

Factors influencing the distribution, abundance and nest-site selection of an endangered Egyptian vulture (*Neophron percnopterus*) population in Sicily

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Abstract

The Egyptian vulture (*Neophron percnopterus*) breeds in Sicily and, in 22 years of monitoring, has shown a decline followed by a slight recovery. We used Generalised Linear Models to predict: (1) the distribution range, (2) the habitat selection within the range, (3) the quality (i.e., occupation rate, breeding success) of breeding sites. Some 60% of Sicily proved to be unsuitable, being either too densely forested and without cliffs for nesting, or too densely populated, along with intensive agriculture. The models converged, indicating that the pairs select a precise upland habitat where low cliffs, distant from urban areas, are surrounded by arboreal crops and Mediterranean vegetation. The variables predicting the quality of a site are also related to human disturbance, including the distance from a road or the presence of heavy traffic. Natural restocking, in the last 3 years, is occurring in quiet sites and in proximity to extensive grazing land rich in sheep and goat herds. These results focused on short-term programmes for local management of the species aimed at protracting the natural restocking: namely, the activation of (1) a stable system of artificial feeding stations, (2) nest site protection with joint activities for increasing public awareness, (3) a reintroduction project, by hacking, of juveniles born in captivity in Italian and European breeding centres.

INTRODUCTION

The Egyptian vulture (*Neophron percnopterus*) is a medium-size scavenging bird with a wingspan of 163–171 cm (Forsman, 1999). It feeds on small vertebrate and domestic livestock, but can also prey upon small animals. Most of the European population is concentrated on hilly or mountainous dry, open Mediterranean landscape, generally below 1800 m above sea level, where it nests on cliffs. Under optimal conditions, it seems limited only by breeding cliff availability (Donázar, Ceballos & Leon, 1989). Many European birds winter in sub-Saharan Africa within the 14°–17°N belt (Thiollay, 1989). The species is endangered in its Palaearctic range and is classified in category 3 according to the Species of European Conservation Concern (Del Hoyo, Elliot & Sargatal, 1994; Donázar, 1997; Heath, Borggreve & Peet, 2001) because the populations, with a dramatic decrease of some 50% (i.e., 900–1500 pairs) from 1984 to 1994, have declined or are extinct in many North African and European countries (Levy, 1996). The Italian population, which is 'critically endangered' (Bulgarini *et al.*, 1998), is found in the central and southern Apennines and in

Sicily (Liberatori & Massa, 1992; Liberatori & Penteriani, 2001). The current Sicilian population lives only in the western part of the island, nesting in areas between 400 and 1000 m above sea level (Seminara, 1985; Lo Valvo, Massa & Sarà, 1993). It experienced a sharp decline from some 30 pairs in 1970–80 (Iapichino & Massa, 1989), to three pairs in 1997. Since 2000, however, the population has increased to 10–13 pairs.

Although varying throughout Europe, the factors leading to the decline are all due to human activity. The top-ranked causes include killing, nest robbery and poisoning, followed by land-cover change and modification in traditional livestock-breeding practices (Grubaè, 1989; Elosegi, 1989; Donázar, 1993; Liberatori & Massa, 1992; Levy, 1996; Abuladze & Shergalin, 1998; Liberatori & Penteriani, 2001).

Habitat quality is involved in the regulation of the raptor populations and determines the species' settlement pattern (Newton, 1998). Investigation of the habitat requirements of endangered species is crucial to many aspects of conservation (Manly, McDonald & Thomas, 1993; Noss, O'Connell & Murphy, 1997). Several raptors, such as the Egyptian vulture, show pronounced philopatry and site-fidelity (Newton, 1979). It seems essential, therefore to explore the factors limiting the population density as well as to describe its habitat quantitatively.

At a regional level, it is important to focus on what are the main causes that led to the decline and then increase of the Sicilian population, judging to what extent the changes in land use and anthropogenic pressure are involved. This information could help to predict how the population would respond to habitat modifications. This could help in developing targeted plans for conservation as well as for better evaluating the future effects of the European Union's agricultural and environmental policies regarding this endangered species.

This paper deals with a long-term quantitative study of the Sicilian Egyptian vulture population. Our main objectives are: (1) to define predictive models based on environmental variables that identify the local breeding range and the selection of breeding sites; (2) to test the relationships among population size, breeding success, site fidelity and environmental factors; (3) to use such information for making recommendations about conservation management.

MATERIAL AND METHODS

The study area

Sicily, the largest Mediterranean island, has an area of 25414 km²: Almost 24.4% of the territory is mountainous, 61.4% is highland and 14.2% is lowland. Forests and Mediterranean vegetation, of which almost 6% burns each year, cover 8.4% of this surface. The island is also one of the most populated in the western Mediterranean (195 inhabitants per km²).

Sicily was formed by the Miocene drift of tectonic micro-plates and has three main geological sectors: the 'chain', or Sicilian Apennines; the central-southern 'foredeep' and the southeastern 'foreland' (Agnesi, Macaluso & Masini, 1997). An old geographic-administrative delineation also divides the island in three parts: the Demone valley, in the eastern part of the chain, including Mount Etna; the Mazara valley, in the western chain, which includes the southwestern foredeep (Castelvetro trench); the Noto valley, or Iblean plateau, which is part of the southeastern foredeep (Caltanissetta trench) and the foreland (Fig. 1 and Appendix 1).

Data collection

The Egyptian vulture population has been monitored, more or less continuously, from 1970 to 1989 (Seminara, 1985; Iapichino & Massa, 1989). Our censuses, monitoring the period 1990–2002 in order to detect nest-sites occupation and breeding success, began each year in early March and lasted until early September. An average of three to four visits per some 20 sites, including deserted ones, occurred each year, totalling around 1000 'vulture-trips'. We had access to the raw data for 1970–89, and since exhaustive and comparable censuses were available for the years 1980, 1982, 1985 and 1987–89, we used them in our analyses. We considered 1980 to be the starting point of our study and this is the year to which later status changes refer.

We were able to work out a checklist of 41 breeding sites for the whole period 1970–2002, from which we excluded four insufficiently known sites (three active during the early 1970s and one discovered in 2002). Pairs or territorial singles occupied the 37 remaining sites; singles were carefully followed in order to check for late arrival of the partner or their territoriality. Cross-observations made by trained ornithologists helped to clarify the cases of cliffs occupied by close neighbouring pairs and/or territorial singles.

For predictive model testing, we estimated the spatial dispersion of the occupied sites, and we defined the minimum area around the cliff in which the bird travels in search of food as the minimum utilized home range (MUR). Circular plots centred on each nest-site were used to calculate the composition of the landscape within the MURs. Usage is, therefore, the quantity of habitat (land-cover classes) within the MUR, whereas availability is a random sample of the same quantity of habitat accessible to the population.

All the cliffs occupied during one reproductive season were mapped. This allows calculation of the average nearest-neighbour distance (NND) per given year and per the entire sample of sites ($N = 219$) occupied during the period 1980–2002. We used the NND to delimit the MUR, which is thus a circular plot with radius equal to the gross mean NND/2. In some years, some birds moved their nesting sites very close to the previous year's sites and the circular plots, almost completely overlapping past sites, would have produced a bias in the habitat composition. We corrected such bias enlarging the radius to 5.6 km by averaging the midpoints between the nearby sites.

We also considered the number of years a site was occupied by a pair and/or a single divided per the long ($N = 21$ years) and medium ($N = 10$ years) period of study. This gave us the nest-site occupation rate (OR) and the number of consecutive years of occupation, i.e., the longest endurance (LE). Only single birds shown holding a stable territory were included in the calculations of NND, OR and LE.

We recorded data on breeding success by focal observations, at a secure distance, of old-growth chicks or just fledged young, during July and August. Year productivity was expressed as the ratio between the nests, which fledged at least one young per total number of controlled pairs (Newton, 1979).

Analysis of distribution and habitat utilization

We performed an analysis of habitat utilization at the first two levels of the selection process (Johnson, 1980). At a first-order selection level, we investigated the particular distribution range of the Egyptian vulture in Sicily, to discover the factors correlated to the species' absence from the Noto and Demone valleys. This can help in estimating the potential carrying capacity of the island. In order to do so, we initially tested the total composition of the landscape (land cover classes) in the three valleys (Appendix 1) and later compared a sample ($N = 25$) of breeding sites from the Mazara valley

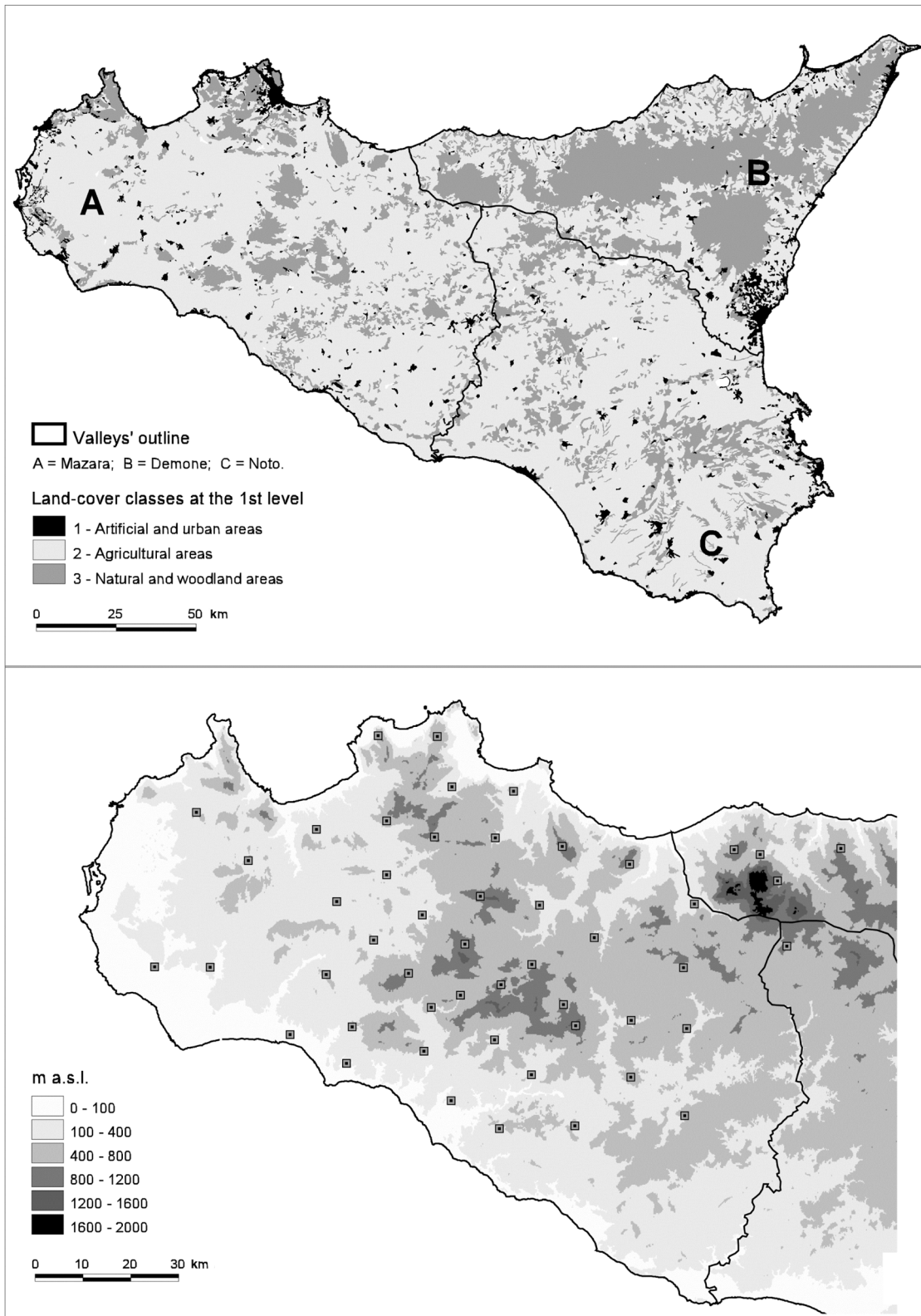


Fig. 1. Map of Sicily with the 50 circular plots used to analyze the habitat composition of the Egyptian vulture (*Neophron percnopterus*). Data source and graphic elaboration by 'Ambiente Italia – Osservatorio Sicilia' Research Institute.

Table 1. Population trend of the Egyptian vulture (*Neophron percnopterus*) in Sicily, expressed as the number of occupied sites, of breeding pairs and of UTM cells ($\times 100 \text{ km}^2$), and as the yearly nearest-neighbour distance (NND) mean

	1980	1985	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
No. occupied sites	29	20	18	19	15	10	6	8	8	7	6	7	6	11	14	12	13	14
No. pairs	29	20	18	19	15	9	6	7	6	5	6	6	3	7	7	10	11	13
No. of territorial singles	nr	nr	nr	nr	nr	1	0	1	2	2	0	1	3	4	7	2	2	1
No. checked pairs	29	19	17	18	0	9	6	7	6	5	5	5	3	6	4	10	10	8
No. juveniles fledged	30	19	15	18	nr	7	7	9	7	5	6	6	2	4	2	7	8	11
Productivity ^a	1.03	1	0.88	1	nr	0.78	1.17	1.29	1.17	1	1.2	1.2	0.67	0.67	0.5	0.7	0.8	1.38
N UTM	24	17	13	15	12	8	6	7	7	7	6	5	5	6	10	11	10	10
NND	7.18	6.92	7.73	6.6	6.27	8.16	10.9	9.95	9.95	10.2	6.63	9.67	8.51	7.11	9.38	9.82	8.1	8.46

^aNo. fledglings/No. checked pairs; nr = not recorded

(A in Fig. 1) to a random sample in the other Valleys (Appendix 2).

We further analyzed, at the second-order selection level, if and how the Egyptian vulture selects the breeding habitat in the Mazara valley, contrasting the habitat composition in the sample of 25 MURs (usage) versus the composition of a control block of 25 plots centred on cliffs never used by the Egyptian vulture (availability) (Appendix 2).

We also divided the 25 plots into two groups, low-OR (< 0.50) and high-OR (≥ 0.50) sites, to check for the environmental factors correlated to the quality of a breeding site. To study the factors correlated to the recolonization of pairs, we divided the sites into today-occupied (2000–2) and today-deserted sites (Appendix 3).

All the circular plots were interpolated and processed, by Arcview GIS 3.0, to the land-cover digital maps (scale 1:100,000) and to DEMs, the digital elevation maps (1:50,000) of Sicily, available from the Department of Environment and Land Management. The regional system of land-cover mapping is set on three hierarchical levels and divides the area into hectares of four, ten and 32 land classes present in each plot. Only the land categories meaningful to the species' ecology were considered.

The data on changes of the number of refuse dumps were obtained from the MEDECO (1990) census. The data on the sheep and goats reared in farmsteads with 5 to >100 ha of land came from the periodical census of the National Statistics Institute (ISTAT, 1986, 1991, 2002). These data were assumed to give the best approximation to the potential food available in the breeding range.

In our censuses, we tried to record the complete breeding population, and we assumed that only a very few pairs or singles escaped our study, so our sample does not have a bias of habitat usage. This study has the characteristics of a Design II (Manly *et al.*, 1993), where usage and availability are sampled for the whole study area, but individuals (sites) are recognized. Each site was assumed to provide an independent measure of habitat use within the population (Aitchinson, 1986). We recorded only nesting pairs and territorial single adults, hence sex- and age-class variability (Aebischer, Robertson & Kenward, 1993) was assumed to be negligible. We also

did a preliminary ANOVA on the 25 inhabited circular plots to check for individual variation.

Statistical analyses

We used Generalized Linear Models or GLZs (Hosmer & Lemeshow, 1989; Agresti, 1996) as a mathematical tool to describe: (1) the presence/absence of the Egyptian vulture in the Sicilian valleys; (2) the habitat selection, i.e., the presence/absence of breeding sites, in the Mazara valley; (3) the quality (occupation rate, productivity) of the breeding sites.

GLZs have already been used for running predictive models in raptor ecology and conservation (Donázar, Hiraldo & Bustamante, 1993; Bustamante, 1997). They are an extension of the linear modelling process that allows models to be fitted to data that follow probability distribution other than the Normal, such as Poisson or Binomial. GLZs also relax the assumption of equality of variances that is required for hypothesis testing in traditional linear models. A non-linear link response (LP, or linear predictor), which is required to be monotonic and differentiable, specifies the relationship between the response and the explanatory variables. The logistic function is the appropriate LP for our models that constrains the predicted values to lie between 1 and 0. This means that the probability of having a positive response (e.g., presence of the Egyptian vulture in one of the valleys in model 1) has a logistic and S-shaped function. The third GLZ component is the error function, which is also binomial when using our models (1 or 0 = to presence/absence in models 1 and 2; 1 or 0 = to high/low OR, high/low productivity, today-present/today-deserted sites in model 3). We used the software STATISTICA 6.0 to run the GLZs. Each of the explanatory variables was tested in turn and only those significant at $P < 0.05$ were included in the model to obtain a set of significant predictor variables explaining our observations (response variables). We used a stepwise modelling procedure to test all the alternative combinations of the selected explanatory variables, but always in order to minimize the loss of accuracy of the model prediction. The combination of explanatory variables giving the smallest loss function

(i.e., the sum of squared deviation of the observed scores from the predicted scores) resulted to be the best predictive logistic regression. We tested the goodness of fit of the alternative models by estimating the percentage of correct classification of our observations and by the resulting χ^2 values, when they yielded estimated models with a significantly better fit to the data than the nulls. We also considered the scatterplot of the observed versus the predicted values, which in the best model must follow a straight line, and we checked the outliers in our observations by inspection of the normality of residuals.

To test for habitat selection we ran an ascending compositional analysis with the software RSW 1.0 (Leban, 2002). RSW automatically performs the substitution for missing (zero) values in the data matrix (default = 0.001). STATISTICA 6.0 allowed running all the other statistical tests, which were two-tailed and set at a statistical significance $\alpha = 0.05$.

RESULTS

The population trend

The Egyptian vulture population was present in western and central Sicily, with 39 out of the 41 sites clumped in six mountainous districts (subpopulations) with a mean 6.5 ± 4.2 (min-max: 3–14; $N = 39$) breeding sites per district. The gross mean nearest-neighbour distance resulted in 8.05 ± 5.27 km (min-max: 2.4–38.8; $N = 219$), and its half-value, 4.02 km, proved to be equal to that recorded in other studies (Braillon, 1987; Ceballos & Donazar, 1988; Baumgart, 1991).

Table 1 shows the trend of the Sicilian population from 1980 to 2002. A high positive correlation ($r = 0.97$; $P < 0.01$; $N = 18$) is found between the number of occupied sites and the number of Universal Transverse Mercator cells (UTMs of 100 km²) in which the species was recorded during the Regional Atlas Project. The changes in number of occupied sites correspond exactly to those in the species' range, i.e., the decrease was generalized over all the districts, with the smallest emptying out before the largest. On average, we recorded 12.40 ± 6.20 occupied sites (and 11.1 ± 6.8 breeding pairs) in a mean range of 994 ± 493 km². From 1980 to 1989, this range contracted from 2400 to 1200 km² and kept on decreasing during the years 1991–98 to a minimum residual core area of 500 km², which was the last stronghold for the species. From 1999 to 2002, the species began recovering, reaching 13 pairs in 1000–1100 km². The number of occupied sites is negatively correlated to the average nearest-neighbour distances ($r = -0.56$; $P < 0.02$; $N = 18$), as the correlation between the mean number of Universal Transverse Mercator cells and the mean nearest-neighbour distance ($r = -0.50$; $P = 0.05$). The species' trend distinguishes itself in three phases. In 1980–89, during the population decrease from 29 to 15 pairs, the nearest neighbour distances averaged around 7 km; later, in 1990–98, years of deep crisis, the pairs decreased to three and the nearest-neighbour distances

Table 2. GLZ models for the Egyptian vulture presence in Sicily (model 1), for nest-site selection within the distribution range (model 2) and for nest-site quality (model 3a–c), using a binomial distribution of errors and a logistic link

Model 1		
Final loss: 16.78; $\chi^2_{[2]} = 17.36$; $P = 0.00017$		
	Parameter estimate	Standard error
Constant	-3.283	1.425
Artificial areas (ha)	-6.466	2.466
Natural areas (ha)	1.811	0.988
Model 2		
Final loss: 24.77; $\chi^2_{[3]} = 19.77$; $P = 0.00019$		
	Parameter estimate	Standard error
Constant	-2.015	1.852
Urban areas (ha)	-2.852	1.240
Developmental areas (ha)	-0.522	0.489
Mediterranean vegetation (ha)	1.645	0.605
Model 3a		
Final loss: 5.30; $\chi^2_{[3]} = 12.44$; $P = 0.00602$		
	Parameter estimate	Standard error
Constant	-3.227	1.818
Height of cliff (m)	-6.072	3.575
Height of nest (m)	3.641	2.326
Distance from road (m)	4.702	2.901
Model 3b		
Final loss: 11.18; $\chi^2_{[3]} = 11.94$; $P = 0.0076$		
	Parameter estimate	Standard error
Constant	-1.450	1.370
Urban areas (ha)	-0.021	0.011
Presence of local road (1/0)	2.391	1.277
Arboreal crop (ha)	0.001	0.000
Model 3c		
Final loss: 12.88; $\chi^2_{[2]} = 6.91$; $P = 0.031$		
	Parameter estimate	Standard error
Constant	-3.769	1.779
Sheep and goat density (head/km ²)	0.019	0.009
Presence of local road (1/0)	2.103	1.461

Table 3. The occupation rate and the longest endurance (LE) of breeding site by the Egyptian vulture (*Neophron percnopterus*) pairs

	High occupation rate (HOR > 0.50)	Low occupation rate (LOR < 0.50)
Long-term known sites (21 y)	10 (33.33%)	20 (66.67%)
LE (median)	8	1.5
LE (min–max)	4–17	1–5
Medium-term known sites (10 y)	6 (85.71%)	1 (14.29%)
LE (median)	4.5	3
LE (min–max)	2–5	—
Total known sites	16 (43.24%)	21 (56.76%)

rose significantly to 9 km ($t = 3.12$; $P = 0.002$). From 1999 to 2002, new pairs settled on new sites or recolonized old ones but the nearest-neighbour distances were always around 9 km. We also tested whether the 18-year nearest-neighbour-distance groups followed the Poisson's distribution. None of them proved to be distributed at

random (e.g., in 1980: $G_{[3]} = 19.98$, $P = 0.01$; in 1990: $G_{[1]} = 4.01$, $P = 0.05$; in 2000: $G_{[1]} = 21.08$, $P = 0.01$). This meant that all the pairs during one reproductive season were very close or very far from each other, giving rise to nearest-neighbour distances clumped at one or two tail of the distribution.

These results suggest that the Egyptian vulture pairs were neither randomly dispersed nor uniformly distributed, but aggregated in some areas, and that this depended on the habitat selection of more suitable sites and/or on the resistance in less disturbed sites of a given pair.

Presence of Egyptian vulture only in the Mazara valley

The lack of this species from the Demone valley seemed obvious and was therefore not checked statistically. This is a high-altitude valley, almost entirely without nesting cliffs, covered by dense forests of *Quercus* spp. and *Fagus sylvatica*. Typical of almost 25% of Sicily, this type of habitat is unsuitable for the Egyptian vulture, despite the presence of the good livestock density and garbage dumps. The only district (Madonie Mountains) having suitable habitat features was occupied by four breeding sites until 1985 (Fig. 1). Bray–Curtis similarity between the Mazara and Noto valleys is high (82.24), while the Demone valley is quite different from the Noto (56.19) and the Mazara (69.85) valleys. The landscape of the Noto and Mazara valleys was analyzed comparing, with a one-way ANOVA, the GIS polygon ($N = 4931$) surfaces divided by each of the land-cover classes (for names, codes and the hierarchical levels used see Appendix 1). The Noto valley resulted to be more anthropized, since the extension of total artificial areas ($F_{[1,600]} = 16.49$; $P = 0.00005$), and specifically that of ‘continuous urban areas’ ($F_{[1,252]} = 14.78$; $P = 0.0001$), is more widespread than in the Mazara valley. Another important sign of human pressure, with respect to Mazara, is the extension of greenhoused areas ($F_{[1,38]} = 4.82$; $P = 0.034$). Also the total surface of agricultural ($F_{[1,2544]} = 42.85$; $P = 0.00$) and natural ($F_{[1,1715]} = 4.61$; $P = 0.032$) territories are statistically different. The land used for arable ($F_{[1,694]} = 35.58$; $P = 0.00$) and mixed cultivation ($F_{[1,565]} = 28.16$; $P = 0.00$) determines the significant effect within the first class, whereas the Mediterranean vegetation ($F_{[1,1102]} = 4.42$; $P = 0.036$) extensions determine the effect within the natural territory.

The statistical comparison, by a GLZ model, of 25 circular plots with (Mazara) and without (Noto) Egyptian vulture sites, allowed us to check the set of environmental variables, which together can account for the species’ presence/absence in the two valleys, confirming the above ANOVA results. The probability of having an Egyptian vulture site increases with a smaller percentage of urbanized areas and with a greater percentage of natural areas (i.e., Mediterranean vegetation). This model correctly classified 64.28% of the plots predicted to be without a breeding site and 80% of those predicted to be with a breeding site (see model 1 in Table 2). The potential food availability, as quantified by the number of rubbish dumps and by livestock

density (Appendices 1, 2), is equivalent in the two valleys and does not enter in the group of predictor variables.

Habitat selection of Egyptian vulture in the Mazara valley

The mean composition of the land-cover classes within the 25 circular plots, which corresponds to the average habitat composition within the species’ MUR, is shown in Appendix 2. The 25 plots do not show any significant variation in their habitat composition ($F_{[24,744]} = 0.02$; $P = 1$). They are chosen ($F_{[1,48]} = 9.05$; $P = 0.04$) at a higher elevation above sea level (min–max: 156–1095) with respect to those taken at random (min–max: 87–900). The overall comparison of habitat usage versus habitat availability gave a $\Lambda = 0.1394$ ($\chi_{[10]} = 49.2624$; $P < 0.0001$). That means that Egyptian vultures do not establish their breeding sites at random. Arboreal crops, Mediterranean vegetation and mixed agricultural areas are the top-ranked categories, used more with respect to their availability, while the artificial areas are counter-selected and used less.

The forward stepwise procedure for determining the set of environmental variables, best explaining the habitat selection in the Mazara valley, produced a GLZ with three explanatory variables (model 2 in Table 2). These indicate that the probability of having a breeding site in a plot increases with the extension of Mediterranean vegetation and decreases with the urbanized surface area. This led to a correct classification of 80% of the plots predicted to be without a breeding site and 72% of those predicted to be with a breeding site.

From the early 1980s to the early 1990s, land-cover change in the Mazara valley was negligible and not significant (Wilks’ $\lambda = 0.997$; Rao’s $R = 2.07$; $P = 0.08$). Artificial areas increased some 10%, while agricultural areas decreased some 7% and woodlands 3%. However, abandoned arable cropland turned into suitable habitats (grassland, xerothermic steppe) for the Egyptian vulture, as did the woodlands and high maquis, degraded and opened by fires.

The potential food availability decreased only in the number of active dumps, as they changed from 139 in 1980 to six in 2000. On the contrary, sheep and goat density, in the 5 to >100 ha farmsteads, increased (+35%) from 1980 to 1990. Later, in 2000 this density was again similar (+10%) to the 1980 values. The Mazara valley did not show any apparent change in livestock density and husbandry practices and, as a consequence, the availability of potential food was dismissed as a predictor variable in the GLZ model 2.

Nest-site quality

Nest-sites are located in cliffs high on average 78.1 ± 51.1 m (min–max: 12–200; $N = 30$), 22 of which have a southern exposure (from southeast to southwest). The mean nest height is 47.3 ± 41.7 m (min–max: 5–170; $N = 30$). Twenty-five nests were found in hollows, three in ledges and two in rock niches. There is a not significant difference ($t_{[31]} = 1.22$; $P = 0.22$) between the mean

distance from local roads, trails (405.5 ± 260.7 m; min–max: 40–1000; $N = 23$) and more heavily trafficked provincial roads (535 ± 275.9 m; min–max: 150–1000; $N = 10$). Over the long-term study period (21 years), only 33% of 30 breeding sites have shown a high occupation rate, with a median occupation of 8 years. However, the high OR class increases when we added the seven short-term known (10 years or less) sites (Table 3). From 1970 to 2002 a total of 198 pairs were checked, producing 187 juveniles with a mean breeding success of 0.90 ± 0.40 (min–max: 0–1.37). The highest productivity in 1991–96 may have concurred to naturally restock the population by the arrival in 1997–99 of more breeders and territorial singles, whose mean number during 1997–2002 (3.6 ± 2.1) is significantly higher ($t_{[12]} = 2.35$; $P = 0.04$) than that observed before (1 ± 0.82).

We modelled the relationships between the nest-site characteristics and the surrounding habitat by using the data available for 13 years (1990–2002). According to the GLZ, the probability of having a site with high (> 0.50) productivity increases with the height of the nest and the distance from roads and decreases with the total height of the cliff where the nest-site is placed (model 3a in Table 2); this model correctly classified 100% of sites predicted to have a low productivity and 60% of those predicted to have a high productivity. Since we do not have enough data directly to model productivity and environmental variables, we used the OR which is well correlated to productivity ($r = 0.59$; $P < 0.01$; $N = 21$), dividing the 25 inhabited plots into high (HOR > 0.50 , $N = 11$) and low occupation rates (LOR < 0.50 , $N = 14$) and contrasting them to their corresponding land-cover classes. The best GLZ model included the presence of local roads near the breeding site, and the extension of urban areas and of arboreal crops (model 3b in Table 2). The model correctly classified 92.9% of the sites predicted to have a LOR and 81.8% of those predicted to have a HOR, thus stating that the probability of high occupation rate (and hence of high productivity) increases when a local and not a heavily trafficked road is near a site, when the orchard surface is larger and when the urbanized surface is smaller.

Fifteen sites were occupied from 2000 to 2002, since some pairs changed sites or were not present in all three years. Seven of these are historically known, HOR sites. One was recolonized after 11 years, and the remaining

seven were new colonization occurring in the last years. When we divided those sites into today-occupied and today-deserted sites to check for variables predicting the occupation of a new site, once again the presence of a local road was selected, together with the density of sheep and goats (model 3c in Table 2). Those variables correctly classified 87.5% of sites predicted to be deserted and 44.4% predicted to be occupied today.

DISCUSSION

Habitat selection

At a coarse-grained level, some 60% of Sicily's surface proved to be unsuitable for the species. This analysis allowed estimating the potential carrying capacity of the island, which would not surpass the 35–40 pairs, almost entirely concentrated in the Mazara valley (10.330 km²). Only this area proved to have the right combination of the ecological features necessary for the species' presence. This does not mean that in the Noto and Demone valleys there are absolutely no good places to nest, but simply that they are secondary habitats where colonization can begin only after exceeding the Mazara valley carrying capacity.

Some 35% of the Sicilian territory, the Noto valley or Iblean plateau, is a dry, open landscape, rich in mesas and canyons, and seems, at first glance, a suitable habitat for the species. Nevertheless, historical records of its presence in this valley, except for few sites during the early 1970s (B. Massa, pers. comm.), is lacking (Iapichino & Massa, 1989). Statistical analyses suggested that this valley is too heavily impacted by humans and has the scarcest extension of Mediterranean vegetation. An analysis on the connectivity of landscape patches would probably reveal more details than that on absolute surface areas.

GLZs converged on the same explanatory variables, suggesting that, in establishing a breeding site, the Egyptian vulture selects a habitat where human settlements (urban and other artificial areas) are underrepresented and where a precise mixture of natural (Mediterranean vegetation) and agricultural (arboreal crop) upland dominates. These last land-cover categories add up, on average, to 58.72% of the minimum utilized home range.

Surprisingly, arable cropland, although consistent in extension (averaging 24.50% of the minimum utilized home ranges), does not appear in any GLZ model and is counter-selected by compositional analysis. This habitat has, as a matter of fact, high human disturbance during late spring and summer, owing to threshing and other mechanical activity, and rarely hosts domestic herds. Grazing, in fact, occurs in Sicily mostly in Mediterranean vegetation and open arboreal crops, and especially in those orchards that are today no longer exploited. The counter-selection of cropland (which indeed adds to urban areas as a negative [estimate: -0.171 ± 0.498] predictor variable in the GLZ model 1 when using the 2nd level class variables) can further explain the species' absence from the Noto valley. In this area, cropland is much more extensive than Mediterranean vegetation and arboreal crop, with a ratio of 1.23:1, than in the Mazara valley (which has a reversed ratio of 0.51:1).

Table 4. Causes of breeding failure of the Egyptian vulture in Sicily (1974–2000).

	Incubation	Fledging	Source
Shooting	9 (+3?)	–	Falcone, 1987; present study
Poisoning	4	–	Seminara, 1985; Marsili & Massi, 1991
Unknown	1	–	present study
Robbery of young	–	5 ^a	present study
Human disturbance at the nest	3 ^a	–	present study
Natural causes (storm)	–	1 ^a	present study
Number	17–20	6	

^aThree individuals recovered and reintroduced in 1999–2001 by the Bird Rehabilitation Centre working in the area.

This means that in the Noto valley, for each km² of suitable habitat where a pair can forage for themselves and their young, there is a tare of almost 1.23 km² of less suitable cropland. In other words, the home range of a pair, to include the minimum 50–60% quota of suitable habitat, should be much larger than that normally recorded (present study and Braillon, 1987; Ceballos & Donazar, 1988; Baumgart, 1991).

Breeding-site quality

Explanatory variables in the different models converged rather well also in this case and were all related to human disturbance. We assumed thus that the sites with a low occupation rate and those today-deserted sites were those more exposed to human disturbance, as indirectly confirmed by the available data of human persecution and disturbance at nest (Table 4).

The quality of a site (in terms of productivity and occupation rates) can be reasonably predicted by the category (local rather than trafficked roads) and the distance from the nearby road, as already noted by Liberatori & Penteriani (2001); by the localization in lower cliffs, as well as by the presence of potential food. Twelve (80%) of the today-occupied sites are near a local road and in proximity to extensive grazing land rich in sheep and goat herds.

The species' preference for low cliffs (10–30 m) and low nests (5–30 m) has already been recorded in some European countries (Grubač, 1989; Ceballos & Donazar, 1989; Vlachos *et al.*, 1998), but never statistically tested.

The southern cliff exposure was dropped as predictor for quality sites. It cannot, however, be dismissed because it is an important variable that is probably pre-selected when choosing the breeding site. The percentage of southern exposed nests is always >70% elsewhere in the species range (Ceballos & Donazar, 1989; Abuladze & Shergalin, 1998; Vlachos, Papeigeorgiou & Bakaloudis, 1998; Liberatori & Penteriani, 2001). In Sicily it is weakly correlated to mean productivity ($r = 0.37$, $P = 0.10$) that, however, increases from east (0.17 ± 0.19) to southwest (0.58 ± 0.41).

The localization of a site within a protected area (IBAs, Natural Reserves and Regional Parks) is another variable dismissed by the GLZ models 3a–c, which is why protection can be judged to some extent tardy or 'virtual'. In several cases the recent, or very recent, institution of the preserve area occurred after the pair was gone, whereas in some others there is a generalized lack of surveillance and/or an increasing recreational use which can prevent colonization or lower the breeding success. Twenty-six (70%) of the studied breeding sites, but only seven (47%) of the today-occupied sites, lie inside a protected area. Information on such percentages can, in the future, help the species' management.

Population trend

Several factors are probably involved in the population trend in Sicily. Heavy human disturbance by killing, poisoning and robbery of young may have characterized the decline. A recovery phase of the population may have occurred in late 1990 and we can assume, to some extent,

that the relative increase monitored from 1997 onwards is a delayed response depending on the positive fluctuation of productivity during 1991–96.

The Egyptian vulture juveniles disperse for 5–6 years before reaching sexual maturity and returning to the natal areas for breeding (Levy & Segev, 1996; Forsman, 1999), and some of the young produced during 1991–96 would presumably have begun to come back to Sicily since 1997 as new colonizers. They reoccupied old sites after years of desertion or occupied brand new sites, such as the seven we began recording in 2000. Decreasing human disturbance at some of the breeding sites (e.g., some renowned poachers retired, three birds recovered in the area, see Table 4) as well as a better survival rate in wintering areas, may also be invoked as other factors explaining the population recovery.

After a decline, breeding success seems to increase again (see the 2002 high value in Table 1). This latter and the former high productivity years may depend on higher food availability as already shown in the Egyptian vulture (Levy & Segev, 1996). We can speculate from some field observations that in 2002, a year of heavy drought in Sicily, sheep and goat mortality increased. To bypass the Italian and European Union laws regulating the removal of livestock carcasses from the field, dead animals are declared 'lost and wandering' by the owners and thus are still available as food for the Egyptian vulture as was the case during the early 1980s.

Conservation and management implications

The importance of maintaining intact the biological potential of endangered species is today widely recognized, and populations, even small in number, that have been historically isolated, represent an important evolutionary legacy (Ryder, 1986; Avise & Ball, 1990; Moritz, 1994). A significant genetic differentiation in the Egyptian vulture populations from the Balearic and Canary Islands has recently been detected (Donazar *et al.*, 2002a,b). These islands host sedentary populations, unlike the migratory Sicilian population. The observation that the Egyptian vulture populations have different migratory routes, which may correspond to different wintering grounds (Thiollay, 1975; Galea & Massa, 1985; Leshem, 1985; Porter & Beaman, 1985), added to its philopatry, allow us to hypothesize that the exchange of individuals among geographic areas may be quite infrequent. This may lead to the existence of several small isolated populations (e.g., Sicily, Italy, the Balkans, Greece) in its range that may have the characteristics of metapopulations (Gilpin, 1991) and show negative effects owing to population size reduction (Clark & Seebeck, 1990; Frankham *et al.*, 2002).

After years of decline, Sicily today hosts a source population that, if adequately helped, can become important for the species' conservation in Italy and Europe. The quantitative description of nesting habitat selection and the modelling of environmental variables predicting, at least partially, the population change were fundamental to the proposal of guidelines for a local

action plan (Ceccolini, Sarà & Di Vittorio, 2002). At least three compelling, concrete short-term action plans would help the natural restocking of the Sicilian population. These plans, waiting for funding, are urgent in order to avoid future damage to the species' current positive status. First of all, considering that livestock density, and hence the potential availability of food, is the best variable predicting the current presence of a pair, this determines the utility of setting up a stable artificial feeding station system, as used in Europe (Terrasse, 1985; Gallardo *et al.*, 1987; Liberatori & Cortone, 1991, Gomez *et al.*, 2001) and the Middle East (Levy, 1991). The second point derives from the demonstrated species' preference for low nesting cliffs. This exposed and still exposes some pairs to high risk of robbery and killing and determines the programming of nest-site protection by guards or volunteer camps with joint activities for increasing public awareness in towns nearby. Our investigation recognized and ranked the top-quality breeding sites in which to start setting protection camps. Thirdly, reintroduction into the wild is proposed, by hacking, of juveniles born in captivity in some Italian and European breeding centres.

The past population decline in Sicily cannot be related to major landscape changes, occurring from 1980 onwards. Nevertheless, Mediterranean vegetation and orchard territories, not already protected in western and central Sicily, are the major habitats to be preserved from future modification of the landscape. Without adequate planning, intensive agriculture (greenhouses, tomato, vineyards, etc.), which is beginning to grow even in the core area of the species, can inexorably alter the territory of several pairs. Regional agricultural policy should take into account the wildlife consultants' conclusions for developing, in the near future, sustainable agricultural modifications and an appropriate habitat-site management for those breeding sites most directly impacted by land-use changes.

In conclusion, there is the impending threat of windtowers and windturbines, whose destructive impact on birds is increasingly a subject of debate (Anderson & Estep, 1988; Winkelman 1992*a,b*). At least a dozen stations are being programmed inside or near protected areas where the Egyptian vultures live. Regarding the windturbines and their operation in wind resource areas, we strongly suggest that the Regional Administration collect information necessary for predicting and mitigating their potential impact on avifauna and hence to oblige strict and rigorous incidence evaluation procedures before their construction.

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Appendix 1. The codes, between parenthesis, names and total surfaces in km² of the land-use classes, relevant for the Egyptian vulture in the three Sicilian valleys and used for GLZ model 1. Mean altitude was calculated by Arcview GIS 3.0 on 6248 height classes (55,342,623 pixels). (Source and elaboration: 'AmbienteItalia – Osservatorio Sicilia' Research Institute).

Land-use classes	Demone	Mazara	Noto
(111) Continuous urban areas	80.81	112.83	55.23
(112) Sparse urban areas	201.45	199.42	145.83
(12) Industrial areas	23.34	23.02	46.73
(13) Development areas	3.79	43.77	19.42
(1) Artificial	309.39	379.03	267.21
(21) Arable	771.89	3349.24	3926.85
(212) Greenhoused areas	0.00	6.98	97.19
(22) Arboreal crop	1755.22	3407.88	1836.08
(23) Mixed	186.22	1380.38	1130.14
(2) Agricultural	2527.11	6764.10	5860.12
(31) Woodland	1188.08	477.99	435.99
(32) Mediterranean vegetation	1661.00	1178.64	1029.03
(33) Rocky ground	371.26	112.32	80.83
(3) Natural	3406.57	3149.34	2675.99
(4) Wetland	0.00	17.30	8.42
(5) Bodies of water	3.00	17.87	28.09
Total surface (km ²)	6246.06	10327.64	8839.82
Altitude (m a.s.l.)	1655±956	803±463	666±385
No of dumps in 1980 ^a	138	139	22
No of dumps in 1990 ^a	75	79	19
Head/ km ² . ^b	65.91	34.0	48.98

^aMEDECO, 1990

^bsheep and goat average density in 1990 (ISTAT, 1991)

Appendix 2. Mean in km² (if not elsewhere indicated) and standard error of variables used in GLZ model 2

Variable	With breeding sites in Mazara valley		Without breeding sites in Mazara valley		Without breeding sites in Noto valley	
	Mean	SE	Mean	SE	Mean	SE
Urban	150.13	47.12	315.34	106.72	224.77	58.27
Industrial	23.07	17.40	2.45	2.38	18.53	13.08
Development	24.98	6.86	37.14	16.70	20.34	20.34
Archaeological	4.68	4.68	0.00	0.00	0.00	0.00
Arable	2389.31	336.92	3487.78	536.83	4038.45	555.44
Arboreal crop	2708.10	379.42	3214.39	300.88	2963.84	644.97
Mixed	983.40	221.33	1324.95	285.28	1174.86	286.82
Woodland	1224.69	266.44	392.65	114.82	312.25	129.18
Mediterranean vegetation	1970.37	252.67	818.09	175.94	938.81	211.78
Rocky ground	152.01	50.63	72.89	17.15	64.09	29.97
Inland water	42.86	15.02	0.44	0.44	6.97	6.97
Mean altitude (m a.s.l.)	680.88	264.85	482.32	197.01	399.56	179.90
Head/km ² . ^a	28.40	5.24	25.31	5.11	27.66	5.16

^aAverage density of sheep and goats during the period 1970–82 and 1990 (ISTAT, 1986, 1991)

Appendix 3. Mean in km² (if not elsewhere indicated) and standard error of variables used in GLZ models 3a–c

Variable	HOR breeding sites (N = 11)		LOR breeding sites (N = 14)		Today-occupied sites (N = 9)		Today-deserted sites (N = 16)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Occupation rate (0/1)	0.64	0.04	0.18	0.03	0.61	0.06	0.26	0.05
Altitude (m asl)	630.27	85.10	720.64	67.80	628.22	100.21	710.50	61.96
Protection (0/1)	0.73	0.14	0.64	0.13	0.67	0.17	0.69	0.12
Road type (0/1)	0.91	0.09	0.50	0.14	0.78	0.15	0.63	0.13
Productivity	0.59	0.10	0.03	0.03	0.57	0.12	0.28	0.16
Distance from road (m)	0.49	0.08	0.33	0.08	0.43	0.06	0.38	0.09
Towns, villages	72.48	16.32	121.40	21.44	87.83	18.36	106.65	20.55
Sparse urban areas	2.83	2.00	87.52	65.70	5.30	2.77	75.54	57.78
Industrial	38.44	19.43	63.96	30.78	36.35	21.49	61.95	27.46
Arable	2137.23	355.89	2587.37	539.27	2374.62	474.51	2397.57	464.99
Arboreal crop	2873.52	710.39	2578.14	408.20	3098.50	818.81	2488.51	387.09
Mixed	1280.98	244.10	749.59	340.47	1310.59	310.58	799.36	295.39
Woodland	1137.86	375.77	1292.92	384.55	800.08	277.17	1463.54	379.29
Mediterranean vegetation	2119.03	435.45	1853.57	305.73	2047.56	536.08	1926.95	270.25
Rocky ground	109.07	71.86	185.75	71.64	17.79	12.20	227.52	72.86
Inland Water	27.77	13.28	54.72	24.75	20.59	14.05	55.39	21.81
Head/km ^{2,a}	94.81	17.98	77.37	21.20	121.97	29.74	64.28	12.30

^aAverage density of sheep and goats during the period 1970–82, 1990 and 2000 (ISTAT, 1986, 1991, 2002)