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Territory selection of breeding Golden Eagles *Aquila chrysaetos* in a low-density population

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Abstract - Territory selection by birds of prey is an essential process influencing survival and productivity. For Golden Eagle *Aquila chrysaetos*, research in Europe has focused primarily upon migrating and high-density populations, and rarely on the territory selection in low-density populations. We analysed Golden Eagle breeding sites in Central Apennines (Italy), spanning from 29 sites in 1980 up to 38 sites in 2020, verifying in 4 different years (1980, 1990, 2000 and 2020) their status of occupancy or vacancy, through cross-checking data from available literature and field observations. In the chosen years, each site was characterized by land use and neighbouring distances variables, to individuate the presence of a possible common selection process. The different protection status of each area (unprotected or Natural/National Parks) was tested, assuming that habitat protection could have positive effects on Eagles' territory selection. The so obtained panel data was statistically analysed by means of t-test, $\chi 2$ test and probit models. In one hand, Golden Eagles in the Apennines showed a continuous recolonization of territories, including seven previously vacant and two undiscovered sites. On the other hand, half of the vacant sites remain unoccupied. Our results suggest that Golden Eagles, in a low-density population, tend to minimize the effect of lower quality habitats by choosing a breeding territory which can guarantee low intra-specific interferences: 35% of 2020 breeding pairs have, at least, one nearby vacant territory. Depending on the quality of the available breeding habitat, Individual Adjustment Hypothesis (IAH) supports or replaces Habitat Heterogeneity Hypothesis (HHH).

Keywords: breeding behaviour, Central Apennines, birds of prey, raptors, population density, population dynamic.

INTRODUCTION

Territory selection is a delicate process for animals in order to guarantee the reproductive success of an individual, thus contributing to demographic and population dynamics (Martinez et al. 2006). The process of high-quality habitat occupancy involves several ecologically relevant aspects, that relate to habitat selection on different spatial scales and differ depending on landscape features (Sergio et al. 2003, Penteriani et al. 2002). Territoriality is a high-cost

behaviour which involves the search and maintenance of a selected area with a certain degree of habitat quality (Gordon 1997, Adams 2001), and territory selection is extremely important for territorial birds, such as Golden Eagle *Aquila chrysaetos*. This large bird of prey is well known for its territorial displays towards intruders (Kochert et al. 2002) and requires specific land features to successfully breed (Chambert et al. 2020).

In Italy, the main breeding Golden Eagle populations live in mountainous areas, such as the Alps and the Apennines (Fasce & Fasce 2017), characterized by wide open hunting areas (Spinetti 2018). Golden Eagles occupy the Central Apennines with a low-density population (3.5 pairs /1,000 km^2), with some high-density clusters located mainly in National Parks (Magrini et al. 2013). After a long-standing density and productivity decline (Di Carlo 1980, Zocchi & Panella 1996), today we observe a continue recolonization of most of the known vacant sites (Fasce & Fasce 2017). Nevertheless, several known sites remain vacant, including some within protected areas.

Protected areas play an important role for wildlife conservation (Arcese & Sinclair 1997, Geldmann et al. 2013) and have a positive effect on biodiversity (Barnes et al. 2016, Kiffner et al. 2020). Regarding Golden Eagles, the area protection could guarantee higher prey density (e.g. Devictor et al. 2007, Johannesen 2007), and, by limiting hunting activities to ungulates, avian scavengers are less exposed to lead contamination, which in Southern Europe affects almost half of the population (Bassi et al. 2021), therefore we expect that protected areas may have a positive effect on Golden Eagles' populations.

Both in National Parks and protected areas, the density-dependent productivity of large birds of prey, can be explained by two different hypotheses (Kruger et al. 2012): the Habitat Heterogeneity Hypothesis (HHH), i.e. as more individuals occupy the available space, lower quality habitats are more widely used (Dhondt et al. 1992, Ferrer & Donazar 1996), leading to higher density populations, with a secondary decline in productivity (Fasce et al. 2011); and the Individual Adjustment Hypothesis (IAH), i.e. increasing population to higher density, competition on resources increases interference among individuals, with a negative impact upon breeding performance (Chambert et al. 2020).

The aim of our study is to analyze the selection process of a low-density Golden Eagle population, including the role of habitat quality, the presence of neighbouring pairs, and the area protection status. Analyzing territory selection through literature analysis, direct observations, mortality data recovery and habitat analysis, we hypothesize that Golden Eagles in low-quality habitats follow the IAH hypothesis to avoid intraspecific competition (Withfield et al. 2006), regardless of the protection status of the area.

MATERIALS AND METHODS

Study area

The study area includes the Central Apennines massif, from Sibillini mountains (North) to Matese mountains (South), with elevations comprised by 500 and 2900 meters a.s.l., for an extension of about 6500 km^2 of which 4000 km^2 are included in heterogenous protected areas (i.e. three National Parks and eight Natural Parks).

In the last forty years, the area has been subject to an increase in the extension of protected areas (Cardinale 2008), including some historically known Golden Eagle vacant territories. In addition, wild ungulates such as wild boar *Sus scrofa*, red deer *Cervus elaphus* and Apennine chamois *Rupicapra pyrenaica ornata* have increased in density (Apollonio 2004, Ferretti et al. 2015, Bocci et al. 2016). The entire area hosts temperate, alpine, and Mediterranean climatic features (Cutini et al. 2021).

Data recovery

Data on the presence and productivity of Golden Eagle pairs were collected through direct observations over the last 40 years, integrating with literature review (Di Carlo 1980, Chiavetta 1995, Borlenghi & Corsetti

1996, Borlenghi & Corsetti 2002, Corsetti et al. 2011, Artese et al. 2017), and interviews to experts or local population. We checked the historical and recent presence of the species in occupied or vacant sites, although relevant boundaries are difficult to define precisely. Undulating flight displays from December to April were used to establish territories' core areas (e.g. Reid et al. 2019). Though we used different cross-checked methods to establish Golden Eagles presence in the area, due to the long period of data sampling of our study (1980-2020), analyses were conducted on four different years (1980, 1990, 2000, 2020) to highlight possible trends in the explored variables. Territory sizes are partially unknown, but nesting areas and main hunting grounds of each pair have been individuated by direct observations, made in each known site, with at least three different observations per-site, lasted 5-8 hours, during 1990, 2000 and 2020.

Data on eagles' mortality (SM5) was also recovered by online searches (keywords included searches by region, territory, mountain chain, National Parks, cause of death), and by interviewing protected areas officers or large birds of prey experts. For each event, we took date, age, area, death causes and protection status of the area.

Habitat quality data

We focused on the second-order selection (Johnson 1980), which corresponds to home-range and territory selection. Each occupied or vacant site has been characterized by measuring a set of variables in a standard circle, named T5, of 78.5 km^2 (radius = 5 km), following Pedrini & Sergio (2001), by analyzing CORINE Land Cover (CLC) Level 3 database corresponding to the study period (1990, 2000 and 2018). Our approach is based on habitat features of settlement areas used by floaters of Bonelli's Eagle *Aquila fasciata* and Golden Eagle (Caro et al. 2011). Measured variables such as maximum elevation, minimum distances to neighbouring sites (first neighbour: NND1, second neighbour: NND2, vacant: NNDX, NND1/NNDX) have been included in order to evaluate the role of IAH, as they underpin intraspecific competition: in one hand shorter distances between occupied sites increase the possibility of interactions, on the other hand, the presence of a vacant site increases distances while reducing competition. The study area consists of heterogeneous habitats in terms of environmental quality. Long-term productivity measured for the species equals to 0.5-0.6 (Magrini et al. 2013, Borlenghi et al. 2014, Artese et al. 2017), which is in line with a medium-low quality habitat occupied by a low-density population. On the other hand, low-density populations frequenting high-quality territories show higher productivity (e.g. Chambert et al. 2020).

To approximate habitat quality of Golden Eagles, we measured the extension of open areas, that mainly are used by eagles as hunting grounds (Watson 2010, Magrini et al. 2013). Open-land predators, in fact, prefer to hunt in areas with higher probability to capture preys, which are more available in open areas (e.g. Casagrande et al. 2008). Furthermore, open areas host several prey species, such as hares (*Lepus europaeus* and *Lepus corsicanus*), which represent the main preys in Apennine Golden Eagle populations (Forconi & Dancali 2005). Therefore, as proposed by Borlenghi & Corsetti (2002), the presence of hares can be related to the eagles' permanent occupation of a territory, despite the lack of data on prey density makes it difficult to use it as a variable. Furthermore, to evaluate the impact of HHH's mechanism, we measured the extension of meadows and open areas used as hunting grounds, including those preferred by hares (Pelorosso et al. 2008, Spinelli 2009, Magrini et al. 2013). Although hares still represent Golden Eagle's primary preys (Forconi & Dancali 2005), we have measured the extension of woodlands and agroforestry systems, which can guarantee the presence of further prey species.

Statistical analysis

Following the hypothesized positive impact of territory protection towards Golden Eagle recovery observed in the study area (Magrini et al. 2013,

Artese et al. 2017), we tested if territory occupancy is influenced by area protection, by χ^2 test (Kim 2015). The size of protected areas, along with their type, seems to have no effects on species extinction rates and density (Parks & Harcourt 2002) and then the protected areas were analysed regardless of their degree of protection. Furthermore, the impact of protection over occupancy was tested by means of χ^2 test with Yates correction for small sample size (Adler 1951, Tallarida et al. 1987). The statistical significance of the effect of area protection on occupied sites was also tested by means of t-test.

After this preliminary analysis, we tested the hypotheses of IAH *vs* HHH based on the habitat selection process following the statistical significance of the estimates from a probit model, whereas the occupation status of breeding sites represents the dependent variable. The independent variables in the first two models were the ratio of differences and the natural logarithms of different land use classes, while the second two models were the ratio of distances over the ratio of different land use classes. The hypotheses have been tested by Bayesian Information Criteria (BIC) and Akaike Information Criteria (AIC), following Penny (2012).

Eagle mortality data was used to evaluate the human pressures on population dynamics by calculating the number of individuals that died within and outside protected areas.

All the analysis were conducted with R Core Team 2018 and package pgls, Google Earth v7.3.4.8248 and QGIS v.3.10.7.

RESULTS

We have examined 138 cases: for 1980, 16 occupied by breeding pairs and 13 vacant sites with abandoned nests (Di Carlo 1980); for 1990, 20 occupied and 13 vacant sites; for 2000, 20 occupied and 18 vacant sites, and for 2020, 26 occupied and 12 vacant sites. Over occupancy show a statistical impacting difference the presence of a protected area ($X^2 = 12.72$, $P < 0.05$), as well as distances among neighbors and extensions of open areas and forest patches (SM1). We observed the reduction of distances between sites (mean NND1, from 16.7 km in 1980, to 12.6 km in 2020) and more strongly NND1/NNDX (from 1.81 in 1980, to 1.01 in 2020), while the mean extension of open areas has almost remained the same between 1980 and 2020 (35.4 km^2 *vs* 36.9 km^2).

Furthermore, we found confirmation that territories in protected areas present shorter neighbouring distances in comparison of those measured between non-protected territories, even though the relevant extensions of hunting grounds do not present significant differences (SM2).

Probit models' regressions confirmed over the occupancy the role of protection and of the distances from next neighbours (occupied and vacant, NND1/NNDX). Nevertheless, unexpectedly, the omission from the model of the protection does not significantly modify the results (ΔAIC = 2% and ΔBIC = 0.9%).

The results show that interference, the IAH related variables, and specifically NND1/NNDX is the main selection process followed by Golden Eagles in non-protected sites, while it seems not appearing for protected sites, where a higher habitat quality (HHH variables) is expected to drive the selection process (SM3).

Variables representing the quality of territories, was found to be 20% larger for territories that resulted occupied in 2020 compared to vacant sites, presenting a ratio between prairies and forests visited by hares of 0.57 against 0.47. This indicator is also different for recently occupied territories (0.71) in comparison to historic sites (0.50). This also differentiates vacant sites present in protected areas and those present in unprotected areas ($\chi^2 = 7.2$, $P < 0.05$), mainly due to the differences in extension of open areas for hare (26.7 ± 5.9 km^2 vs 11.4 ± 4.0 km^2, t-student = 5.34, $P < 0.05$).

When looking at mortality data, despite with an empirical analysis, we found no differences in the number of Golden Eagles deaths inside (n = 6) and outside (n = 6) protected areas.

DISCUSSION

During the recolonization process of low-density Golden Eagle populations in Central Apennines, pairs show preferences in the choice of breeding territory. Our findings, based on direct observations and literature review, suggest that distances from neighbouring pairs could play an important role in territory selection processes, and contrarily, the area protection does not seem to have any effects. In fact, despite protected areas have an overall positive effect on wildlife, the effects of individual areas can vary greatly basing on social and environmental context (Kiffner et al. 2020). Protected areas do not facilitate the occupation of new territories by generalist and territorial species, such as Golden Eagles, demonstrating the ineffectiveness of some Natural/National Parks (e.g. Johannesen 2007, Garriga et al. 2012) and that habitat quality is more important than protection status (Kays et al. 2017). Our theory is confirmed by the presence of several vacant sites as well as deceased Golden Eagles found in protected areas.

Despite our study does not consider the strong environmental and climatic changes that occurred in recent decades, which may have influenced the recolonization or abandonment of some Golden Eagles' territories, we analysed the habitat quality role in the recolonization process. The long-term productivity of Golden Eagles in Central Apennines, ranging around 0.5-0.6 (Artese et al. 2017, Borlenghi et al. 2014), is in line with a heterogeneous habitat with low-medium quality. While high quality habitats with low Golden Eagle density are expected to have high productivity (Chambert et al. 2020), low-medium productivity in low density populations is an indirect indicator of low-medium quality habitats. Furthermore, we can assume that the territory selection process in Central Apennines is not based on habitat quality. During the second order of territory selection (Johnson 1980), Golden Eagles face this habitat variability reducing the possible interferences with neighbouring territorial pairs. During the study period, Golden Eagle pairs seem to search for habitats closer to vacant sites than to occupied ones, suggesting that interposed vacant sites can play a significant role in the selection process of the breeding territory (SM4). Direct observations, show that several vacant sites are embedded into the closest occupied territory (Whitfield et al. 2006), presumably due to lower quality characteristics, as pairs in these areas show medium-low productivity (Borlenghi et al. 2014, Artese et al. 2017).

For the HHH hypothesis, we suggest that further studies should also include presence of carcasses, other available preys, habitat heterogeneity and level of human disturbance (e.g. road density, traffic, climbing and outdoor activities). By adding new variables (e.g. new mortality data, habitat analysis, prey density) to the analysis, these could improve the results obtained in this study and give a better insight on this interesting conservation topic.

Even if with just 12 observations from 2013 to 2023, the mortality data shows no difference between protected and unprotected areas (SM5). The presented mortality survey, due to the difficulty in finding data, is certainly an understatement of this phenomenon. Anthropogenic mortality, in fact, is probably the greatest threat for Golden Eagles in Central Apennines (e.g. Bassi et al. 2021), independently from the area's protection status. In the Central Apennines, an area with a positive breeding population dynamic (Magrini et al. 2013, Artese et al. 2017, Borlenghi 2017), a dozen of Golden Eagles were found dead in the last 20 years due to direct or indirect anthropogenic causes (SM5). These deaths can be considered additive (Tack & Noon 2017) and could have produced a negative effect on the population dynamic itself (Borlenghi & Corsetti 2002). Nevertheless, the measured rate of mixed breeding pairs (subadult with adult) remained similar throughout the last 20 years: 7.5% (Borlenghi & Corsetti 2002) compared to 9% (Borlenghi 2017).

In conclusion, the present work, although limited in addressing all the topics tackled due to the lack of data over a so long period about environment and prey dynamics, still represents a useful first analyses

about the factors that determine the selection process of the breeding territories by Golden Eagle in a so wide area such as the Central Apennines. For these reasons we want to underline the importance of long-term monitoring studies on large eagles' populations, that can reflect the conservation status of several species, and the faunal and natural heritage of the Apennines.

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