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Landscape-scale Spatial Distribution of the Lanner Falcon (*Falco biarmicus feldeggii*) Breeding Population in Italy

Falco biarmicus feldeggii is one of the most threatened taxa in Europe. Its global population is estimated at a few hundred pairs unequally scattered in a vast and fragmented area stretching from Sicily to the Caspian Sea. Most recent counts showed that Italy hosts a large part (>25%) of the whole population. Consequently, Italian authorities promoted a national action plan. In this framework, we carried out the first national survey for the Lanner Falcon in Italy (2003–2004). Our study area covered the whole breeding range, i.e., Sicily and the Italian peninsula (n = 2909 cells 10 × 10 km). When possible, we considered also additional information from previous regional investigations (1993–2001). First, we estimated size and distribution of each breeding subpopulation. Then, we tried to identify, at landscape level, the main environmental features linked to the spatial distribution of the nesting sites. We found the Lanner Falcon in 184 cells (6.4% of the total grid map), but we estimated no more than 140–172 pairs (70–80 of which are in Sicily) in the same breeding season. Higher levels of isolation characterize the continental breeding cells whereas in Sicily cells are much more clustered. Altitude is the main factor influencing cell aggregations in Italy; nevertheless, other environmental variables, such as climate, precipitation, and vegetation may be important. Our results show that the conservation measures adopted in Italy are somewhat inadequate given the low number of breeding pairs included in protected areas (23%–28%). Many small and scattered special areas of conservation (SAC) devoted to conserve priority habitats fit the irregular spatial aggregations of Lanner Falcon sites better than several large special protection areas (SPA).

Lanner Falcon *Falco biarmicus feldeggii* (Photo: S. Fanfani).

INTRODUCTION

The choice of the best conservation measures for threatened taxa strictly depends on basic knowledge about their population size, distribution, and overall trends. However, it is difficult to gather such information in the field. In fact, focal species are often rare and have complex distributional patterns related to sink-source or metapopulation models (1–3). Thus, investigations on these species need big efforts to find out valuable conservation strategies (4).

The Lanner Falcon (*Falco biarmicus*) is a Mediterranean and Afrotropical polytypic species, adapted to severe steppe and predesert habitats (5–7). There are four or five recognized subspecies of this falcon, and *F. b. feldeggii* is the only one living outside the vast arid plains. This subspecies lives mainly in southern Europe and in some small and scattered areas of the Caucasian region (7, 8); nevertheless, it prefers warm and dry environments, perhaps because of the African origin of the species. Previous studies explained the rarity and fragmented distribution of the Lanner Falcon in Europe as result of its low tendency to occupy cold and rainy areas (9, 10). Population sizes of *F. b. feldeggii* are markedly unequal among countries, and most recent counts showed that Italy hosts >25% of the whole population (7, 11, 12).

The European Union listed *F. biarmicus* as a vulnerable species among those of great interest in Europe because of low population and continuing decline (13,14). Consequently, Birdlife for the EU Commission drafted an international action plan, followed by the Italian plan produced by the Italian Wildlife Institute (INFS), on behalf of the Minister of Environment (11, 12). When INFS started to gather data for the national action plan, no long-term and coordinated studies existed on trends, biology, and ecology of *F. b. feldeggii*, in spite of several efforts made by local study groups. In fact, information on size and trends of different breeding subpopulations showed them to be inadequately homogeneous and complete owing to the utilization of different survey protocols (12). Therefore, in 2003–2004 a detailed survey of the breeding pairs was carried out to fill the gaps in the knowledge on the breeding population.

This study focused on size and status of the Italian populations of the Lanner Falcon and related conservation issues. The main aims were: *i)* to estimate breeding subpopulation sizes in Italy; *ii)* to assess their distribution patterns to evaluate the degree of isolation of each cell cluster, and *iii*) to identify, at landscape level, the main environmental features linked to the spatial distribution of the pairs.

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Table 1. Categorical variables related to cells occupied by breeding pairs.

Variables	Classes
Climate	Subtropical, Temperate, Warm Temperate, Subcoastal Temperate, Subcontinental Temperate, Cool Temperate
Altitude (m a.s.l.)	0–100; 100–200; 200–500; 500–1000; 1000–1500; 1500–2000
Precipitation (mm)	<50; 50–60; 60–70; 70–80; 80–90; 90–100; 100–110; 110–120
Main land uses	Forests, extensive cultivated areas, pasturelands
Number of habitat patches	1–2–3–4–5
Human density (inhab/km^2)	0–50; 51–100; 101–150; 151–300; 301–1000

MATERIALS AND METHODS

Study Area and Landscape Attributes

The Lanner Falcon historically bred in Italy from the northern Apennines (Bologna province) to southern Sicily (7). Thus in our study area, we omitted the Alps and Sardinia, where we have no nesting record from the past. The data set followed a spatial resolution of cells of 10 × 10 km (n = 2909 cells) through MapInfo 7.5 GIS software (MapInfo Corporation 2003). We defined cell size according to average distances among nesting sites (A. Andreotti and G. Leonardi unpubl. data).

First, we identified cells with at least one confirmed breeding site during 1993–2004. Then, for each selected cell, we associated landscape attributes as categorical independent variables (climate, precipitation, altitude, human density, vegetation, and number of main habitat types) provided by national thematic maps (Table 1) (15).

Data and Pattern Analysis

More than 70 field observers gathered information in 12 regions following standard procedures, and a national board together with local coordinators approved each card returned by the observers. Most of the data were recorded over 2 years (2003–2004), but, when available, we considered also the information from previous surveys (1993–2002).

We used these data to ascertain spatial patterns of cells where the Lanner Falcon is breeding in Italy. Around each confirmed breeding cell, we created two frames (Fig. 1) containing the adjacent cells (F_{adj} n = 8 cells) and the external ones (F_{ext} n = 16 cells). Then, we counted the occupied cells inside each selected frame. Thus, for each cell we used as two dependent variables the number of occupied cells (N_{adj} and N_{ext}) inside F_{adj} and F_{ext} frames to assess different level of aggregation of breeding pairs (Fig. 1).

Statistical Analysis

We ran generalized linear models (GLM) to verify if environmental variables significantly affect the aggregation level of each cell, evaluated as N_{adj} and N_{ext} counts. No significant two-way interaction terms were removed from the model one-by-one and the model was run again (16). Thus, we ran a multivariate analysis of variance (MANOVA) to determine if spatial patterns of cells significantly differ about landscape attributes (17). We ran all statistical analyses through SYSTAT 11 (SYSTAT Inc. 2004).

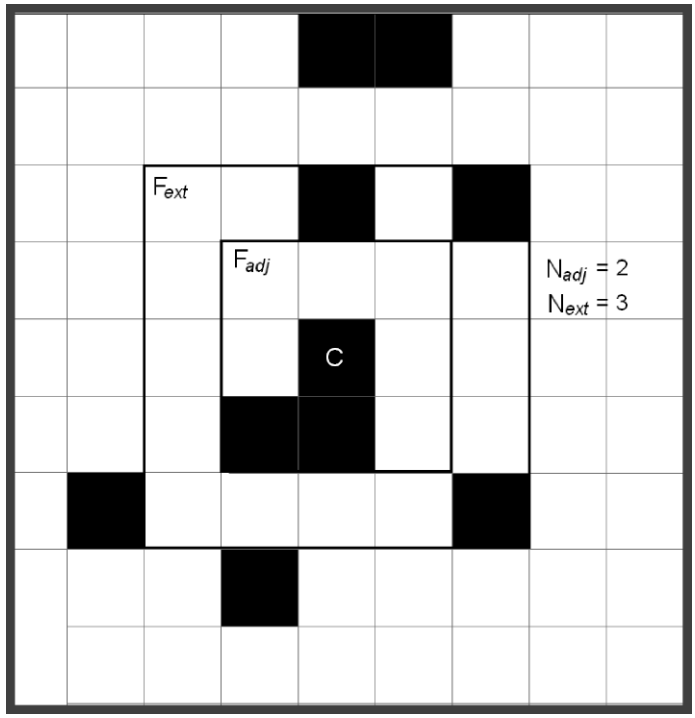

Figure 1. Example of calculation procedures of N_{adj} and N_{ext} inside F_{adj} (n = 8) and F_{ext} (n = 16) frames surrounding a cell of the geographical grid (C). Occupied cells are in black.

RESULTS

Status and Distribution in Italy

We found the Lanner Falcon in 184 cells (6.4% of the total grid map [n = 2909] [Fig. 2A]). A small deme (0–3 pairs) seemingly survives isolated in northern Apennines. Central-northern Italy hosts the main subpopulation (31–51 pairs) of the mainland, whereas central-southern regions have 12–17 stable pairs. Another small deme (5–7 pairs) is located in the Gargano rocky peninsula. In southern Italy, 25–33 pairs have been recorded but no data exist for the NW southern zone (Campania). The most important subpopulation of 70–80 pairs lives in Sicily.

We estimated 140–172 breeding pairs in Italy, assuming at least three to four active nests in Campania (Table 2).

Table 2. Estimated breeding pairs in Italian administrative regions and their proportions (%) inside protected areas (SACs = special areas of conservation; SPAs = special protection areas; IBAs = important bird areas).

Administrative regions	Breeding pairs (n)	Natural parks and reserves (%)	SACs (%)	SPAs (%)	IBAs (%)
Emilia-Romagna	0–3	0	0	0	0
Tuscany	11	27	18	9	18
Marche	11	54	27	27	9
Umbria	5–9	22	44	33	10
Lazio	5–6	33	33	50	33
Abruzzo	6–8	62	75	62	62
Molise	4–6	33	90	—	67
Apulia	11–16	44	50	44	94
Basilicata	10–13	38	15	15	31
Campania[1]	3–4	—	—	—	—
Calabria	4–5	0	0	0	40
Sicily	70–80	0	8	9	28
Italy	140–172	23–28	28–33	21–25	35–38

[1] Supposed breeding population size.

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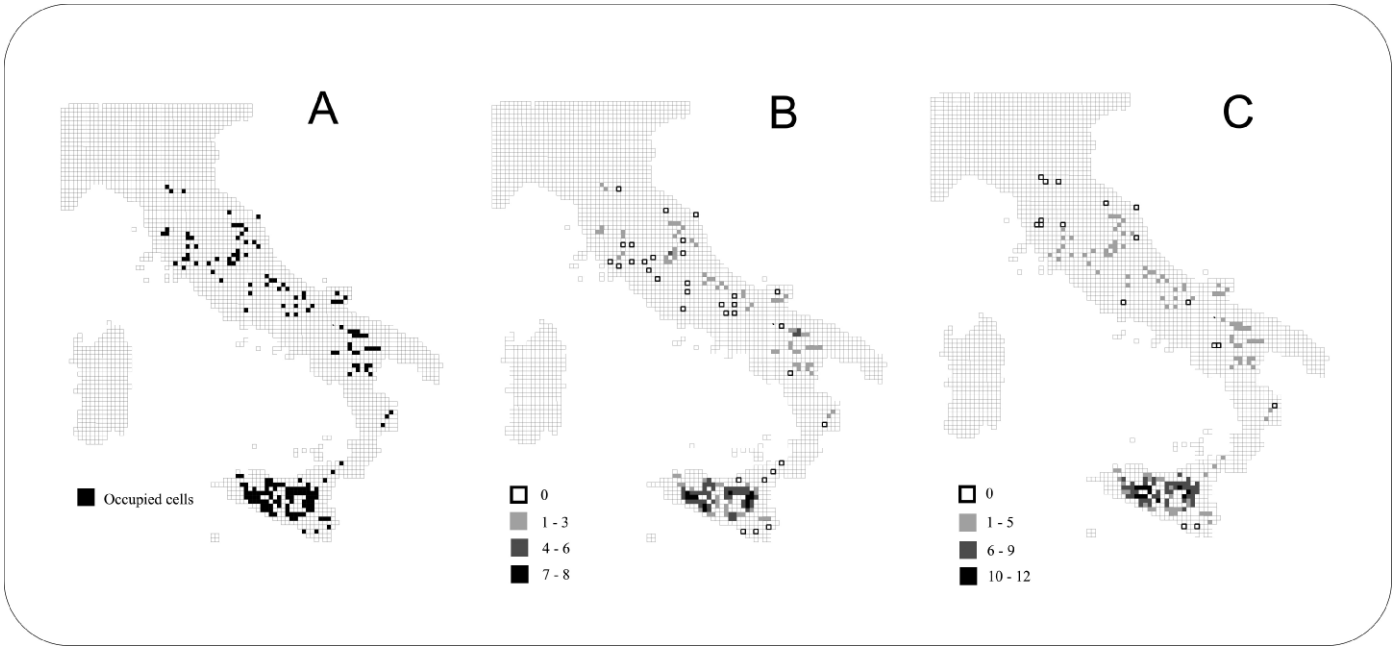

Figure 2. Distribution of (A) the cells occupied by the Lanner Falcon during 1993–2004 and their subdivision on the base of (B) N_{adj} and (C) N_{ext} values. Zero scores characterize isolated cells.

Spatial Patterns of Cells

In the whole breeding area, an occupied cell is surrounded on average by three adjacent ($N_{adj} = 2.6 \pm 2.1$) (Fig. 2B) and four external cells ($N_{ext} = 4 \pm 3$; n = 184) (Fig. 2C). Breeding cells in Sicily are much more clustered ($N_{adj} = 4 \pm 1.9$; $N_{ext} = 6.1 \pm 2.8$; n = 91) than continental ones ($N_{adj} = 1.2 \pm 1.1$; $N_{ext} = 1.8 \pm 1.2$; n = 94).

When considering the whole data set, we found a direct positive correlation between the number of cells counted in F_{adj} and F_{ext} ($r_s = 0.678$, n = 183, $p < 0.01$) (Fig. 3). Thus, we can hypothesize that the number of cells occupied in F_{ext} should be a good indicator of the degree of isolation of cells (Fig. 2C). Also, the lack of adjacent cells ($N_{adj} = 0$) is more diffuse throughout the country (Fig. 2C), and small aggregations are frequent ($N_{adj} = 1$–3). This is especially true in the Italian peninsula, where N_{ext} values (0–4) never exceed N_{adj} (Fig. 3, white dots).

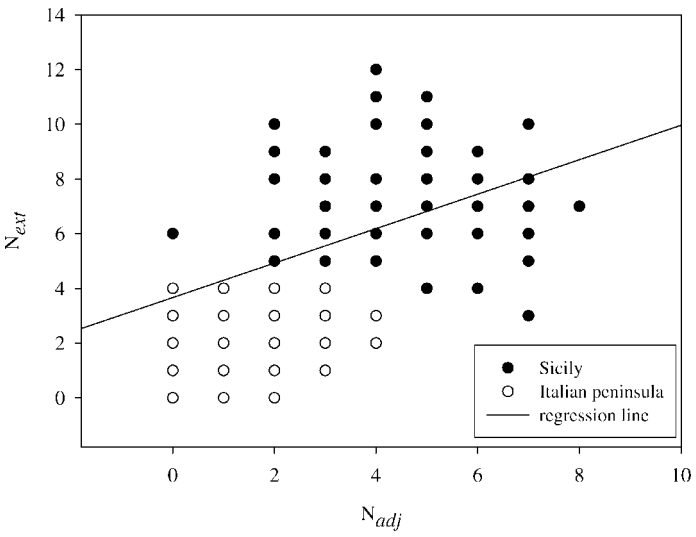

Figure 3. Direct relationship between the number of contiguous pairs in adjacent (N_{adj}) and external positions (N_{ext}).

Landscape Attributes of Occupied Cells

Overall, the Lanner Falcon in Italy mostly occupies cells with altitude between 200–500 m above sea level (44%), annual rainfalls between 600–800 mm (62%), human presence between 50–150 inhabitants per square kilometers (63%), and extensive cultivated areas (73%).

Analyzing the whole data set, the altitude seems to be the main factor influencing cell aggregations in Italy (Table 3). This is also true for the F_{adj} and F_{ext} subsets, but in association with other environmental variables (Table 3). Climate becomes important only for the F_{adj} group; precipitation and vegetation for the F_{ext} group (Table 3). Human densities and habitat composition *per se* have no effects at the landscape level.

DISCUSSION

In the late 1970s, ornithologists for the first time carried out systematic surveys searching out nesting falcons in Sicily and northern Apennines (18, 19). Afterward, several different monitoring schemes were conducted in other areas (20–25). In the last 10 years, this large amount of data was used for a better estimation of the Italian population size and breeding performances for conservational purposes (26–30). Unfortunately, local studies were asynchronous, and some comprehensive analysis involved no more than a few bordering regions (26, 28, 31). Thus, this is the first, most complete overview of the status and distribution of the Lanner Falcon in Italy, which was also one of the main goals of the action plan (12). Nevertheless, some areas are still inadequately monitored, especially in southern Italy and some Sicilian mountainous zones (Iblean plateau and part of the northern mountain ranges).

Our results confirm the Sicilian subpopulation value, as well as the apparent increase of central-northern small subpopulations, mainly in Tuscany (Fig. 1A; Table 2) (7, 28). Conversely, isolated clusters of breeders persist in many areas, likely affected by local human activities, landscape modifications for agriculture practices, and, perhaps, competition with peregrines (12, 29). The conservation measures adopted in Italy are somehow inadequate, given the low number of breeding pairs included in protected areas (23%–28%; Table 2). In fact, the preferred

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Table 3. Environmental variables predicting the levels of aggregation of the cells occupied by the Lanner falcon in Italy.

Dependent variables	Source	df	MS	*F*	p
N_{adj}	Climate	4	11.176	3.166	0.015
	Altitude	5	14.484	4.104	0.002
	Precipitation	7	5.801	1.643	0.126
	Error	167	3.529		
	Total	183			
N_{ext}	Climate	4	15.726	2.064	0.088
	Altitude	5	42.429	5.570	0.000
	Precipitation	7	18.666	2.450	0.020
	Land use	2	37.492	4.921	0.008
	Error	165	7.618		
	Total	183			
	Source	**df**	**Pillai's statistic**	***F***	**p**
MANOVA	Climate	8308	0.073	1.455	0.173
	Altitude	10 308	0.219	3.787	0.000
	Precipitation	14 308	0.113	1.318	0.195
	Land use	4308	0.041	1.620	0.169

habitats of the Lanner Falcon, such as steppes, pasturelands, scrublands, and abandoned fields, are not well represented in the protected areas, especially in Sicily, which holds the largest subpopulation. Nevertheless, many small and scattered SACs devoted to conserving priority habitats fit the irregular spatial aggregations of the breeding sites better than several large SPAs (Table 2).

The wide and scattered distribution of the breeding sites suggests a good interconnectivity among occupied cells, according to a metapopulation dynamic model (Fig. 2). We suppose that new colonization processes toward isolated suitable cells is related to different sizes of clustered subpopulations surrounding them (Figs. 2B, C) (2). Nevertheless, this pattern depends on spatial diversity, habitat requirements of the species, and its rates of dispersion through various habitats comprising the landscape mosaic (32, 33). In addition, environmental constraints should be overcome by the potential demographic features of the species such as high fecundity or high survivorship (34). Long-term studies on the peripheral subpopulation in northern Apennines (Fig. 2B, C) suggest a continuous process of extinction–colonization, which affects smaller and more isolated clusters (35). Conversely, the large subpopulation in Sicily is probably sustained by good numbers of pairs in contiguous cells (Figs. 2B, C), balancing high nest failures at early reproductive stages (up to 45%; Leonardi unpubl. data). No evidence supports the role of Sicilian subpopulation as a source for continental ones, though it comprises as much as the half of the entire Italian population. In fact, movements of immature, subadult, and adult individuals through the Strait of Messina are rare and scattered (19).

Our total population estimate is conservative because we counted only simultaneously occupied nesting sites and assigned low importance to poorly monitored areas. This approach may justify the differences from previous estimates and the recent Sicilian Vertebrata survey (36), which reported 90 historical sites in Sicily, including some cells with more nesting pairs. No clear trends can be interpolated given the uneven methods adopted to assess the size of the breeding population in the studies carried out in the past.

The population size of a rare and localized bird varies significantly according to several extrinsic factors, including the occupied biogeographical region, the selected habitat, and the altitude. Thus, their demography is not completely dominated by a single factor (4). Although species of lowlands are more sensitive to environmental variability, systematic responses of population size to single factors are generally difficult to detect (4, 37). Considering the Lanner Falcon distribution, the altitude is the main environmental feature related to the aggregation of pairs, both for the whole data set and for F_{adj} and F_{ext} subsets, independently analyzed. Nevertheless, effects of other factors vary at different level of cell aggregation (Table 3). In fact, other environmental factors (i.e., climate, vegetation, and precipitations) influence quality and profitability of potential nesting sites (Table 3).

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