. These ten cells were excluded from our calculations because the target species does not nest at coastal sites (only one pair of lanner falcon, in the past, nested on coastal cliff). Therefore, only 279 cells were considered in our study.

Presence and absence data, recorded on the UTM 10 × 10 km grid of Sicily, were obtained from surveys conducted for the Sicilian biodiversity atlas (Di Vittorio, 2007; AA.VV., 2008). We used UTM squares since they are commonly utilised in ornithological surveys (Penteriani and Faivre, 1997; Ontiveros, 1999; Martínez *et al*., 2003; Sarà, 2008). The home ranges of the 65 pairs fall within 80 UTM squares. These UTM squares were considered as effectively occupied by the species, independently of the part of home range falling within each cell (see insert in fig. 1).

Occupied (n = 80) and unoccupied (n = 199) UTM squares were independently sampled to collect information on 17 distinct variables by using a GIS. The selected variables were those that best describe Sicilian environmental variability and that are most frequently used in published raptor studies in this geographic region (Di Vittorio, 2007). The measured variables included bioclimatic and topographic factors, and the number of favourite prey species, recorded in every UTM square (table 1). Climatic variables were obtained from the Database of the Sicilian Department of Environment

TABLE 1

Explanatory variables used to characterize the habitat selection by lanner falcon in Sicily. CORINE Land Covers (CLC) refers to land use surfaces expressed in hectares, with current CLC codes in parentheses.
[Variables explicativas usadas para caracterizar la preferencia de hábitat del halcón borní en Sicilia. CORINE Land Covers (CLC) indica la superficie de distintos usos del terreno en hectáreas, con los códigos CLC en paréntesis.]

Scale	Subset	Variables	
Landscape	Ecological	BIOC	Bioclimatic (Rivas-Martínez) index
		DAIN	De Martonne aridity index
		PET YR	Potential annual evapo-transpiration
		PET JN	Potential evapo-transpiration in January
		PET JL	Potential evapo-transpiration in July
		PREY	Number of lanner prey species
	Land use and climatic	ART	Artificial areas (1)
		AGR	Agricultural areas (2)
		FOR	Forest and semi-natural areas (3)
		WET	Wetlands and water bodies (4 and 5)
		AT YR	Annual ambient temperature
		AT JN	Ambient temperature in January
		AT JL	Ambient temperature in July
		SLO	Range of slope (min-max)
		ASL	Range of altitude a.s.l. (min-max)
		TAE	Thermal annual excursion
		ARF	Annual rainfal

TABLE 1 (cont.)

Scale	Subset	Variables	
Home range	Land use	ART	Artificial areas (111, 112, 113, 124 and 131)
		ARA	Arable land (211)
		VIN	Vineyards (221)
		ORC	Fruit trees and berry plantations (222)
		OLI	Olive groves (223)
		CRP	Annual crops associated with permanent crops (241)
		CCP	Complex cultivation patterns (242)
		MIX	Land occupied by agriculture, plus significant natural vegetation (243)
		BLF	Broad-leaved forest (311)
		CONF	Coniferous forest (312)
		MIXF	Mixed forest (313)
		NGR	Natural grassland (321)
		MHL	Moors and heathland (322)
		SCV	Sclerophyll vegetation (323)
		TWS	Transitional woodland/shrub (324)
		SVAR	Sparsely vegetated areas and bare rock (33)
		INW	Inland waters (51)
	Mosaic and topographic	R	Relative CLC richness = (s/smax) × 100
		D	Mean Fractal dimension = (logP/logA)
		D0	CLC Dominance = log s + H’
		H’	CLC Diversity = – Σ pi log pi
		s	Number of different Land Cover Classes
		NPA	Number of habitat patches of any cover type
		LPA	Surface of the largest patch/home range surface (×/1260 ha)
		SLO	Mean of slope
		ASL	Mean of altitude a.s.l.

and Land Management. Topographic variables were obtained from a digital elevation model (DEM) with an accuracy of 20 m pixel of horizontal and vertical resolution. Potential prey species were determined from literature data (Massa *et al*., 1991; Grenci and Di Vittorio, 2004).

Measuring the habitat variables performed at the home range scale

The process of modelling the ecological distribution of the study species was performed through a case-control design (Hosmer and Lemeshow, 2000; Keating and

Cherry, 2004). Nesting sites and control points were georeferenced on digital shape files, and the Minimum Utilised home Range (MUR) was determined by using a circular plot of 2 km radius around nest sites and control points (i.e., a MUR of 1,256 ha). Since the mean home range size of a lanner falcon pair remains unknown, a 2 km radius circle was used because this area corresponds to the minimum observed distance between two pairs (1,942 m) in Sicily and across the rest of Italy (Andreotti *et al*., 2008).

Using GIS, we sampled occupied (n = 65) and randomly selected unoccupied (n = 65) plots, in order to get information on 26 topographic, land use and mosaic pattern variables (table 1). Here too we used the variables that have most often been used in raptor studies in Mediterranean habitats, including in Sicily (Di Vittorio, 2007; Di Vittorio *et al*., 2012, 2015). Land use of all plots was obtained from a CORINE Land Cover (CLC) digital map (scale 1:25 000) of Sicily available from the Sicilian Department of Environment and Land Management. CLCs were coded according to the third hierarchical level (EEA, 2000) apart from inland waters, sparsely vegetated areas and artificial areas (buildings, roads and artificially surfaced areas), which were considered at the second level. Perimeters, areas and CLC of single patches of all plots were obtained from the same digital map, and mosaic patterns were redrawn from Forman (1995; see table 1).

The model

As a mathematical tool to express the presence/absence of the study species in Sicily, we fitted a Generalized Linear Model (GLM forward stepwise regression, see Hosmer and Lemeshow, 2000; Agresti, 1996; for applications on raptor conservation ecology see Donázar *et al*., 1993; Bustamante, 1997). This procedure was run independently to exclude those variables within each subset (topographic, land use and habitat structure) that did not contribute significantly ($p > 0.05$) to the occurrence of the study species (Carrete *et al*., 2007). The binomial dependent variable (presence/absence of falcons) was processed using the logit link function, with the error structure assumed to be binomial (McCullagh and Nelder, 1989). We built three different occurrence models at landscape scale and two at home range scale by including separately each subset of topographic, land use, climatic and habitat structure variables as independent predictors. We did not introduce all variables in the model to avoid over-parametrisation and over-fitting problems (Harrel, 2001; Grand and Cushman, 2003; Poirazidis *et al*., 2004; Balbontín, 2005; López-López *et al*., 2007). Environmental variables were standardised to eliminate the effect of differences in measurement scale. Spatial autocorrelation (sensu Legendre and Legendre, 1998) was minimised by including in every model the third-degree polynomial equation of the central latitude (x) and longitude (y) of each square:

$$G(x) = b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + \\ + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3.$$

This cubic trend surface ensures that (i) linear gradient patterns were extracted, and (ii) that more complex features (i.e. patches or gaps, which require quadratic and cubic terms to be correctly described) were also extracted (Legendre and Legendre, 1998).

A forward stepwise regression with the nine terms of the equation as predictor and the presence/absence of the lanner falcon as dependent variable was carried out to remove the non-significant spatial terms (Legendre and Legendre, 1998). Significant spatial terms ($p \leq 0.05$) were then included in the model with the other predictors in every model, in order to test whether they accounted for a significant change in the deviance. After the production of independent GLM regressions corrected for spatial autocorrelation, two different occurrence models were built for the landscape scale and two for the home range scale. We then repeated the GLM procedure by running the best subset regression option in order to select the most parsimonious model at every scale, thus reducing the explanatory variables because this process finds the smallest subset of variables that best predicted the response of a dependent variable by employing the second order Akaike Information Criterion (AICc) procedure.

The significant predictors selected after the GLM procedures at both spatial scales were further analysed to determine their relative influence over the presence of the study species. To take into account the interactions between the environmental predictors affecting the species occurrence at the two spatial scales, a hierarchial partitioning procedure was performed in order to specify the amount of the variation explained by the pure effect of each explanatory variable and what proportion was attributable to their interaction (Carrete *et al*., 2007).

The process of partial linear regression and variation partitioning (Legendre and Legendre, 1998, Lobo *et al*., 2002) split the total variation within the dependent variable (i.e. lanner falcon presence at a given scale) among the subsets of explanatory variables obtained from the GLM, and calculated the percentage of explained deviance for the pure effect of any single subset, for the joint effects of any combination of two (e.g. land use and ecological, land use and spatial, etc.) and for the joint effect of the three subsets together.

The jackknife randomisation procedure (Gotelli and Ellison, 2004) was used to assess the predictive power of the models. Thus, each model was re-computed deleting one case at a time (at both scales) and repeating the process as many times as there were observations. The model obtained was applied to the remaining cases to acquire a probability on whether or not each could be classified as a lanner territory, thereby providing a measure of the model's performance.

All analyses were performed using Statistica 6.0 and Minitab statistical softwares. Statistical significance for all analyses was $p < 0.05$.

Results

Ecological modelling at the landscape scale

The occurrence of the study species on the UTM map of Sicily (fig. 1) had a significant geographical effect, as can be seen by the fact that the GLM forward stepwise regression of the third-degree polynomial terms of longitude and latitude selected the linear and cubic functions of longitude (x and x^3 in table 2) as significant explanatory variables. Our GLM procedure revealed that the probability of finding a UTM cell occupied by lanner falcons decreases with the bioclimatic index (Rivas-Martínez, 1987) and with the potential evapo-transpiration for the year and in the month of January (table 2).

The ecological and longitudinal variables selected by the model explained 82.1% of the total deviance. With regards to the land use and climatic subset, the only statistically significant CLC variable predictor was the surface of artificial areas within a UTM cell, which displayed a negative relationship with the presence of falcons. Therefore, the probability of lanner falcon occupation decreased with the increase in artificial areas. This model, which also included the linear and cubic functions of longitude, explained 86.3% of the total deviance.

The performance of the occurrence model at this scale was satisfactory. The best model including ecological, land use and climatic variables showed a success rate (i.e., cases correctly predicted) of 92.1% (83.7% and 95.5% of presences and absences correctly predicted, respectively). After the jackknife

TABLE 2

Generalized linear model (GLM) estimates and significance statistic by the Wald test showing the probability of occurrence of lanner falcon in Sicily. The percentage of explained deviance is indicated in parentheses. The best subset and the Akaike test give the performance of the habitat preference models using every subset as independent predictors.
[Estimas de un modelo lineal generalizado (GLM) y significación estadística mediante la prueba de Wald de la probabilidad de presencia del halcón borní en Sicilia. El porcentaje de varianza explicado se indica entre paréntesis. El mejor subgrupo y la prueba de Akaike indican la resolución de los modelos de preferencia de hábitat utilizando cada subgrupo como predictores independientes.]

Scale	Subset	Estimate	SE	Wald	p	AICc	df	L. Ratio χ^2	p
Landscape	Ecological					283.386	5	63.394	0.0000
	Intercept	−1.331	0.191	48.558	0.000				
	BIOC	−1.506	0.432	12.137	0.000				
	PET YR	−1.034	0.301	11.786	0.001				
	PET JN	−0.766	0.376	4.152	0.042				
	x	4.680	1.310	12.758	0.000				
	x^3	−5.350	1.380	15.037	0.000				
	Explained deviance	(82.06%)							
	Land use and climatic					284.744	3	57.812	0.0000
	Intercept	−1.490	0.235	40.270	0.0000				
	ART	−1.300	0.488	7.084	0.0078				
	x	4.773	1.279	13.936	0.0002				
	x^3	−5.465	1.355	16.253	0.0001				
	Explained deviance	(86.33%)							
Home range	Land use					153.926	4	36.593	0.0000
	Intercept	0.089	0.215	0.171	0.6790				
	ARA	0.842	0.232	13.107	0.0003				
	MIX	1.135	0.383	8.771	0.0031				
	NGR	0.565	0.216	6.866	0.0088				
	SCV	0.749	0.239	9.789	0.0018				
	Explained deviance	(76.48%)							
	Mosaic and topographic					167.043	2	19.294	0.0000
	Intercept	0.010	0.190	0.003	0.9573				
	SLO	0.932	0.305	9.353	0.0022				
	ASL	−1.071	0.283	14.309	0.0002				
	Explained deviance	(86.59%)							

procedure, the success rate increased to 96.8% (94.6% and 97.3% of presences and absences correctly predicted).

To separate the effects of explanatory variables, we partitioned the variables in order to have more precise information about the relative weight of single predictors and the importance of their joint effects. At a landscape scale (fig. 2 A), most variation in model deviance (total model = 18.00) was explained by the pure effect of spatial coordinates (4.60). The pure effect of ecological variables was weak (4.40) and that of land use was negligible (0.10). The land use and ecological variables joint effect (5.40) was somewhat stronger as was the joint effect between longitude and ecological variables (11.20) and that of the three subsets together (–12.50). The negative value of the joint combination of the three subsets was due to their opposite effects on the presence of lanner falcon in the landscape. 82% of variation remained unexplained (fig. 2 A).

Ecological modelling at the home range scale

There were no significant spatial effects at this scale because of the arbitrariness of the control plots. Concerning land use, our GLM modelling showed that the probability of finding an occupied nesting territory increased (i) with the amount of arable land, (ii) with the amount of land occupied by either agriculture or significant patches of natural vegetation, (iii) with the amount of natural grassland, and (iv) with the amount of sclerophyll vegetation (table 2). The land use model explained 76.5% of the total deviance. Concerning the mosaic and topographic subsets, the probability of occurrence of a lanner falcon nesting site increased with the mean slope and decreased with the mean altitude, and the model explained 86.6% of the total deviance.

According to the validation procedure, our model performance was also satisfactory. The

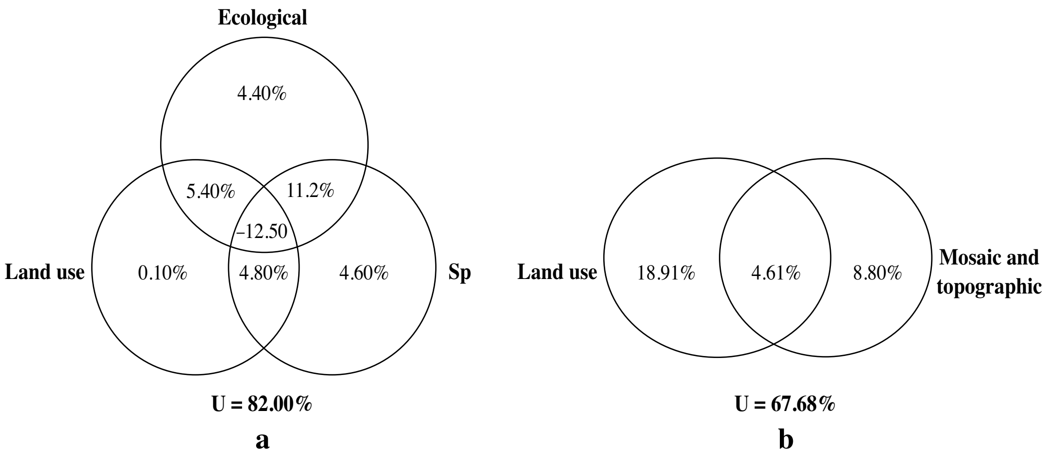

FIG. 2.—Result of the variation partitioning of the final model using the explanatory subsets: A = landscape level; B = home range level. Values shown in the Venn diagrams are the percentage of deviance explained by any given subset and by their interactions.

[Resultado de la partición de la varianza en el modelo final usando los subgrupos explicativos: A = nivel de paisaje: B = nivel de área de campeo. Los valores que se muestran en los diagramas son el porcentaje de varianza explicada por cada subgrupo y sus interacciones.]

best model, including land-use and mosaic and topographic predictors, correctly predicted 76.1% of cases (75.4% for presences and 76.9% for absences). After the jackknife procedure, the success rate increased up to 76.8% (73% of presences and 80.6% of absences correctly predicted). At this scale, neither latitude or longitude figured in any significant model. Variation partitioning showed that the pure effect of land use factors accounted for 18.9% of the explained variation, followed by mosaic and topographic factors (8.8%). The interaction between land use and mosaic and topographic components explained 4.6% of the variability, with 67.7% of the variation remaining unexplained (fig. 2 B).

Discussion

The habitat preference of lanner falcon in Sicily was described, at the two scales of analysis, by a limited number of ecological variables. At the landscape scale, our results confirmed that these birds select dry and warm environments (Ferguson-Lee and Christie, 2001; Di Vittorio, 2011; Sarà, 2014) and avoid artificial areas, whose expansion represents one of the main threats highlighted to date for this species (Andreotti and Leonardi, 2007).

Drier, warmer and rockier open habitats are concentrated especially in the southwestern and mid-eastern parts of Sicily; therefore, the linear function of bioclimatic index explains well the preference of the subspecies *feldeggii* for the dry Mediterranean landscapes of Sicily. 59% of the UTM cells occupied by the study species were situated within the xeric belt, from the lower dry thermo-Mediterranean horizon to the lower sub-humid thermo-Mediterranean. The remaining occupied cells, instead, ranged from the upper dry meso-Mediterranean to the lower subhumid meso-Mediterranean. No cells occupied by lanner falcons were found in less arid UTM cells found from the upper subhumid meso-Mediterranean to the upper humid supra-Mediterranean.

Humid conditions (ombrotype) appeared to be more important as a limiting factor for the presences of the study species than cool ambient temperatures (thermotype). This result is consistent with the previously described preference of *F. b. feldeggii* for dry, warm and sunny habitats and the semi-desert environments of the Caucasus (Cramp and Simmons, 1980; Abuladze *et al*., 1991; Andreotti and Leonardi, 2007). Conversely, the fact that annual and coldest month (January) PET values appeared as significant negative predictors for the falcon presence remains unexplained. Lanner distribution merged in UTM cells within the PET range of 700-1000 mm: lanner falcons are present in 32.5% of UTM cells with PET between 700-800 mm, in 62.5% of UTM cells with PET between 800-900 mm and are only present in 5% of those with PET between 900-1000 mm. Millimetres of PET give the joint value for water loss from the land surface and vegetation that would occur given unlimited provision of water (Aber and Melillo, 2001), and PET is currently used as an alternative to express energy availability in an area. Regions with the highest PET are considered most likely to support the highest diversity of tree species (Currie and Paquin, 1987; Adams and Woodward, 1989). However, PET itself correlates strongly with the total of plant biomass that accumulates through photosynthesis in a given area (Currie and Paquin, 1987). Therefore, our supposition is that forested regions will have larger PET values. Consequently, the negative relationship between PET values (either in the coldest months or through the year) and the presence of the study species may explain its absence from those UTM cells that were mostly covered by woodland and continuous forest cover.

The extent of CORINE Land Cover artificial areas was on average fivefold less in the 80 UTM cells where lanner falcons occurred than in the 199 cells where they were absent (mean ± SE: 2.36 ± 4.19 vs. 9.20 ± 15.40 km^2). Hence, we may conclude that this falcon keeps away from all types of artificial terrain. This active avoidance of 'altered' areas by the study species may have strong conservation implications, since any anthropogenic interference near a lanner falcon site could, in many cases, produce nest desertion (Di Vittorio, 2004; Andreotti and Leonardi, 2007; Di Vittorio, 2011) .

Indeed, considering the distribution referred to in Di Vittorio (2007), at least 15 sites that were once occupied by the lanner falcon are now occupied by peregrine falcons *Falco peregrinus*. We think that it is possible that the presence of the peregine falcon, which is currently increasing in Sicily (Sarà, 2008), together with habitat changes, could constrain lanner occupancy of territories (Sarà, 2014). However, according to Di Vittorio *et al*. (2004) and Amato *et al*. (2014), the substitution by peregrine falcons could affect mainly lanner falcon pairs with low occupancy rates and low productivity, and occurs mainly in sites where heavy human disturbance also occurs.

At the home range scale, our explanatory model showed that the species selected patches of natural (grassland and sclerophyllous vegetation) and agricultural (arable and agricultural land use mixed to natural vegetation) habitats at low altitudes, confirming the results of Di Vittorio (2011) and Sarà (2014). In this regard, it is noteworthy that low altitude was identified as good predictor to explain a high occupancy rate in another study (Amato *et al*., 2014).

A significant spatial autocorrelation effect explained a large amount of model variation at the landscape scale, implying that the population of lanner falcons in Sicily is not randomly distributed across space.

As cliff availability is often related to the slope and ruggedness of the terrain (Carrete *et al*., 2000; Balbontín, 2005; Muñoz *et al*., 2005), it is reasonable that the observed high preference for sloping terrain may actually reflect the relative availability of cliffs for nesting. Our results hence confirmed the species preference for steppic and pseudosteppic mediterranean habitat (Bassi *et al*., 1992; Leonardi, 1994; Morimando *et al*., 1997) with abundant rocky ground and open areas (Abuladze *et al*., 1991).

In the Mediterranean area, the protracted interactions in the past between ecosystems and humans developing land use practices have produced particular landscapes deriving from the mixture of many habitats in different stages of regeneration and degradation (Blondel and Aronson, 1999), forming the characteristic cereal-steppe habitat selected by this falcon within its Mediterranean range (Bassi *et al*., 1992; Leonardi, 1994; Morimando *et al*., 1997). This therefore highlights the importance of the habitat generated by admixture of natural and agricultural habitats in Mediterranean ecosystems for species richness (Tews *et al*., 2004) and for steppe-land birds (Bota *et al*., 2005; Wolff, 2005; Onrubia and Andrés, 2005) and of necessary urgent changes in the Common Agricultural Policy to halt biodiversity loss (European Commission, 2006).

Overall, our findings suggest that the maintenance of a stable lanner falcon population in Sicily should be addressed at both small and large scales. Sicily hosts the largest European population of lanner falcons, and less than 20% of the Sicilian population breeds within Special Protection Areas (SPAs) or Special Areas of Conservation (SACs), since lanner falcons prefer habitats that are not well represented in protected areas (Andreotti *et al*., 2008).

A great transformation in open habitat and agricultural land has occurred over the last 20 years, especially in central and southern

Sicily, due to the expansion of vineyards, infrastructure (roads, wind farms) and artificially managed forest. Land abandonment is of special concern: the extensive decline in traditional husbandry and agriculture in hilly and rugged areas is causing extensive habitat degradation at several lanner falcon sites.

According to our models, conservation actions should minimise anthropogenic interference and infrastructure building in any lanner falcon territory, but they should maintain extensive agricultural land uses and practices in the territories of the stable pairs most exposed to habitat changes. It is also essential to establish continuous monitoring of the population, to prevent the theft of eggs and chicks from nests, a development that is having a profound impact on the populations of a number of raptor species in Sicily (López-López *et al*., 2012; Di Vittorio *et al*., 2015).

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