CLIMATE AND LAND-USE CHANGES AS DETERMINANTS OF LESSER KESTREL *FALCO NAUMANNI* ABUNDANCE IN MEDITERRANEAN CEREAL STEPPES (SICILY)

CAMBIOS EN EL CLIMA Y EN EL USO DEL SUELO COMO DETERMINANTES DE LA ABUNDANCIA DEL CERNÍCALO PRIMILLA *FALCO NAUMANNI* EN ESTEPAS CEREALISTAS MEDITERRÁNEAS (SICILIA)

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SUMMARY.—*Climate and land-use changes as determinants of lesser kestrel* Falco naumanni *abundance in Mediterranean cereal steppes (Sicily).*

Monitoring of lesser kestrels *Falco naumanni* is necessary to promote conservation of this vulnerable species. To this end, 35 colonies of this species located in the NNW and SE of Sicily were monitored from 2003 to 2009. Counts of the active colonies and resident pairs were modelled by loglinear Poisson regressions to assess population trends over the study period. Afterwards, a GLM with an analysis of covariance design and a backward removal stepwise regression was performed to relate the observed trend to local- or global-scale climatic variation and to local land-use changes. Colony counts provided a better fit to the loglinear models than pair counts. Loglinear models separated the increasing trend of the SE population breeding in buildings and living in a flat semi-arid area from the non-increasing trend of the NNW population, which breeds on cliffs at higher altitudes and lives in a warm temperate area. The effect of the covariate 'population' suggests a considerable role for the geographic range in modelling the abundance of colonies, which appears to also be relevant when it interacts with climatic and land-use changes. Land-use variables have the greatest weight in predicting the abundance of lesser kestrel colonies. The transformation of arable land negatively correlates with the abundance of colonies in both areas, and the intensification of woody crop cultivation (vines, hops and orchards) is likely to be the major cause of the observed population trend in NNW Sicily. Warm, dry climatic conditions in March and April, during the onset of reproduction, negatively affect lesser kestrels and the large-scale climate significantly interacts with land uses. Conservation efforts aimed at the management of suitable habitat conditions of the SE population and the recovery of the NNW population must incorporate the effects of global warming in addition to land-use practices to allow for more effective actions to be taken.

Key words: climate change, *Falco naumanni*, land use, lesser kestrel, loglinear model, Mediterranean cereal steppes, population trends.

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RESUMEN.—*Cambios en el clima y en el uso del suelo como determinantes de la abundancia del cernícalo primilla* Falco naumanni *en estepas cerealistas mediterráneas (Sicilia).*

El seguimiento de poblaciones de cernícalo primilla *Falco naumanni* es necesario para promover la conservación de esta especie amenazada. Con ese fin, se censaron 35 colonias de la especie ubicadas en el N-NW y SE de Sicilia entre 2003 y 2009. Los conteos de colonias activas y parejas residentes fueron modelados con regresiones de Poisson log-lineal con el fin de valorar las tendencias de la población durante el periodo de estudio. Posteriormente, se realizó un GLM con un diseño de análisis de covarianza y selección de variables por pasos hacia atrás para relacionar las tendencias observadas con variaciones locales o globales en el clima y con cambios locales en el uso del suelo. Los conteos de colonias arrojaron un mejor ajuste log-lineal que los conteos de parejas. Los modelos separaron la tendencia al alza de la población SE, que nidifica en edificios y habita un área llana semiárida, de la tendencia no creciente de la población N-NW, que nidifica en cortados a mayores altitudes y habita un área templada calida. El efecto de la covariable 'población' sugiere un papel considerable del rango geográfico en el modelado de la abundancia de colonias, que parece ser también relevante cuando interacciona con cambios en el clima y usos del suelo. Las variables de usos del suelo tuvieron el mayor peso a la hora de predecir la abundancia de colonias de cernícalo primilla. La transformación de tierra agrícola correlacionó negativamente con la abundancia de colonias en ambas áreas, y la intensificación de los cultivos de árboles frutales es probablemente la mayor causa de las tendencias poblacionales observadas en N-NW de Sicilia. Las condiciones climáticas cálidas y secas en marzo y abril, durante el comienzo de la reproducción, afectan negativamente a los cernícalos primillas, y el clima a gran escala interacciona significativamente con los usos del suelo. Los esfuerzos de conservación encaminados al manejo del hábitat adecuado de la población SE y la recuperación de la población N-NW deben incorporar los efectos del calentamiento global además de los usos del suelo para permitir acciones más efectivas.

Palabras clave: cambio climático, cernícalo primilla, estepas cerealistas mediterráneas, *Falco naumanni*, modelo log-lineal, tendencias poblacionales, usos del suelo.

INTRODUCTION

Many threatened bird species in Europe live in steppe-like habitats (Tucker and Heath, 1994), where low intensity cereal agriculture is rapidly changing as a result of intensification in farming practices and land abandonment (Donald *et al.*, 2001), and the widespread decline of European farmland birds currently presents a major conservation challenge (Pain and Pienkowski, 1997). Additionally, it is forecasted that by the end of the century, climate change and its impacts may become the dominant direct drivers of biodiversity losses and changes in ecosystem functioning at the global level (IPCC, 2002; Godfrey *et al*., 2009), and Mediterranean countries are known to be suffering the largest impacts of climate change (IPCC, 2007).

Within this framework, studying the lesser kestrel *Falco naumanni* in the cereal steppes of a Mediterranean area such as Sicily is important. Though it was once considered one of the most abundant birds of prey of the Palaearctic region, the lesser kestrel has undergone a dramatic decline throughout Europe and most of its Asian range, as well as in its African wintering grounds (BirdLife International, 2004). As a consequence, it has been classified as 'vulnerable' by the IUCN and is among the 65 priority bird species occupying the steppe habitat in Europe (Tucker and Heath, 1994; Tucker and Evans, 1997). This concern about the lesser kestrel renders it necessary to continue monitoring this species to detect any change in its abundance and distribution across spatial and temporal scales with the aim of promoting its conservation.

Moreover, this small migratory, colonial falcon is an outstanding biological indicator for monitoring environmental changes because lesser kestrels are currently associated with high value habitats of the western Palaearctic (Cramp and Simmons, 1980), where they live in open ecosystems transformed by agriculture and feed mostly on large Orthoptera and Coleoptera (Negro, 1997). The causes of lesser kestrel decline may vary across their range and have been attributed to a reduction in the availability of nest sites, increases in the use of agricultural pesticides and changes in land use (Bustamante, 1997). Similar causes are cited as affecting all wildlife of the European steppe-like habitats (Bota *et al.*, 2005). Therefore, monitoring lesser kestrels will promote a better understanding of management strategies that could prove useful for preserving European steppe lands (Tella *et al.*, 1998) and, furthermore, will provide insight into the ways in which European agricultural policies could be adapted to significantly reduce the rate of biodiversity loss (European Commission, 2006).

Rapid anthropogenic climate change is now accepted as a major threat to biodiversity (IPCC, 2002; Thomas *et al.*, 2004) and has prompted urgent and rapidly expanding research in conservation biology. Many Palaearctic lesser kestrels are trans-Saharan migrants and winter in Africa (Rodríguez *et al.*, 2009). There is increasing evidence of relationships between climate change and vertebrate migration and of the effect of climate changes on habitat associations, timing of arrival and travel risks (Robinson *et al.,* 2009). The effects of climate change may add to or multiply those associated with other anthropogenic factors, such as habitat loss and the intensification of agriculture (Jetz *et al.*, 2007). Thus, understanding these interactions will be crucial in formulating appropriate conservation strategies (Travis, 2003).

Very few ecological studies have been conducted to date on lesser kestrels outside of the Iberian Peninsula (e.g., Parr *et al.*, 1997; Prugnolle *et al.*, 2003; Vlachos *et al.*, 2004), in spite of the numerical prevalence of several other southern European populations. In the present study, I followed an initial population monitoring effort of this species (Mascara and Sarà, 2006) and documented the effects of climate and habitat modifications on the abundance of lesser kestrels in Sicily. In particular, I addressed whether: i) there is a detectable population trend over a short-term period (< 10 years); and ii) to what extent any existing trend might be related to climatic variation at local or larger scales or to local land-use changes.

MATERIALS AND METHODS

Study area

Sicily, the largest Mediterranean island, extends over an area of 25,414 km^2 and is one of the most populated regions of Italy (195 inhabitants per km^2). The altitude of the first study area, located in the north-north-western part of the island (hereafter NNW), is elevated due to the presence of the Palermo and Sicani mountain ranges (figure 1, table 1). Most of the island's Mediterranean forest and shrub vegetation is also localised in this area, intermingled with *Pinus* spp. and *Eucalyptus* spp. Mediterranean xeric grasslands of *Ampelodesma mauritanica* and wheat croplands remain widespread (EEA, 2000), but large extents of this habitat (e.g., around 54,000 hectares in the NNW; ISTAT, 2010) are being replaced by vineyards, olive tree plantations and irrigated crops.

The second study area, the Gela plain (about 474 km^2), is located in the south-east of Sicily (hereafter SE) and is one of the largest plains in Italy. Most of this low altitude habitat (figure 1, table 1) consists of wheat cropland, fallow land and pastures (EEA, 2000), but as in the first area, it is being re-

placed by olive trees and irrigated crops. The most common crop in the region is artichokes (*Cynara* spp.); vineyards and green-houses are widespread on the coasts but are still rare inland (Prato and Signorello, 2009). Mediterranean shrubs, together with garrigues and dry grasslands, are present on the slopes of the hills or on abandoned land.

Most of the NNW sample area falls within the meso-Mediterranean sub-humid and meso-Mediterranean dry bioclimate; whereas most of the SE area falls within the thermo-Mediterranean dry bioclimate (table 1). The De Martonne aridity index (Ai) reflects the past-30-year climate history of the region and categorises the NNW area as warm temperate (Ai = 20-30) and the SE as semi-arid (Ai = 10-20). Other notable differences between the study areas are the location of the lesser kestrel colonies in cliffs in the NNW versus in man-made buildings in the SE and the species occupancy on the UTM grid (table 1).

TABLE 1

Features of the lesser kestrel *Falco naumanni* focal sub-populations in Sicily. NNW = north-north-western population, SE = south-eastern population. (*) Student-t test significant differences, P < 0.001. *[Características de las subpoblaciones focales de cernícalo primilla* Falco naumanni *en Sicilia. NNW = población norte-noroeste, SE = población sudeste. (*) Diferencias significativas en test de t de Student, P < 0.001.]*

|	NNW	SE
Thermo-Mediterranean dry	17%	86%
Thermo-Mediterranean sub-humid	28%	–
Meso-Mediterranean dry	6%	14%
Meso-Mediterranean sub-humid	50%	–
De Martonne's aridity index	Warm temperate	Semiarid
Species Occupancy (N 10 x 10/5 x 5 UTM cells)	18/20	7/14
Area of occupancy (km^2)	500	350
N colonies	19	16
N breeding sites	28	50
Mean ± SE breeding sites per colony (*)	1.474 ± 0.193 (min-max: 1-4)	3.125 ± 0.397 (min-max: 1-7)
Mean ± SE altitude m a.s.l. (*)	626.2 ± 34.93 (min-max: 280-955)	160.3 ± 14.27 (min-max: 15-406)
Breeding sites in man-made structures (buildings, bridges)	8%	84%
Breeding sites in cliffs	92%	16%
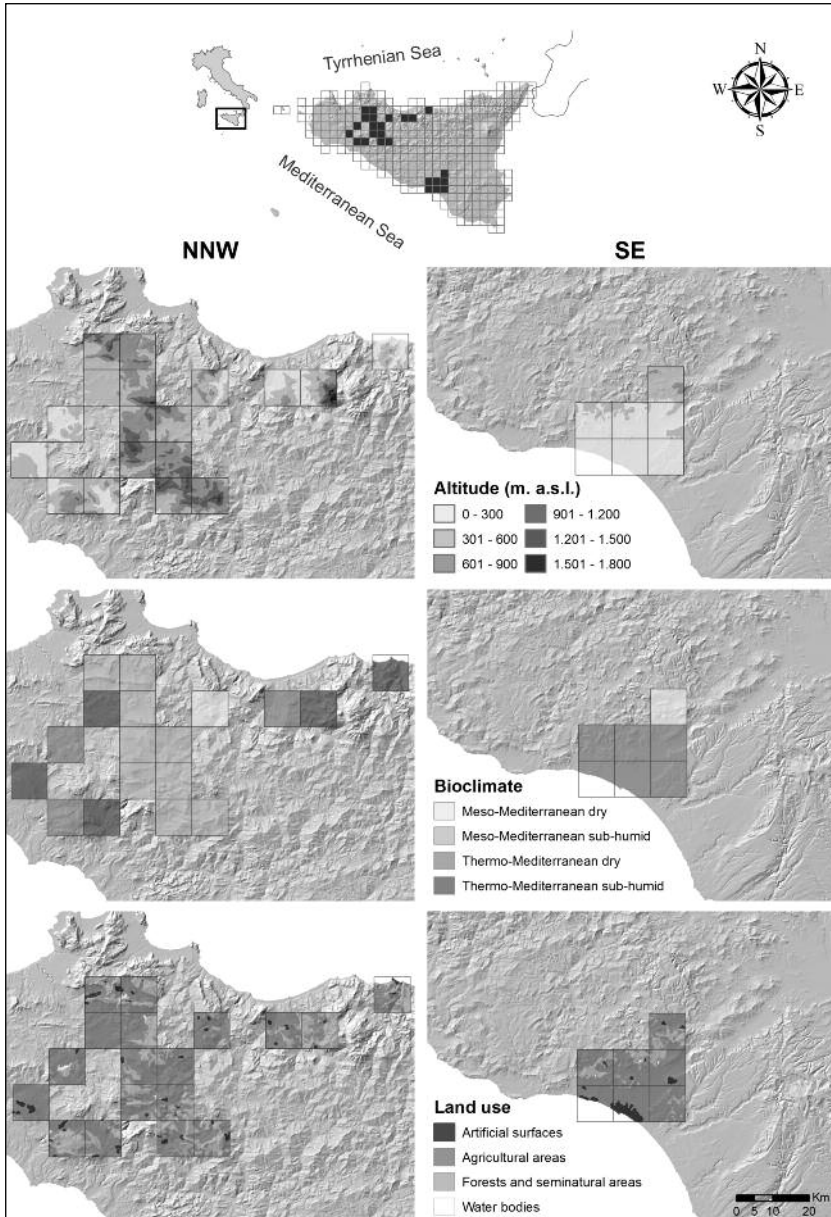
FIG. 1.—Location of the two sub-populations of lesser kestrel *Falco naumanni* considered in the study, as mapped into the UTM grid of Sicily at a 10 x 10-km scale resolution (shaded in dark grey in the central insert). Altitude, bioclimate and 1st level of CORINE land uses have been reported for every UTM cell in which the north-north-western (NNW) and south-eastern (SE) populations are situated.
[Localización de las dos subpoblaciones de cernícalo primilla Falco naumanni *consideradas en este estudio sobre rejilla UTM de 10 x 10 km (gris oscuro en inserción central). Se muestra la altitud, el bioclima y los usos del suelo de primer nivel de CORINE para cada celda UTM de la población norte-noroeste (NNW) y sudeste (SE).]*

Data collection

I used field information about the abundance of colonies (i.e., main plus secondary breeding sites active across years) and colony sizes recorded during the breeding season (April-July) in at least one year within the study period (2003-2009) in the two study areas (NNW and SE). A site with lesser kestrels was considered as a breeding site when at least one pair of kestrels was performing reproductive behaviour (e.g., male delivering prey to female, copulation, inspection of nest chambers, feeding of nestlings). A colony is, therefore, a main breeding site (e.g., cliff or building), which could be surrounded by a varying number of secondary breeding sites (hereafter referred to as satellites). Very often, satellites contain fewer pairs, have been colonised more recently than the main site and are occupied or abandoned over successive years. I considered all such sites falling within a radius of 1 km around the main breeding sites as satellites. The breeding sites discovered within the NNW and SE sample areas were grouped into colonies to account for the processes of dispersal and conspecific attraction that have been described for the lesser kestrel (Serrano *et al.*, 2001, 2003; Serrano and Tella, 2003) and the spatial expansion of the fast-growing SE population (Mascara and Sarà, 2006). The coordinates and characteristics of the lesser kestrel colonies that were recorded in the field using a Garmin GPS, were identified on 1:50,000-scale maps and assigned to a UTM cell. Population surveys were performed in 25 UTM 10 x 10-km cells, representing two sub-populations: the NNW population, with 19 colonies including 28 breeding sites, and the SE population, with 16 colonies including 50 breeding sites (figure 1, table 1). During the surveys, the deserted breeding sites, especially those that were satellites and the areas nearby, were carefully inspected to confirm the absence of the species and, therefore, avoid errors of false

omission (undetected presences). Colony surveys were undertaken following a rotating schedule, and most of the colonies were counted for 6-7 years. Notwithstanding, there were missing observations, and the individual colonies had different histories of detection over the 7-year period, during which time desertion, colonisation and re-colonisation of major sites and satellites occurred.

Accordingly, colony size is the sum of the resident pairs occupying all of the breeding sites within a colony in each year. In this study, I expressed the abundance of lesser kestrels in a colony in terms of resident pairs irrespective of confirmed reproduction and breeding success. Pairs were counted during two or three visits per year, which were usually conducted at the time of site occupation and egg-laying (early April-early May), incubation and hatching (mid May-early June) and fledging (mid June-early July), by comparing the number of males flying over the colony and foraging nearby with the number of nests visited by birds. Visits at a given site lasted a minimum of one hour and were always carried out by 2-4 observers well versed in this species' behaviour, with everyone checking a focal side of the site. Visits were carried out avoiding windy or rainy days and the middle hours of the day (13:00-16:00). Observations were conducted using 10 x 40 binoculars and 20-60 spotting scopes.

Data analysis

To assess population trends in the NNW and SE lesser kestrel populations, I used TRIM (TRends and Indices for Monitoring data; Pannekoek and Van Strien, 2005), a software platform developed for the analysis of counting data including incomplete data (missing observations) and zero counts. TRIM processes zero counts and imputes missing observations in the dataset by means of a log-linear Poisson regression (a form of GLM,

Generalized Linear Models; McCullagh and Nelder, 1989), which is a statistical model that uses an iteratively re-weighted least-squares algorithm (Ter Braak *et al.*, 1994). After fitting the model by generalised estimating equations, the model and its estimated site-effects and time-effects are used to predict the counts that were missing (Van Strien *et al.*, 2004). Indices can then be calculated on the basis of a complete dataset with the model-estimated counts replacing the missing counts. Nonetheless, it is recommended not to use data with more than 20-50% missing counts. In the present study, only 11% and 18% of the colony and pair count datasets, respectively, were deemed to be missing counts (table 2) and replaced using the TRIM method. Overdispersion indicates the degree of deviation from the Poisson distribution, whereas serial correlation describes the density-dependence of the counts from successive time-points (i.e., years). Substantial overdispersion (> 3) and serial correlation (> 0.4) hinder the evaluation of the fit of the model (Pannekoek and Van Strien, 2005). The latter is tested by the χ^2 (chi-square) test and the likelihood ratio. Generally, the results of these tests are similar, and if the p-value of these tests is below 0.05, the model is rejected; nevertheless, it can be evaluated using Akaike's information criterion (AIC; Akaike, 1973; Pannekoek and Van Strien, 2005). To test for trends before and after every year of monitoring (except in 2009 and using 2003 as baseline), I used a linear trend model with all years as change-points, setting the TRIM software to search for significant change-points by a stepwise procedure. After a preliminary exploration without covariates, I extended the model by incorporating the covariate 'population' (NNW population = 1 and SE population = 2), to take into account bioclimatic and other environmental differences between the two sub-populations of lesser kestrels (table 1).

TRIM preliminarily modelled changes in the abundance of colonies and colony sizes across the period 2003-2009 and over the two sample areas (NNW and SE of Sicily). To identify the variables that best predicted changes in the number and sizes of lesser kestrel colonies, I built a GLM (McCullagh and Nelder, 1989) in which the response variables were the TRIM-derived imputed number of:

i) the main breeding sites plus their satellites;
ii) the resident pairs in 35 colonies over 7 years (n = 245).

The variances of these counts were much larger than the mean; therefore, they were normalised using a square root transformation. I assumed a Gaussian error distribution and an identity link function with an analysis of covariance (ANCOVA) design and a backward removal stepwise regression. The ANCOVA design incorporates the 'population' as a fixed categorical predictor, and different GLMs were performed for four subsets of continuous predictors including the following climatic and land-use variables:

1) Colony climate. In this subset, I included variables describing the local weather during lesser kestrel arrival to the breeding areas and settlement. Mean minimum and maximum temperatures (ºC), accumulated precipitation (mm), and the number of rainy days from January to April of every year during the study period were provided by SCIA (2008).
2) Regional climate. This subset includes a regional global indicator of annual weather conditions over the western Mediterranean area. The Western Mediterranean Oscillation (Martin-Vide and Lopez-Bustins, 2006) was expressed by the WeMO index obtained by the difference between the standardised surface pressure values

recorded at San Fernando (SW Spain) and Padua (NE Italy). With low pressures over central Europe and high pressures over the south-western Iberian Peninsula, WeMO becomes positive, while heavy rainfall is associated with negative values. The annual WeMO index of the year, the annual WeMO of the previous year and the monthly indices from January to April were downloaded from www.ub.edu/gc/English/wemo.htm.

TABLE 2

TRIM model accounting for population trends of lesser kestrel in cereal steppes of Sicily. Parameters come from a linear trend model with stepwise selection of change-points and covariate 'population'. The fit of the model is with P > 0.05 hence the colony model should be accepted. Conversely, the model of pair counts departs significantly from a loglinear fit (P = 0.000) and should be rejected. This latter model also shows higher estimated overdispersion and serial correlation than the colony model. The annual trend across the study period is represented by the additive parameterization of the slope of the model and only the significant changes in slope have been reported.
[Modelo TRIM para las tendencias poblacionales del cernícalo primilla en estepas cerealistas de Sicilia. Los parámetros provienen del modelo de tendencia lineal con selección por pasos de puntos de cambio y la covariable 'población'. El ajuste del modelo fue con P > 0.05 y por tanto el modelo de colonias fue aceptado. Contrariamente, el modelo de conteo de parejas difiere significativamente de un ajuste log-lineal (P = 0.000) y fue descartado. Este último también mostró mayor sobredispersión estimada y correlación seriada que el modelo de colonias. La tendencia anual a lo largo del periodo de estudio está representada por la parametrización aditiva de la pendiente del modelo, y sólo los cambios significativos en pendiente son presentados.]

	Colonies			Pairs		
Overdispersion	0.354			2.811		
Serial correlation	0.044			0.163		
Missing counts	11%			18%		
Goodness of fit		d.f.	P		d.f	P
χ^2	63.01	178	1.000	449.7	160	0.0000
Likelihood ratio	69.72	178	1.000	466.8	160	0.0000
AIC	–286.28			146.8		
Significance of covariate						
Wald's test	18.26	3	0.0004	25.81	3	0.0000
Significance of changes in slope						
Wald's test year 2003	—	—	—	25.09	2	0.0000
Wald's test year 2004	20.62	2	0.0000	—	—	—
Wald's test year 2006	9.27	2	0.0097	6.39	2	0.0410
Wald's test year 2008	4.23	2	0.1209	4.26	2	0.1186

3) Global climate. To account for a large-scale climatic indicator of annual weather conditions in Europe, I used the North Atlantic Oscillation as expressed by the winter NAO index (Hurrel, 1995; www.cgducar.edu/≈jhurrel/nao.html). I considered the annual NAO index of the year, the annual NAO of the previous year and the NAO indices from January to April.

4) Land use. Land-use changes within a 1-km radius around the colonies were obtained from GIS databases of CORINE Land Cover (CLC) digital maps (scale 1:25,000) of Sicily (http://dataservice.eea.europa.eu/data service/). For each plot, I calculated the percentage of variation across the years for the non-irrigated arable land (cereals, legumes, fodder crops, root crops and fallow land), the semi-permanently irrigated arable land (artichokes), vineyards, olive groves and other ligneous crop plantations. Habitat modification around the colonies was quantified by comparing different CLC digital maps with direct field validation and, in some cases, by using the 'historical imagery' feature of Google™ Earth version 5.1 (http://earth.google.com).

I did not build a global model including variables of all subsets to avoid overparameterisation and overfitting (Harrel, 2001), and every subset was considered to be an independent model. For each logistic regression model, a backward removal procedure was used including all variables in a given subset at once and removing non-significant values stepwise using Wald's test to exclude the variables that did not contribute significantly ($P > 0.05$) to lesser kestrel annual abundance (Carrete *et al.*, 2007). Then, I built a new GLM including all of the significant predictors from the four subsets, and the

final model selection was carried out using the AIC. A further 4th-degree factorial regression design was used to determine the relative influence of single predictors and of their interactions on the abundance of lesser kestrels. The proportion of variance explained by the regression models was expressed as R^2_{adj}, which represents the success of predicting the response variable from the set of explanatory variables (Rao, 1973). All analyses were performed using Statistica version 8.0 for Windows (StatSoft, 2007). Statistical significance for all analyses was set at $P < 0.05$.

RESULTS

The lesser kestrel population trends resulting from a TRIM model with a linear trend design are presented in table 2. The colony dataset had few missing counts (11%), and the TRIM model showed a good fit ($P > 0.05$) as well as negligible serial correlation and overdispersion (table 2). The NNW colonies exhibited a 12% decrease between 2004 and 2006, a larger increase (25%) from 2006 to 2008 and a second strong decrease (21%) from 2008 and 2009 (figure 2). This fluctuation, with significant points of inflection (table 2), yielded an overall uncertain trend across the study period with a slight 2% increase. For the SE colonies, the change of the slope corresponded to a strong increase of 33% between 2004 and 2006. Between 2006 and 2008, the SE population exhibited a 1.5% decrease, followed by a 20% recovery from 2008 to 2009 (figure 2). The overall model predicts a statistically significant ($P < 0.01$) 13% increase for the SE population across the study period (figure 2). The trend for the two populations taken together represents an increase ($P < 0.05$), but the uncertain performance of the NNW population combined with the increasing population in the SE lowers the overall increase to 9%. The pair
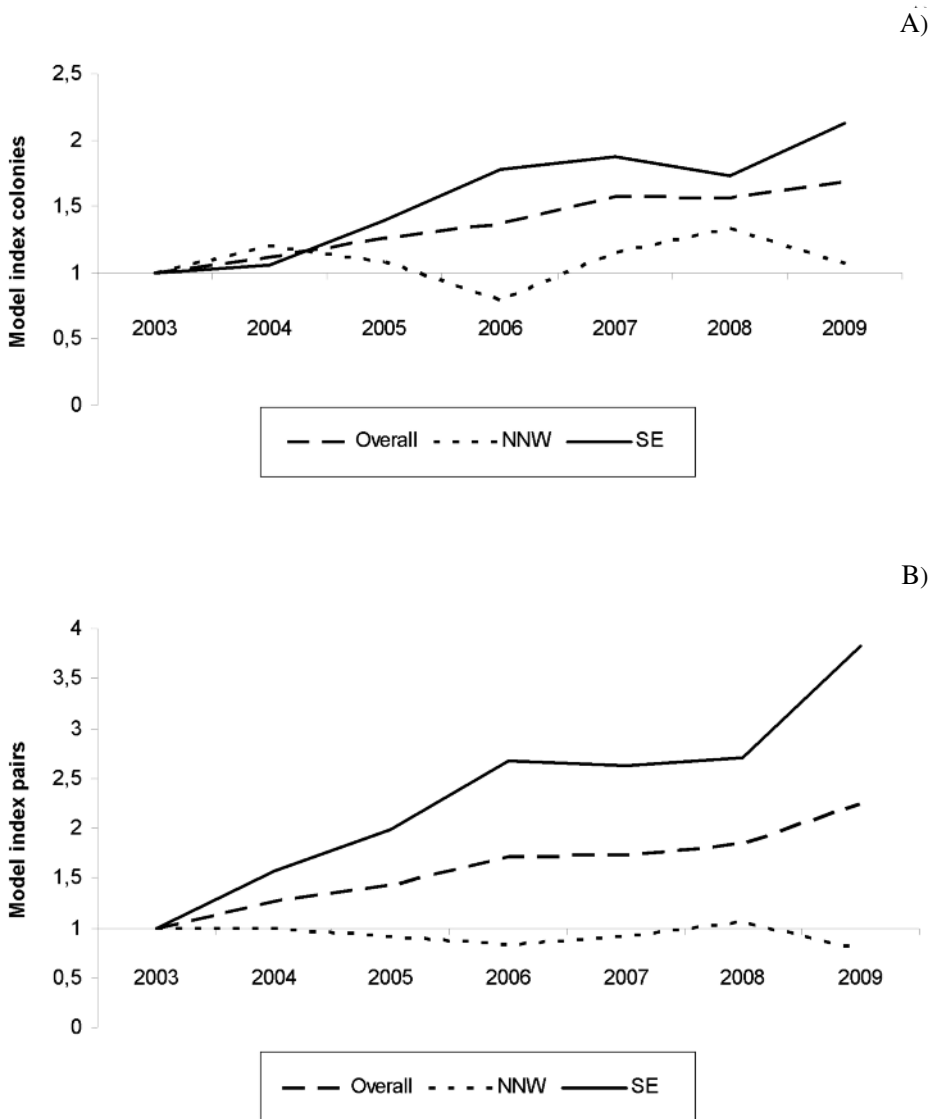
A)

B)

Fig. 2.—Population trends of lesser kestrel in cereal steppes of Sicily. TRIM model-based indices for (A) colony counts and (B) pair counts are shown. Dashed line stands for the overall index, continuous line for the SE population and dotted line for the NNW population. In the y-axis, 1 represents the baseline index and any value greater than 1 is an increase in the number of colonies or pairs whereas any value less than 1 represents a decrease.
[Tendencias poblacionales del cernícalo primilla en estepas cerealistas de Sicilia. Se muestran los índices basados en modelos TRIM para (A) conteo de colonias y (B) conteo de parejas. La línea discontinua muestra el índice global, la línea continua el de la población SE y la línea punteada en de la población NNW. En el eje y, 1 representa el índice de referencia y cualquier valor mayor que 1 se corresponde con un incremento en el número de colonias o parejas, mientras que valores menores que 1 representan una disminución.]

model departed significantly from a loglinear fit (P = 0.000) and should be rejected, and moreover, this model showed higher overdispersion and serial correlation values than the colony model. Although there was a better statistical fit of the colony model, the pair model produced similar results to the colony model, showing an overall (13%) increase due to the SE population and an uncertain trend (–2%) in the NNW abundance of pairs. The population and overall trends based on pair counts have been reported in figure 2b, nevertheless pair counts were not considered further.

The significant explanatory variables that predicted changes in colony abundance independently extracted by backward removal stepwise regressions are reported in table 3. The fixed covariate, population, is selected as being significant in every case except for the land-use model (table 3). A further group of the variables selected by the ANCOVA GLM can be removed, resulting in a best subset of ten (1st Model; table 4) or even eight variables (2nd Model; table 4). According to the results of these models, the mean precipitation in March and the mean minimum temperature in April are important predictors of the trends in the colonies, but they can be removed with only a negligible loss of information (table 4). In fact, local weather conditions around the colonies would be predicted to match at a larger scale with the NAO index of April and the WeMO index of March and, therefore, might be redundant. A large group of land-use variables explains the annual trends of the colonies and relates to the extent of dry grasslands, which are used mainly for grazing, though the fodder may be harvested mechanically; the extent of artificial areas (e.g., towns and villages, roads, or quarries); and the modifications to land use. This last feature is largely related to the decrease of arable fields and the increase of artichoke fields in the SE and the increase of intensive vineyards in the NNW.

The final 4th degree factorial model produced a set of eight positive and negative single effects in addition to 154 positive and negative interactions among the explanatory variables, explaining the 61.5% of total variance contained in the counts of colonies (R^2_{adj} = 0.615; F = 7.294; P = 0.000; table 5). Five out of eight single explanatory variables were pooled, and only the covariate 'population', the WeMO index of March and the increase of artichoke fields were retained as significant (table 5), in addition to 42 other significant interactions among two, three or four variables. Interactions among significant land-use variables explained 49.7% of the total variance, followed by those representing interactions between climate and land use (44.6%), then population and land use (33.3%), and finally, population and climate (27.4%).

DISCUSSION

Predictive geographical modelling has recently gained importance as a tool to assess the impact of accelerated land-use and other environmental changes on the distribution of organisms (Guisan and Zimmermann, 2000). The inferential approach developed using loglinear Poisson regressions is useful for estimating annual abundance, between-year changes and trends over a number of years (Ter Braak et al., 1994; Van Strien et al., 2004). The loglinear models obtained in this study produced two estimates of lesser kestrel yearly abundance, separating the increasing trend of the SE population from the uncertain, but apparently non-increasing trend of the NNW population, hence revealing the influences of local environment on the presence of the species. Because the model's response variables are based on direct field observations, they are likely to predict the realised ecological niche of the lesser kestrels (Malanson et al., 1992), and as a consequence, biotic in-

TABLE 3

The four independent GLM models for the effect of land-use and climatic variables on lesser kestrel abundance of colonies. Variables predicting the abundance of colonies were selected by an analysis of covariance (ANCOVA) design and a backward removal stepwise regression. WeMOi = Western Mediterranean Oscillation index; NAOi = North Atlantic Oscillation index.
[Cuatro modelos GLM independientes para el efecto de usos del suelo y variables climáticas sobre la abundancia de colonias de cernícalo primilla. Las variables que predicen la abundancia de colonias fueron seleccionadas mediante un análisis de covarianza (ANCOVA) y una regresión por pasos hacia atrás. WeMOi = Índice de Oscilación del Mediterráneo Occidental; NAOi = Índice de Oscilación del Atlántico Norte.]

Effect	Wald statistics	P
1) Colony climate		
Accumulated precipitation March	17.549	0.000
Population	78.464	0.000
Accumulated precipitation January	6.537	0.011
Mean minimum temperature April	10.662	0.001
Explained variance (R^2_{adj})	0.285	
Pearson χ^2 goodness-of-fit test	0.263	
Log-likelihood	–159.264	
2) Global climate		
Population	77.844	0.000
NAOi February	4.327	0.038
NAOi April	5.040	0.025
Explained variance (R^2_{adj})	0.244	
Pearson χ^2 goodness-of-fit test	0.285	
Log-likelihood	–189.923	
3) Regional climate		
WeMOi March	5.863	0.015
Population	77.981	0.000
Explained variance (R^2_{adj})	0.249	
Pearson χ^2 goodness-of-fit test	0.285	
Log-likelihood	–189.923	
4) Land use		
Increase artichoke surface (%)	13.618	0.000
Dry grassland surface (ha)	11.942	0.001
Decrease arable field surface (%)	44.631	0.000
Artificial area surface (ha)	14.007	0.000
Vineyard surface (ha)	13.700	0.000
Explained variance (R^2_{adj})	0.391	
Pearson χ^2 goodness-of-fit test	0.228	
Log-likelihood	–160.498	

teractions and competitive exclusion are intrinsically considered (Guisan and Zimmermann, 2000). Lesser kestrels living in urban habitats benefit from a reduced level of predation (Tella *et al*., 1996) and this suggestion was supported by some cases of nest destruction by ravens and raptors being recorded in the NNW population (author's unpublished data). It is thus possible that the NNW population, which lives on cliffs at a higher altitude and in a relatively cooler bioclimatic area, might be also limited by higher levels of predation than the SE population living in buildings. Apparently, for this dataset, TRIM based on colony counts provides a better fit to loglinear models than pair counts. During large-scale monitoring, precise pair counts are more difficult and time-consuming to ob-

TABLE 4

The first two subsets of variables best explaining the colony abundance of lesser kestrel in Sicily. This second GLM modelling searched the best combination of explanatory variables (lowest AIC) among those previously selected independently by the ANCOVA design (table 3). The 2nd ranked model excluded the two colony-climate variables (accumulated precipitation in March and mean minimum temperature in April) with a very little decrease of information (ΔAIC) and loss of explained variance. + represents the variables included in the model.
[Dos primeros subgrupos de variables que explican la abundancia de colonias de cernícalo primilla en Sicilia. Este segundo GLM buscó la mejor combinación de variables independientes (menor AIC) entre aquellas seleccionadas previamente de forma independiente con el diseño ANCOVA (tabla 3). El segundo mejor modelo excluyó las dos variables climáticas (precipitación acumulada en marzo y temperatura mínima media en abril) con una pérdida muy pequeña de información (ΔAIC) y de varianza explicada. + representa las variables incluidas en el modelo.]

	1st Model	2nd Model
Accumulated precipitation March	+	−
Mean minimum temperature April	+	−
NAOi April	+	+
WeMOi March	+	+
Increase artichoke surface (%)	+	+
Decrease arable field surface (%)	+	+
Artificial area surface (ha)	+	+
Vineyard surface (ha)	+	+
Dry grassland surface (ha)	+	+
Population	+	+
d.f.	10	8
AIC	304.720	304.741
ΔAIC	0.000	0.020
P	0.000	0.000
Explained variance $\left(R^2_{adj}\right)$	0.417	0.414

TABLE 5

Fourth-degree factorial regression model for the interactions between land-use and climatic variables which affect colony abundance of lesser kestrel in cereal steppes of Sicily. Only the significant 2nd rank interactions between explanatory variables are reported in groups congruent with large scale effects.
[Modelo de regresión factorial de cuarto grado para las interacciones entre usos del suelo y variables climáticas que afectan a la abundancia de colonias de cernícalo primilla en estepas cerealistas de Sicilia. Sólo se muestran las interacciones significativas de segundo orden entre variables independientes en grupos coherentes con efectos a gran escala.]

	Comment	Parameter	SE	t	P
Intercept		0.817	0.181	4.513	0.000
Population		0.595	0.219	2.714	0.007
NAOi April	Pooled				
WeMOi March		–0.416	0.107	–3.868	0.000
Increase artichoke surface (%)		1.350	0.536	2.518	0.013
Decrease arable field surface (%)	Pooled				
Artificial area surface (ha)	Pooled				
Vineyard surface (ha)	Pooled				
Dry grassland surface (ha)	Pooled				
Population * Climate $\left(\mathbf{R}^2_{adj} = 0.274\right)$					
Population * NAOi April		–0.122	0.050	–2.460	0.015
Population * WeMOi March		0.471	0.144	3.269	0.001
Climate * Land use $\left(\mathbf{R}^2_{adj} = 0.446\right)$					
WeMOi March * Increase artichoke surface (%)		0.334	0.129	2.597	0.010
WeMOi March * Decrease arable field surface (%)		0.315	0.089	3.540	0.001
WeMOi March * Artificial area surface (ha)		–0.952	0.277	–3.444	0.001
WeMOi March * Vineyard surface (ha)		–47.333	22.077	–2.144	0.033
NAOi April * Decrease arable field surface (%)		–0.113	0.046	–2.472	0.014
Population * Land use $\left(\mathbf{R}^2_{adj} = 0.333\right)$					
Population * Decrease arable field surface (%)		–1.554	0.339	–4.584	0.000
Population * Artificial area surface (ha)		4.550	1.158	3.929	0.000
Land use $\left(\mathbf{R}^2_{adj} = 0.497\right)$					
Increase artichoke surface (%) * Decrease arable field surface (%)		–1.394	0.354	-3.936	0.000
Increase artichoke surface (%) * Artificial area surface (ha)		4.298	0.707	6.079	0.000
Decrease arable field surface (%) * Dry grassland surface (ha)		–65.111	20.161	–3.230	0.001
Vineyard surface (ha) * Dry grassland surface (ha)		–59.128	12.006	–4.925	0.000

tain in the field compared to colony counts and, hence, produce datasets with higher rates of missing counts and larger overdispersion, which are parameters that can hinder model evaluation. Recording the presence/absence of colonies rather than counting pairs in any given colony of lesser kestrels is fast and produces robust estimates of trends and, hence, is methodologically advisable, especially when large-scale monitoring is needed, or operational and logistic circumstances would produce many missing values for pair counts.

Habitat preference models developed using GLM techniques are useful for finding relationships between habitat features and species distribution (Bustamante and Seoane, 2004). The considerable effect of the covariate 'population' suggests that spatial variation in the abundance and distribution of lesser kestrel colonies is affected by the absolute position in space (Gaston, 2003). This range effect also appears relevant when it interacts with climatic and land-use variables. A composite pattern of explanatory variables predicts changes in lesser kestrel abundance in Sicily, with those variables included in the land-use subset exerting the greatest weight in predicting abundance. Land use and land cover are the main factors affecting the distribution of these kestrels in southern Spain (Bustamante, 1997), and cereal steppe is the main habitat selected by lesser kestrels across their range (Palumbo, 1997; Parr *et al.*, 1997; Franco and Sutherland, 2004). This peculiar habitat preference has been suggested as being related to prey availability (Tella *et al.*, 1998) and the reduction in the extent of their foraging habitat explains the decline of the lesser kestrel population (Donázar *et al.*, 1993) better than a reduction in nest availability (Forero *et al.*, 1996) or pollution from pesticides (Negro *et al.*, 1993). Consequently, agricultural intensification due to irrigation schemes coupled with the abandonment of traditional agriculture and the afforestation of marginal land have strong

detrimental effects on this species (Tella and Forero, 2000; Brotons *et al.*, 2004; Ursua *et al.*, 2005). Results obtained in studies conducted in cereal steppes of Sicily are similar; lesser kestrels are affected by the reduction of arable land around their colonies and by the increasing prevalence of vineyards. Of the populations investigated in this study, the NNW population is apparently more sensitive than the SE population to the quantity of arable land remaining around colonies, exhibiting a drastic decline when the percentage drops below 40%. Transformation of traditional arable land negatively correlates with the abundance of lesser kestrel colonies in both areas. The intensification of vineyards and of hop plantations and other woody crops (e.g., fruit trees, olives and almonds) is likely to be the major cause of the observed population trend in NNW Sicily.

The SE population is apparently less susceptible to the decrease in arable land around their colonies, as this modification seems to be balanced by the positive effect of increasing the artichoke cultivations in that area. Artichoke cultivation, although intensive, is an exception with respect to the effects that intensification of cultivated land has on kestrel populations and might represent a suitable foraging habitat for lesser kestrels. Artichokes are still grown under a scheme of bi-annual rotation with wheat and leguminous crops, and their main harvest ends in April. Following the harvest, artichoke fields are abandoned and harbour rich pest populations of Dynastide beetles (*Pentodon bidens*) and Savi's voles (*Microtus savii*), which are a substantial part of the lesser kestrel diet at the time when they settle at their colonies (author's unpublished data). Ursua *et al.* (2005) reported that the relative weight of crop types provides an indication of how intensive cultivation (alfalfa fields in their case) can represent suitable foraging areas for lesser kestrels. However, the use of chemicals and other pollutants (PVC) in artichoke

farming is very high (Prato and Signorello, 2009; ISTAT, 2010), and this might produce negative effects in some places, interacting with the decrease of arable fields.

Different types of artificial areas elicit opposite responses from the lesser kestrel population: towns, villages and less diffuse and sparse urban areas in the NNW negatively correlate with lesser kestrel colony abundance, whereas in the SE, lesser kestrels benefit from abandoned quarries and buildings. Castillo *et al*. (2008) previously suggested the importance of quarries for cliff-nesting species in human-altered landscapes. The high number of old buildings, farms and stone ruins scattered over the Gela Plain provides what appears to be an unlimited resource for colonies located in suitable foraging habitats (Mascara and Sarà, 2006).

There currently exists unequivocal evidence of climatic warming (IPCC, 2007; Doran and Zimmerman, 2009). A vast amount of scientific literature related to how temperature increases correlate with changes in the phenology, demography and distribution of birds (e.g., Forchhammer *et al.,* 2002; Parmesan, 2006; Carey, 2009) and other species (e.g., Boutin *et al*., 2006) is accumulating; however, other climate variables, including precipitation and the frequency of extreme events, are also changing and may affect wildlife (IPCC, 2002, 2007). In the case of lesser kestrels, precipitation is a good predictor of breeding success (Rodríguez and Bustamante, 2003) and of their survival rate (Minhoub *et al*., 2010). The magnitude of mean precipitation differs markedly between regions globally (IPCC, 2002, 2007). For example, mean precipitation is projected to decrease by as much as 5% per decade in the Mediterranean; however, some areas, such as Sicily, are experiencing increasingly rainy winters (IPCC, 2002; SIAS, 2003-2005). According to De Vita and Fabbroncino (2007) the natural fluctuations of precipitation and air temperatures in southern Italy correlate

well with the NAO index. In addition, climatological research in the northeast of the Iberian Peninsula (Martin-Vide *et al*., 2008) shows a clear association between negative values of the WeMO index and torrential rainfall. Lesser kestrels are a long-distance migratory species, and most of the European population overwinters in the Sahelian belt (Negro, 1997; Rodríguez *et al*., 2009), where a bird banded in my SE population was recovered in 2009 (www.infs-epe.it). Climatic models developed using the GLM technique suggest a significant, but secondary, explanatory role of local and global climatic conditions in lesser kestrel abundance. However, their explanatory power increases when climatic variables interact with land uses, suggesting actions and remedies that might be implemented to abate this relationship. For instance, substantial steps for conservation of steppe-like habitats implemented under the Natura2000 network and the development of agri-environment schemes should be accelerated at the local level to abrogate, at least in part, the negative effects of land use and climate changes.

In Sicily, local precipitation in early spring, as is shown by the WeMO index of March, corresponds to the settling of birds arriving in breeding areas, as does the increase in minimum temperatures in April (NAO index of April), which corresponds to the moment of colony establishment. These months appear to be a critical stage in the reproductive biology of this species because climate controls the timing of reproduction (Sanz, 2002; Carey, 2009), and rainfall and temperature in spring influence the colony occupancy rate of lesser kestrels (Rodríguez and Bustamante, 2003). Additionally, the timing of arrival in the breeding areas is critical because any variation in time may produce a mismatch between the date of egg-laying and peak food abundance; consequently, climatic change is likely to have the most important impacts during the pre-breeding migration

(Kokko, 1999) in this species too. Lesser kestrels in Sicily have shown a linear negative response related to positive NAO phases in April and a positive response to the increase of overall precipitation in March. Years with warm, dry springs may be associated with limited vegetation growth and low prey abundance during pair formation, nest occupancy and egg-laying; colonies would therefore abandoned in favour of others located in more suitable areas (Serrano *et al.*, 2001; Serrano and Tella, 2003).

Because species have different and independent ecological responses to environmental changes (Gaston, 2003) and the effects of climate change will not be uniform across regions, we would expect some areas and species (UNEP/CMS, 2006; Hamer, 2010) to benefit from current conditions of climatic change. In general terms, the regional status of lesser kestrels in Sicily is favourable in that their range of distribution has broadened (AA.VV., 2008), with their density being estimated at approximately 1,200 pairs (Sarà, 2008), and accordingly, the implemented TRIM models showed an overall increase of the abundance of colonies and pairs. In the relatively short period of this study, I am able to conclude that the land uses and general climatic conditions of the SE Sicily are more suitable for lesser kestrels than the NNW area, where no consistent population trend has been documented. Conservation measures aimed at the management of suitable habitat conditions for the SE populations and the recovery of the NNW population must incorporate the effects of global warming in addition to land-use practices to produce a more comprehensive and effective plan of action than is currently in place, as has been advocated by Godfrey *et al.* (2009).

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