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Spatial distribution and breeding performance of Golden Eagles *Aquila chrysaetos* in Sicily: implications for conservation

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Abstract. Understanding ecological requirements of animals is essential to improve habitat management and conservation strategies for endangered species. However, as most studies on Golden Eagle's habitat preferences and breeding ecology have been conducted in northern latitudes (e.g. USA, Scotland, Scandinavia and the European Alpine region), our knowledge of the species ecology in the Mediterranean basin is more limited. Currently, only 16 pairs still remain in Sicily (southern Italy) and in spite of this delicate status of conservation, there were no previous attempts to analyse ecological requirements of the species in the island. Therefore, we monitored Golden Eagles from 1990 to 2012, analyzed habitat characteristics of breeding territories and quantified habitat relationships with breeding performance. We used a case-control design through Generalized Linear Models to examine ecological descriptors at two different spatial scales: (i) "territory" defined as a plot of 4 km radius centered in the nesting area; and (ii) "landscape" by means of the 10 × 10 km Universal Transversal Mercator (UTM) cells where the species was present or absent. At the territory scale, the presence of Golden Eagle was positively related to the ruggedness of the terrain and to the extension of arable land, and negatively to the extension of forests. At the landscape scale the presence of the species was positively correlated with the range of slope and negatively to the aridity of the surrounding landscape and the extension of forest areas. The Golden Eagle has experienced a strong decline in breeding performance during the last two decades in Sicily, which negatively impacted population dynamics. The best model at the territory scale included the surface of sparsely vegetated areas (i.e. a surrogate of prey availability) as the best predictor of breeding output (i.e. number of young fledged). At the landscape scale, the best predictor of breeding output was the average annual temperature (positive effect) and surface of artificial lands (negative effect). Significant differences in environmental characteristics were found between occupied and unoccupied sampling units and between territories of high and low breeding performance. Our results highlight the importance of maintaining the structure of landscape arising from traditional forms of extensive agriculture in the Mediterranean basin, thereby favouring prey availability, and the importance of limiting human activities and changes in land use in rugged mountainous areas.

Key words: agriculture, *Aquila chrysaetos*, distribution, GIS, habitat heterogeneity, Italy, raptors, spatial analysis, variance partitioning

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INTRODUCTION

Understanding and quantifying habitat preferences of animals is essential to improve habitat management and conservation strategies for endangered species, especially in places where human interests and the ecological requirements of priority species come into conflict (e.g. Manly et al. 2002, López-López et al. 2006, 2007a,b, Di Vittorio et al. 2012). This becomes particularly evident in places such as the Mediterranean basin, an outstanding "hotspot" of biological diversity with a long history of integration between natural ecosystems and human activities (Maiorano et al. 2006, Blondel et al. 2010, López-López et al. 2011). The Mediterranean basin is one of the most significantly altered hotspots in the world (Myers et al. 2000), with the human presence being the main modeler of the structure of ecosystems that we currently observe (Blondel et al. 2010). Hence, studies aimed at characterizing the ecological requirements of priority species still inhabiting in human-dominated landscapes are of primary importance to understand their spatial structure and to assess the relative contributions of different factors that determine the overall distribution pattern (López-López et al. 2006, Muñoz & Real 2013).

This paper concerns the case of the Golden Eagle *Aquila chrysaetos*, a long-lived large raptor distributed along the Palearctic, Nearctic and, marginally, in the Indomalayan and African regions (Ferguson-Lees & Christie 2001). Globally, the species is listed as Least Concern (Birdlife International 2013) owing to an extremely large range and large population size. However, the species is classified as rare in Europe, where it has the highest level of protection (Annex 1 of the EU Directive on the Conservation of Wild Birds, EEC/79/409). Population trends are stable or slightly increasing in some parts of its breeding range, mainly in North America as well as northern and central European countries (BirdLife International 2013). However, the species has suffered a severe decline in some southern and eastern European countries (e.g. Albania, Croatia, Greece, Belarus and Ukraine) (Watson 1994, Haller & Sackl 1997, BirdLife International 2013). The combination of human persecution and reduction in prey availability due to habitat degradation and forest expansion as a consequence of abandonment of traditional agro-pastoral practices have been identified as potential long-term threats in several parts of the distribution area (Pedrini & Sergio 2001a,b). In addition, shooting, poisoning, electrocution and trapping are considered the main causes of non-natural mortality (McGrady 1997, Watson 2010).

Most studies about Golden Eagle's habitat preferences have been mainly conducted in the northern and central range of its distribution area (USA, Scotland, Scandinavia and the European Alpine region; e.g. Tjenberg 1983, Watson & Dennis 1992, Pedrini & Sergio 2001b, McGrady et al. 2002, McIntyre 2002, Fasce et al. 2011, McIntyre & Schmidt 2012). However, our knowledge about habitat requirements in the Mediterranean basin is more limited. In particular, there are very few studies focused on Golden Eagle's ecology in Mediterranean landscapes, including studies of breeding ecology (e.g. Carrete et al. 2000), habitat use (e.g. Tapia et al. 2007, Soutullo et al. 2008) and conservation (e.g. Di Vittorio 2007, López-López et al. 2007a). These areas are highly humanized and the change of traditional farming methods and unadvised territorial management has caused a significant biodiversity loss (Massa & La Mantia 2007). A good example of this general pattern is Italy, where the situation of the Golden Eagle is contrasting, with some areas where the species is increasing (Alps and Appenines), while in other areas the species underwent a strong decline (southern regions). There is an estimated population of Golden Eagles that ranges between 500 and 800 pairs in continental Italy, mostly located in the Alps and the Apennines (Spina & Volponi 2008). However, the species suffered a strong decline in Sicily in the last century (Lo Valvo et al. 1993), and currently only 16 pairs still breed in the northern part of the island (Di Vittorio et al. 2003, Di Vittorio 2007, 2011). Previous studies carried out in Sicily reported a strong reduction in breeding performance and in the number of nesting pairs occupying territories (Di Vittorio 2011). As a consequence, this insular population is on the brink of extinction and deserves classification as endangered at regional level.

The aim of this study was to characterize ecological requirements of Golden Eagle in Sicily and to quantify its relationship with breeding performance. To this end we firstly analyzed habitat preferences of the species at two different spatial scales using a case-control design by means of a combination of multivariate analyses. Then, we analyzed the relationship between habitat characteristics and breeding performance. We also compared territories of high and low productivity in order to achieve a better understanding of specific habitat associations of the species in Mediterranean areas. Finally, starting from the current situation in Sicily as an example, we try to provide useful directions for management and conservation of large raptors in human-dominated landscapes.

METHODS

Study area

We focused our study on the island of Sicily, which is the largest Mediterranean island (area — 25,414 km^2) and also one of the most populated in the western Mediterranean (195 inhabitants per km^2). Altitudinal range oscillates from sea level to 3,320 m of Mount Etna. Almost a quarter of the territory of the island is mountainous, mainly volcanic. Sicily has a typical Mediterranean climate with mild and wet winters and hot, dry summers. The high biodiversity of the island results from the biogeographic history, which in turn reflects a great variability of environmental conditions. In the past, traditional land use was mainly devoted to agriculture, which resulted in the presence of rich habitat mosaics. However, in the last decades, Sicily has undergone a dramatic change in forestry and agricultural practices, producing a consequent change in habitat and biodiversity (La Mantia 2002, Massa & La Mantia 2007). Habitat degradation and forest expansion as a consequence of abandonment of traditional agro-pastoral practices are enhancing rapid habitat changes (La Mantia & Barbera 2003). Afforestation, usually carried out using exotic species is another cause of concern (La Mantia & Pasta 2001, Massa & La Mantia 2007).

Field surveys and study design

From 1990 to 2012, 16 breeding territories of Golden Eagles were monitored, 12 of which were regularly occupied (Fig. 1). To study habitat preferences we used a case-control design (Hosmer & Lemeshow 2000, Keating & Cherry 2004) at two spatial scales: (i) a 'landscape' scale, defined as the 10 × 10 km Universal Transversal Mercator (UTM) cells where the species was present or absent; and (ii) a 'territory' scale, focused on the spatial distribution of breeding territories, which were delineated using a plot of 4 km radius centered in the nesting sites. This measure was chosen because, based on telemetry data, a circle with this radius has been shown to represent a good approximation of the core home range of Golden Eagles (Sergio et al. 2006, Haworth et al. 2010). At the scale of landscape, 66 occupied UTM squares were compared with 222 unoccupied squares, using bioclimatic, ecological and land use variables as independent factors (Table 1). We chose this, a priori, unbalanced design to reflect to the greatest extent the habitat heterogeneity of the island and then to obtain the most complete landscape model. At the territory scale, habitat composition of 16 occupied breeding sites was compared with the same number of unoccupied breeding sites randomly selected across the whole island using a buffer of 4 km radius (Sergio et al. 2006). Spatial autocorrelation of territories was tested by means of Moran's I test of the "spatial statistics tools" in ArcMap 10.0. (www.esri.com).

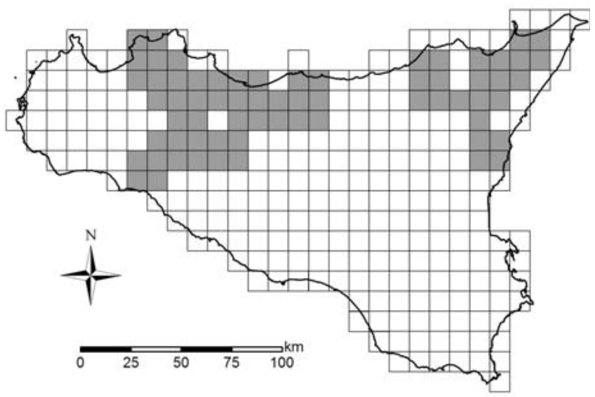

Fig. 1. Distribution of Golden Eagle in Sicily (southern Italy). Occupied 10 × 10 km UTM cells are shaded in grey.

Measurement of habitat variables at the landscape scale

The occurrence of Golden Eagle in UTM squares was obtained from the Atlas of Biodiversity of Sicily (AAVV 2008) and by means of field surveys. All territories were regularly visited during each breeding season to record exact location of nests, occupancy and breeding performance (i.e. number of young fledged). A territory was considered occupied if we observed nests with green branches, typical pair behaviour, courtship, brood rearing activity or young (López-López et al. 2007c). For our analyses, the UTM squares intersected with a buffer of 4 km radius centred on the 16 territories were considered occupied by the Golden Eagle. Thereby, the home ranges of these 16 territories were encompassed within 66 UTM 10 × 10 km squares (mean = 3.22 UTM squares/territory, SD = 1.41), which were considered as occupied by the species.

Next, occupied and unoccupied UTM squares were independently sampled to gather information on 20 environmental variables using a GIS (Table 1). The variables included climatic, topographic and land use factors. Climatic and land use variables (nine of them recorded at the second level of CORINE; EEA 2000) were obtained from the database of the Department of Environment and Land Management of Sicily. Topographic variables were obtained from a digital elevation model (DEM) with 20 m pixels of horizontal and vertical resolution from the Department of Environment and Land Management of Sicily. With regards to bioclimatic characteristics, we used the "de Martonne" aridity index, computed as the ratio of the average annual rainfall (H) and the average annual temperature (C°) increased by 10 (de Martonne 1926). Values of this index are inversely proportional to aridity, thus reflecting the sequence of biogeographic altitudinal zones and thus vegetal associations as the index increases.

Measurement of habitat variables at the territory scale

Nest sites and randomly selected unoccupied sampling units were geo-referenced on a GIS digital shape. Then, we drew a circular plot with radius equal to 4 km around nest sites and unoccupied points to determine the Minimum Utilized Home Range (Sarà & Di Vittorio 2003), avoiding neighbouring territories. Then, both occupied (n = 16) and control (n = 16) points were independently sampled to gather information on 25 variables through a GIS. Environmental predictors included land use and factors describing habitat composition (Table 1). Land use variables were obtained from the CORINE land-use map at 1:25000 scale (Department of Environment and

Table 1. Explanatory variables used to characterize the Golden Eagle's habitat preferences in Sicily. The corresponding CORINE Land Cover class code at third level is shown in brackets.

Scale	Subset	Variable	
Landscape	Climatic and Topografic	BCI	"de Martonne aridity" index
		AT_YR	Average annual temperature
		AT_JN	Average temperature in January
		AT_JL	Average temperature in July
		SLO	Range of slope (min-max)
		SLO m	Average slope
		DPS	Density of primary roads
		DSS	Density of secondary roads
		ASL	Mean of altitude a.s.l.
		TAE	Annual thermal range (min-max)
		RAIN	Annual rainfall
	Land use II CLC	URB	Urban farbric (11)
		ART	Artificial and infrastructures (12, 13, 14)
		ARA	Arable land (21)
		PERM	Permanent crops (22)
		HET	Heterogeneous agricultural areas (24)
		FOR	Forests (31)
		SHRU	Shrubs and/or herbaceous vegetation associations (32)
		OPE	Open spaces with little or no vegetation (33)
		WET	Wetlands and Water bodies (41, 42, 51)
Territory	Land use and mosaic	CUF	Continuous urban fabric (111)
		DUF	Discontinuous urban fabric (112)
		IND	Other artificial areas (121,122, 123, 124 and 131)
		ARA	Arable land (211)
		PERM	Permanent crops (22)
		HET	Heterogeneous agricultural areas (24)
		FOR	Forests (31)
		BL_FOR	Broad-leaved forest (311)
		CON_FOR	Coniferous forest (312)
		MIX_FOR	Mixed forest (313)
		NGR	Natural grassland (321)
		MHL	Moors and heathland (322)
		SCV	Sclerophylous vegetation (323)
		TWS	Transitional woodland/shrub (324)
		BAR	Bare rock (332)
		SVA	Sparsely vegetated areas (333)
		WAT	Inland waters (51)
		R	Relative CLC richness = ($s/smax$) x 100
		H'	CLC Diversity = $- \Sigma\, pi \log pi$
		S	Number of different Land Cover Classes
		NPA	Number of habitat patches of any cover type
		LPA	Surface of the largest patch/territory surface (x/5000 ha)
	Topographic	SLO	Range of slope (min-max)
		SLO m	Average slope
		DSS	Density of secondary road

Land Management of Sicily 2001). We used the CORINE Land Cover Classes (hereafter CLCs) according to the third hierarchical level (EEA 2000) except for inland waters, permanent crops, forests and heterogeneous agricultural areas, which were considered at the second level. The count, perimeter, area and CLC of singles patches of all plots were obtained from the same digital map. The mosaic patterns were redrawn following Forman (1995) using the numbers, surfaces, perimeters and boundaries of patches and CLCs defined in Table 1.

Breeding performance and environmental characteristics

We firstly compared occupied versus unoccupied sampling units (i.e. territories and UTM squares) in relation to environmental characteristics by means of a Mann-Whitney test. Then, we divided the territories into two classes according to their productivity (computed as the number of young fledged in each territory divided by the number of years in which the territory was monitored during the study period) and we compared them using the Mann-Whitney test. Territories with an average productivity below the average productivity in Sicily during the study period (i.e. 0.475 young fledged/year, own data) were classified as "low" quality ($n = 8$) and territories above the average productivity during the study period were classified as "high" quality ($n = 8$) (López-López et al. 2007c). We also compared the differences in average productivity of each territory considering two different periods (from 1990 to 1999 and from 2000 to 2012) using a Wilcoxon matched-pairs test. Changes in annual productivity throughout the study period were also tested using a Monte Carlo ANOVA using Ecosim software (Gotelli & Ellison 2013). All tests were two-tailed and statistical significance was set at $p < 0.05$. Statistics were computed in Statistica 6.0 (www.statsoft.com).

Model design and statistical procedure

Generalized Linear Models (GLZs) were used to model Golden Eagle's habitat preferences and to quantify its relationship with breeding performance in Sicily. Firstly, we used a stepwise forward regression procedure to test the statistical significance of each variable in turn, a technique that has been commonly used to assess habitat preferences of raptors in addition to obtain predictive distribution models for conservation (Hosmer & Lemeshow 2000, e.g. López-López et al. 2006, 2007a,b). In the regression procedure every subset of variables of Table 1 was used as independent predictors. Variables were excluded within each subset when they did not correlate significantly to eagles' presence (Wald test $p > 0.05$) (Di Vittorio et al. 2012). Then, two separate analyses were performed, one using the presence/absence of Golden Eagle as the binomial dependent variable (coded as 1/0), and a second analysis in which the average productivity of each territory during the study period was used as dependent variable. In the first case a logit link function and a binomial distribution of error structure were used, whereas in the second case an identity link function and a normal distribution of error were used (McCullagh & Nelder 1989). In both cases, we did not construct a comprehensive model including all variables at the same time to avoid over-parameterization and over-fitting problems, given that this could be statistically misleading (López-López et al. 2007a, Di Vittorio et al. 2012). We standardised all environmental variables to remove the effect of differences in the original scale of measurement.

To avoid the bias in model parameter estimation caused by spatial autocorrelation, especially when making ecological inference (Legendre & Legendre 1998), we corrected the models including a spatial term using a third-degree polynomial equation of the central latitude (x) and longitude (y) of each square as follows: $b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3$ (Borcard & Legendre 2002). Then, to eliminate the non-significant spatial terms (Legendre & Legendre 1998) we run a preliminary stepwise forward regression with the nine terms of the equation as predictor variables and the presence/absence of Golden Eagle or the average productivity during the study period as dependent variables. Subsequently, we included the significant spatial terms ($p < 0.05$) with other predictors (i.e. climatic, topographic and land-use) in each model to test if they accounted for a significant change in deviance. Finally, after running independent logistic regression models corrected for spatial autocorrelation, we built two different occurrence models for each scale including only significant variables obtained in previous analyses. To select the most parsimonious model at each scale, we then repeated the GLZ procedure by running the best subset regression option. This approach allowed us to reduce the group of explanatory variables finding the smallest subset of variables that best predict the response of a dependent variable (e.g. López-López et al. 2007a, DiVittorio et al. 2012).

Model validation

We validated the predictive power of the models on presence/absence of Golden Eagles by means of a jackknife randomization procedure (Gotelli & Ellison 2004). To this end, we re-computed each model deleting systematically one case in turn, repeating the process as many times as observations were recorded. The resultant model was applied to the remaining cases to obtain a probability on whether or not they could be classified as a Golden Eagle territory, thereby providing a measure of the model's performance (Di Vittorio et al. 2012).

Deviance and hierarchical partitioning

The significant terms of the explanatory variables selected in the most parsimonious models were analysed in order to determine the comparative influence of each variable as well as the separate effect of interactions (Borcard et al. 1992). This analysis was performed at both scales (landscape and territory) likewise DiVittorio et al. (2012). At the landscape scale, spatial, climatic, topographic, and land use variables were included, whereas, spatial, mosaic and topographic variables were included at territory scale. The decomposition of the variation into subsets of explanatory variables was carried out by means of a partial regression analysis (Legendre & Legendre 1998).

RESULTS

Factors affecting Golden Eagle occurrence at landscape scale

Using presence/absence of Golden Eagles as dependent variable, the model including climatic and topographic variables showed that the probability of presence of Golden Eagle increased with the slope range of the UTM square and with the "de Martonne" aridity index (Table 2). The best fitting of spatial terms included the cubic function of latitude and the combined linear function of longitude and latitude as the best predictors. Regarding the land-use subset of variables (second level of CLC classes), the best model evidenced that the probability of Golden Eagles' occurrence decreased with the surface of forested land and a complex combination of spatial terms (longitude and latitude) (Table 2).

Table 2. Generalized Linear Model (GLZ) estimates and significance statistics of the Wald test showing the probability of occurrence of Golden Eagle in Sicily. The Akaike weight (AIC_w) shows the performance of the best habitat preference model of each subset of independent predictors. x — latitude, y — longitude. Other variable abbreviations — see Table 1.

Scale	Subset		Estimate	SE	Wald	p	AIC_w	df	Likelihood Ratio χ^2	p
Landscape	Climatic and Topographic						0.779	4	124.460	< 0.001
		Intercept	0.656	0.751	0.763	0.382				
		BCI	2.317	0.633	13.384	0.000				
		SLO	1.373	0.539	6.488	0.011				
		xy	2.165	0.778	7.748	0.005				
		y^3	1.318	0.633	4.333	0.037				
		Explained deviance	59.87%							
	Land use						0.993	5	129.384	< 0.001
		Intercept	2.949	1.356	4.725	0.030				
		FOR	-2.779	0.959	8.393	0.004				
		xy	-368.614	111.861	10.859	0.001				
		x^2	775.511	238.929	10.535	0.001				
		x^3	-406.937	127.087	10.253	0.001				
		y^3	16.561	5.721	8.378	0.004				
		Explained deviance	57.00%							
Territory	Land use and mosaic						0.960	2	26.574	< 0.001
		Intercept	0.251	0.720	0.122	0.727				
		ARA	3.118	1.397	4.979	0.026				
		FOR	-2.362	1.203	3.855	0.050				
		Explained deviance	54.60%							
	Topographic						0.996	2	44.361	< 0.001
		Intercept	0.004	0.620	0.000	0.995				
		y	0.000	0.000	5.460	0.020				
		SLO m	3.308	1.108	8.919	0.003				
		Explained deviance	44.44%							

At this scale, the largest fraction of the variability (24.80% of explained variance) was accounted for by the combined effect of the spatial components with climatic and topographic factors, followed by the combined effects of topographic and climatic and land-use variables (15.60% of explained variance), as evidenced by the hierarchical partitioning analysis of the variance. The pure effect accounted for land use variables was negligible, while the combined effect of topographic, climatic and land-use variables was negative.

The performance of the occurrence model was satisfactory. The best model at landscape scale including climatic and topographic variables showed a success rate (i.e. cases correctly predicted) of 90.23% (90.91% and 89.55% of presences and absences correctly predicted, respectively). After the jackknife procedure, the success rate was 90.42% (91.16% and 89.68% of presences and absences correctly predicted). The success rate of the best model including land-use variables was 93.27% (92.42% of presences and 95.52% of absences correctly predicted). After validation, the success rate was 93.86% (92.52% for presences and 95.20% for absences).

At this scale, significant differences between occupied and unoccupied sample units were found in relation to climatic, topographic and land use factors (Table 3). Occupied UTM squares were characterized by higher average altitude, lower aridity, higher average temperatures, higher ruggedness, higher coverage of forests and shrublands, and lower surface of arable lands (Table 3).

Factors affecting Golden Eagle occurrence at territory scale

Moran's test for spatial autocorrelation showed that the distribution pattern of territories in Sicily was significantly clustered (Moran's Index = 0.556, z-score = 2.544, p = 0.011). Regarding the land-use subset of variables, the best model showed that the probability of finding an occupied territory of Golden Eagle in Sicily decreased with the surface of forests and increased with the extension of arable lands (Table 2). Considering the topographic subset of variables, the model

Table 3. Comparisons of environmental predictor values (means ± SD) in areas occupied (present) and unoccupied (absent) by the Golden Eagle in Sicily. Mann-Whitney tests were conducted for each variable at both spatial scales. Only significant comparisons are shown. Variable abbreviations — see Table 1.

Scale	Subset	Variable	Present	Absent	Z	p
Landscape	Climatic and topographic	ASL (m)	595.84 ± 340.84	330.85 ± 256.68	6.09	0.000
		BCI (mm/ºC+10)	6.82 ± 2.92	3.82 ± 2.40	7.46	0.000
		TAE (ºC)	3.48 ± 1.14	2.64 ± 0.88	5.92	0.000
		RAIN (mm)	4.62 ± 1.60	3.92 ± 1.02	3.04	0.002
		AT_YR (ºC)	3.90 ± 1.73	2.56 ± 1.31	6.02	0.000
		AT_JN (ºC)	3.36 ± 1.18	2.43 ± 0.93	5.97	0.000
		AT_JL (ºC)	1.52 ± 0.48	1.17 ± 0.32	7.26	0.000
		SLO (degrees)	64.12 ± 7.78	49.13 ± 13.15	8.66	0.000
		SLO m (degrees)	15.33 ± 5.00	9.00 ± 5.22	7.98	0.000
	Land use	ARA (ha)	1822.16 ± 2175.46	3075.42 ± 2477.16	-3.68	0.000
		FOR (ha)	1300.23 ± 1276.39	471.36 ± 885.72	6.07	0.000
		SHRU (ha)	2754.20 ± 1579.62	1724.57 ± 1650.25	4.98	0.000
		WET (ha)	61.40 ± 119.81	29.87 ± 102.09	2.37	0.018
Territory	Land use and mosaic	ARA (ha)	473.74 ± 621.94	2270.09 ± 1341.17	-4.11	0.000
		MIX_FOR (ha)	220.67 ± 217.30	139.70 ± 226.90	1.96	0.050
		BL_FOR (ha)	786.45 ± 812.18	51.34 ± 124.26	3.78	0.000
		NGR (ha)	668.53 ± 360.65	234.86 ± 332.78	3.21	0.001
		SCV (ha)	576.95 ± 422.87	298.22 ± 407.25	2.47	0.013
		SVA (ha)	182.76 ± 261.95	38.68 ± 115.28	2.05	0.041
		S	12.75 ± 2.84	9.31 ± 3.72	2.65	0.008
		R	7.52 ± 1.51	5.61 ± 2.11	2.62	0.009
		LPA (ha)	0.31 ± 0.10	0.52 ± 0.21	-3.09	0.002
		H’	7.31 ± 4.71	12.90 ± 5.31	-3.47	0.001
	Topographic	SLO (degrees)	48.40 ± 7.84	25.14 ± 7.40	4.60	0.000
		SLO m (degrees)	14.57 ± 2.64	6.38 ± 3.07	4.41	0.000

showed that the probability of finding an occupied territory increased with the average slope and the linear function of latitude (Table 2).

At this scale, according to the hierarchical partitioning of the variance, the analysis evidenced that the largest portion of the variability (69.06%) in the Golden Eagle's habitat preferences was explained by the combined effect of land use and topographic variables, followed by the joint effect of spatial components and topographic variables (39.74%). The stronger pure effect was accounted for the topographic variables (9.20%) followed by spatial effects (6.90%).

According to the validation procedure, model performance was also satisfactory at this scale. The best model including land-use predictors managed to predict correctly 87.50% of cases (87.50% for presences and 87.50% for absences). After the jackknife procedure, the success rate slightly increased to 87.91% (88.35% of presences and 87.46% of absences correctly predicted). The success rate of the best model including topographic variables was 93.75% (93.75% in both cases). After validation, the success rate was 93.86% (93.83% for presences and 93.90% for absences).

At this scale, significant differences between occupied and unoccupied sample units were found in relation to land use and topographic factors (Table 3). Occupied UTM squares were characterized by lower surface of arable lands and higher surface of mixed forests, broad-leaved forests, natural grasslands and sclerophylous vegetation (Table 3).

Determinants of breeding performance at two spatial scales

At landscape scale, the best model including climatic and topographic variables selected the average annual temperature as the best predictor of breeding output (Table 4). The best model for land use variables showed a negative relationship between the surface of artificial lands and productivity. No spatial effects were detected at this scale (i.e. latitude and longitude did not enter in any significant model). Variance partitioning showed that the pure effect of climatic and topographic factors accounted for 6.50% of the explained variance, followed by land use (2.9%). The interaction between climatic and topographic components and land use explained 8.1% of the variability. Territories of higher productivity were located in areas of higher altitude and characterized by lower aridity, higher annual rainfall, higher annual average temperature, higher temperature in January and July, and in areas with lower surface of artificial lands and higher surface of open habitats (Table 5).

At the territory scale, the best model included only the surface of sparsely vegetated areas as the best predictor of breeding output (Table 4). No significant models were obtained including climatic and topographic variables and consequently, variance partitioning was not calculated. At this scale no significant differences were found between territories of high and low breeding performance (Table 5).

Trend in breeding performance during the study period

The average annual productivity showed a linear decreasing trend throughout the study period (productivity = 59.75 – 0.03*year; $r = -0.82$; $R^2 = 0.67$, $p < 0.001$)(Fig. 2). There was a significant difference in the average productivity of each territory considering two temporal periods (1990–1999 and 2000–2012) (Wilcoxon matched-paired test, $T = 3.50$, $Z = 3.08$, $p = 0.002$, $N = 16$). Overall, there were significant differences in

Table 4. Generalized Linear Model (GLZ) estimates showing the relationship between environmental predictors and breeding performance of Golden Eagle measured as the average productivity of each territory during the study period in Sicily. AIC_w and likelihood ratio test were not computed because only one significant variable was selected in the best models at both scales.

Scale	Subset	Variable	Estimate	SE	Wald	p
Landscape	Climatic and Topographic	Intercept	0.000	0.113	0.000	1.000
		Annual average temperature (AT_YR)	0.382	0.114	11.269	0.001
		Explained deviance	71.45%			
	Land use	Intercept	0.000	0.115	0.000	1.000
		Artifical (ART)	-0.332	0.116	8.200	0.004
		Explained deviance	89.43%			
Territory	Land use and mosaic	Intercept	0.000	0.199	0.000	1.000
		Sparsely vegetated areas (SVA)	0.571	0.205	7.755	0.005
		Explained deviance	67.36%			

Table 5. Mann-Whitney comparison of environmental predictors recorded in Golden Eagle's territories of high and low average productivity during the study period (n = 8 in both cases). Comparisons were done at landscape and territory spatial scale but significant differences were only found at landscape scale. Only significant results are shown. Variable abbreviations — see Table 1.

Scale	Subset	Variable	High	Low	Z	p
Landscape	Climatic and topographic	ASL (m)	717.18 ± 364.58	441.03 ± 233.46	-3.17	0.002
		BCI (mm/ºC+10)	7.94 ± 3.03	5.39 ± 2.06	-3.53	0.000
		TAE (ºC)	3.85 ± 1.27	3.01 ± 0.75	-2.85	0.004
		RAIN (mm)	5.19 ± 1.70	3.89 ± 1.11	-3.18	0.001
		AT_YR (ºC)	4.52 ± 1.85	3.11 ± 1.18	-3.18	0.001
		AT_JN (ºC)	3.78 ± 1.24	2.81 ± 0.84	-3.09	0.002
		AT_JL (ºC)	1.67 ± 0.53	1.32 ± 0.31	-2.81	0.005
	Land use	ART (ha)	37.02 ± 73.72	125.51 ± 178.26	2.63	0.008
		OPE (ha)	342.69 ± 874.68	50.89 ± 91.11	-2.83	0.005

annual productivity before and after 2003 (Monte Carlo ANOVA, Pseudo F Ratio = 13.09, p = 0.005).

DISCUSSION

Systematic analyses of the relative importance of different factors affecting the distribution of a species as a function of spatial scale are essential to achieve a better understanding of the patterns of occurrence and abundance (López-López et al. 2006, Muñoz & Real 2013). This is particularly important in the case of priority species for conservation such as the Golden Eagle. Our results showed that topographic, climatic, and land use factors are major determinants of Golden Eagle's distribution in Sicily. Golden Eagles still subsist in the major mountain ranges of northern-central part of the island, where this species still finds suitable conditions for breeding and where traditional agriculture, grazing and forest exploitation still occur in a mountainous landscape where extensive agricultural and natural areas are mixed (i.e., Madonie, Nebrodi, Perolitani, Sicani and Etna mountain ranges).

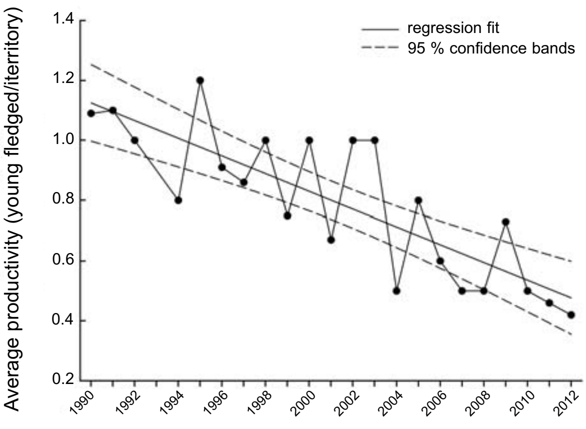

Fig. 2. Annual average productivity of Golden Eagle's territories recorded in Sicily during the period 1990–2012. Linear regression fit and 95% confidence bands are shown.

Our results are in agreement with previous work that shows that there is a hierarchical framework on habitat selection procedure of large raptors (Sergio et al. 2003, López-López et al. 2006, Muñoz & Real 2013). Similar results have been previously found in other study areas where Golden Eagles and potential competitors such as the Bonelli's Eagle *Aquila fasciata* still co-exist in sympatry, showing that the relative contribution of topographic, climatic and land use factors vary with the scale of analysis (López-López et al. 2006, Sergio et al. 2006, Di Vittorio et al. 2012, Muñoz & Real 2013).

We found a significant spatial autocorrelation effect at both scales of analysis. This may correspond to the latitudinal and longitudinal distribution of nesting sites, implying that the population of Golden Eagle is not randomly distributed across space in Sicily as evidenced by the Moran's test (and can be directly observed in Fig. 1). The significance of the linear effect of latitude at territory scale could be reflected by the latitudinal gradient of the distribution of mountain areas in Sicily.

Topographic variables (i.e. slope) were the most important predictors of occupancy at both landscape and territory scale, thus indicating a clear preference for sites characterized by a rugged topography where eagles can find suitable places for nesting. In fact, all breeding pairs had their nests in cliffs and only one pair nested on a tree during the entire study period in a place where cliffs do not exist (Ciaccio 1991). The ruggedness of the topography is clearly indicative of cliff availability (Carrete et al. 2000, López-López et al. 2006), and therefore the observed preference for sloped land reflect the richness of cliffs for building nests (López-López et al. 2004, 2006, 2007a). Furthermore, rugged areas can also increase the probability of finding preys (Watson 1992) by favouring the development of thermals and updrafts which are particularly used by Golden Eagles for hunting (McGrady et al. 2002, McLeod et al. 2002).

The most parsimonious explanatory landscape model suggests that the Golden Eagle prefers rugged areas surrounded by extensive agricultural habitats for nesting, avoiding woodland areas of continuous forest. Interestingly, our results show the importance of environmental heterogeneity created by the presence of agricultural areas, especially non-irrigated arable lands, typical of Mediterranean landscapes, characterized by the presence of large open areas. This provides evidence for the importance of prey availability as a key feature essential in the ecology of this species (Watson 1992, 2010, Pedrini & Sergio 2001b, Sergio et al. 2006, Tapia et al. 2007). In fact, these areas show the highest levels of prey abundance, especially Common Rabbit *Oryctolagus cuniculus* and Corsican Hare *Lepus corsicanus* (Massa & La Mantia 2007), which constitute the main prey of the Golden Eagle in Sicily (Di Vittorio 2007). The significant presence of arable land in the landscape occupied by Golden Eagles evidenced the importance of traditionally extensive agricultural practices as an important factor for conservation. In fact, a significant reduction of agricultural practices is now happening in Sicily (Massa & La Mantia 2007). This reduction, in parallel with the increase of the reforestation of natural areas using exotic tree species could increase the fraction of unsuitable territories for Golden Eagle (Tjenberg 1983, Marquiss et al. 1985, McGrady 1997, Pedrini & Sergio 2001a,b, 2002, Watson 2010).

Cereal pseudo-steppe open areas offer abundant prey, much more than closed areas characterized by high tree cover (Carrete et al. 2000, López-López et al. 2012). This could explain the negative relationship between forest surfaces and the probability of occupation found in our models at both scales of analysis. The expansion of woodland reduces the extension of open areas which are necessary for increasing eagle's breeding performance and range selection (Sergio et al. 2006). Open areas, including scrublands and pseudo-steppe landscapes, have higher densities of hares and a structure of vegetation that allows an easier detection and capture of preys than closed-structured habitat such as forests (López-López et al. 2012). In addition, dry cereal fields are important for conservation since they are the most frequently-used landscape of Golden Eagle in Sicily (Di Vittorio 2007), as well as by other endangered raptors such as the Lesser Kestrel *Falco naumanni*, the endangered Egyptian Vulture *Neophron percnopterus* (Sarà & Di Vittorio 2003) and the Bonelli's Eagle (Di Vittorio et al. 2012).

The preference for areas with higher annual rainfall, higher average temperatures and lower aridity correlated with the latitude of the occupied areas, confirmed that the presence of the species is also influenced by climatic factors (Beecham & Kochert 1975, López-López et al. 2007a, McIntyre & Schmidt 2012). However, our results showed that the relative contribution of individual climatic factors does not explain too much variance. This can be explained by the high ecological plasticity of the species which in fact is reflected in its world distribution range, from the northern taiga to deserts (Ferguson-Lees & Christie 2001).

CONCLUSIONS AND CONSERVATION IMPLICATIONS

By contrast with other areas, such as those of the northern parts of the Golden Eagle's range, the Mediterranean basin has experienced thousand years of landscape changes (Blondel et al. 2010). The case of Sicily is not an exception and in fact it could be a paradigm of what has happened in the Mediterranean hotspot. Habitat change has accelerated in Sicily in the last 20 years. This is of important concern from a conservation point of view. Landscape modifications have occurred, especially at the expense of the open land (natural and agricultural) due to rapid cessation of traditional agricultural practices and pasture abandonment (Pasta et al. unpubl data). These abandoned areas have been subject to recolonization by spontaneous vegetation or to afforestation. These processes had a vast effect on mountain plant and animal communities, strongly affecting biodiversity and causing a significant increase of woodland and shrub communities, which substituted grasslands and pastures (Pasta et al. unpubl data). Moreover, improvement of intensive farming (as vineyards in the central and southern part of Sicily), summer arson and land abandonment caused a deep transformation in many areas of the island. In addition, new infrastructure (e.g. roads, wind-farms) and management of artificial forests are increasingly fragmenting and reducing steppe habitats.

The Golden Eagle's population that still remains in Sicily, mainly owing to its small population size, has a great probability of extinction due to the loss of genetic variability, demographic and environmental stochasticity, and vulnerability to catastrophic events. In recent years, the Sicilian population of Golden Eagle has experienced a strong reduction in breeding performance. This reduction has been particularly accelerated from 2003 onwards. Probably this could be explained by a reduction of its most important prey, especially the Corsican Hare, due to a change and degradation of habitats occupied by this raptor (Di Vittorio 2007, 2011). Therefore, our results evidenced the necessity of appropriate conservation measures to palliate these threats and to decrease the intensification of agricultural practices and artificial forest expansion. Similar measures have been suggested to preserve the Golden Eagle's and other raptors' habitat in other Mediterranean countries (e.g. Gil-Sánchez et al. 2004, Cadahía et al. 2010).

In summary, our results show that the distribution of Golden Eagle in Sicily is associated with the existence of appropriate cliffs for nesting surrounded by areas where preys are abundant (open areas, cereal fields), avoiding the heavy forested areas. Our results highlight the importance of maintaining the structure of land use derived from traditional forms of extensive agriculture and pastoralism, which allows the existence of the species in the island's preferred environmental mosaics. Agricultural areas composed mostly of cereals and the Mediterranean open shrub should be promoted by local governing bodies by favouring the maintenance of these traditional forms of economy. Finally, particular attention should be paid in the planning and building of new artificial infrastructures such as wind-farms and wires in areas occupied or with high favourability for the species.

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STRESZCZENIE

[Czynniki wpływające na występowanie oraz liczbę wyprowadzanych piskląt u orła przedniego na Sycylii]

Właściwe określenie wymagań ekologicznych jest niezbędne do planowania działań ochronnych dla gatunków zagrożonych wyginięciem. W przypadku orła przedniego większość badań prowadzonych jest w północnej części zasięgu tego gatunku — Stanach Zjednoczonych, Skandynawii, Szkocji czy na terenach alpejskich. Dane dotyczące wymagań środowiskowych z terenów śródziemnomorskich są znacznie mniej liczne. W pracy scharakteryzowano wymagania siedliskowe oraz określono zależność między charakterystyką siedliska i liczbą wyprowadzanych piskląt u orła przedniego gniazdującego na północy Sycylii (Fig. 1).

Badania prowadzono w latach 1990–2012. Monitorowano16 terytoriów lęgowych tego gatunku, z których 12 było regularnie zajmowanych. Preferencje środowiskowe analizowano w dwóch skalach przestrzennych: terytorium — definiowanym jako obszar w promieniu 4 km od miejsca gniazdowania, oraz skali krajobrazowej — na podstawie występowania par w kwadratach 10 × 10 km. W skali krajobrazowej rozpatrywano 20 zmiennych przyporządkowanych do dwóch grup: 1) opisujących topografię i klimat oraz 2) użytkowanie terenu, zaś w skali terytorium 25 zmiennych charakteryzujących 1) sposób użytkowania przestrzeni oraz 2) topografię terenu (Tab. 1). Biorąc pod uwagę liczbę wyprowadzanych piskląt w badanym okresie terytoria podzielono na wysokiej i niskiej jakości (w zależności od tego czy wylatywało z nich rocznie średnio więcej, czy mniej piskląt w porównaniu do średniej wieloletniej dla wszystkich gniazd).

Wykazano, że prawdopodobieństwo zajęcia terytorium lęgowego wzrastało wraz ze wzrostem powierzchni terenów uprawnych i nachylenia terenu, zaś malało ze zwiększającą się powierzchnią lasów (Tab. 2). W skali krajobrazowej występowanie gatunku było związane z nachyleniem terenu oraz indeksem jałowości terenu (liczonym jako stosunek średniej rocznej ilości opadów do średniej rocznej temperatury pomnożony przez 10) oraz powierzchnią lasów (Tab. 2).

Porównano także zmienne środowiskowe w kwadratach 10 × 10 km zajętych i nie zajętych przez orły, oraz na zajmowanych terytoriach i losowo wybranych terenach o powierzchni wielkości opisywanego terytorium, stwierdzając szereg różnic zarówno w zmiennych topograficznych, klimatycznych, jak i związanych z użytkowaniem terenu (Tab. 3).

W ostatnich dwudziestu latach sukces lęgowy orła przedniego na Sycylii wyraźne zmniejsza się (Fig. 2). Analizując czynniki wpływające na liczbę wyprowadzanych młodych stwierdzono, że w skali krajobrazowej istnieje dodatni związek pomiędzy tym parametrem i średnią roczną temperaturą oraz negatywny z powierzchnią terenów różnorodnie przekształconych przez działania człowieka. Natomiast w skali terytorium liczba wyprowadzanych piskląt związana była z powierzchnią terenów z rzadka porośniętych roślinnością, co może być rozpatrywane jako wskaźnik dostępności pożywienia (Tab. 4). Porównując terytoria o wysokiej i niskiej jakości stwierdzono szereg zmiennych, głównie klimatycznych i topograficznych, różniących te dwie grupy (Tab. 5).

Uzyskane wyniki wskazują na znaczenie struktury krajobrazu powiązanej z tradycyjną ekstensywną gospodarką rolną, co wpływa na bazę pokarmową orłów, oraz znaczenie przekształceń terenów związanych z działalnością człowieka (m.in. infrastruktura drogowa, farmy wiatrowe, zalesianie).