Griffon Vultures restrict movements around roosts and supplementary feeding stations, even when carrion is available on the field: a call for wind energy zonation to avoid ecological traps on Mediterranean islands

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Abstract Wind energy is developing on Mediterranean islands, where endangered populations of Griffon Vulture (*Gyps fulvus*) occur. As griffons are subjected to collisions with wind turbines while foraging, it is necessary to understand which factors affect their movements, to minimize the potential impact of wind farms.

We assessed habitat use by 37 griffons (n. GPS locations = 130,218) and its overlap with wind farms in Sardinia (Italy), an island where griffon vulture population is increasing thanks to concrete conservation actions and wind energy is significantly expanding.

Griffons in Sardinia cover smaller areas (95% isopleth = 956.3 ± 677.7 km^2, 50% isopleth = 73.8 ± 48.2 km^2) than in mainland Europe, restricting most of their movements within 5-10 km from colonies and roosts.

Concentrated movements aligned with the fact that around roosts and colonies, approx. 20 tons of carrion (21% of estimated available carrion) are provided each year in supplementary feeding stations, while griffons still have enough cliffs to breed. Therefore, our results are highly suggestive that resource availability can constrain griffon movements on Mediterranean islands.

Overall, 6 wind farms out of 29 were built in areas that were covered by moving griffons. Two of them were positioned right outside the areas the most used as foraging grounds, around roosts and supplementary feeding stations.

As griffon movements concentrate around nesting/roosting sites and feeding stations, wind farms should not be built in a buffer zone around these highly utilized areas, and mitigation measures, including the removal of livestock carrion, should be adopted for those that are built at greater distances. There is also an urgent need for updated data about wind energy development. The creation of supplementary feeding stations could be used to shape the enlargement of the foraging grounds of an increasing Griffon Vulture population on Mediterranean islands and to mitigate wind farms impacts.

Warning

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Introduction

The Griffon Vulture (*Gyps fulvus*, hereinafter "griffon") plays a critical role in many ecosystems of the Mediterranean, delivering ecosystem services, such as the reduction of GHG emissions [1], and the mitigation of important zoonotic diseases [2]. However, many griffon populations in the Central and Eastern Mediterranean, although recovering, are fragmented into colonies that often occur in islands [3] and are subjected to limited immigration from mainland. Therefore, any increase in mortality can rapidly impact on their conservation status.

Assessing the risks posed by some threats, such as collisions with man-made structures [4], is particularly urgent for these insular populations. Some of these structures, particularly wind turbines, whose development is occurring at an unprecedented pace [5], can increase griffon mortality, especially when built close to griffon aggregations [6], or in foraging grounds, as griffons cannot detect them while foraging [7]. Therefore, a careful zonation of wind farms is necessary to avoid adverse consequence for insular griffon populations.

However, to develop adequate zonation policies, important insights about the movement ecology of griffons living on Mediterranean islands are still missing. First, although the home range and core area of griffons living on mainland were estimated by various studies (see Table S1 for an overview), only Xirouchakis *et al.* [8] did so for insular griffons in Crete. However, Xirouchakis *et al.* [8] used low-resolution VHF telemetry and the use of the range distribution, which is unsuitable to reveal fine-scale patterns of space use, such as flyways, which are particularly precious to identify collision hotspots, but which require the estimation of the occurrence distribution [9].

Moreover, considered that griffons are susceptible to collisions when foraging, there is a need to understand the extent to which supplementary feeding [10] affects space use, also with respect to its distance from colonies [11]. On Mediterranean islands griffon colonies often occur on coastal cliffs, and foraging could be constrained by the effect of wind over leaving or arriving at the nest [12]. So, although, the effect of supplementary feeding has already been considered for mainland, with sometimes contrasting conclusions (see Table S2)[13][14][15][16][17][18][19][20][21], there is a need to quantify its role over space use by griffons for a Mediterranean island, preferably through high-resolution GPS-telemetry which could reveal small-scale patterns around coastal areas.

In this study we aim at *i*) quantifying space use and *ii*) its overlap with existing wind farms and *iii*) assessing how the presence of supplementary feeding stations, altogether with landscape and topographic attributes, affect resource use by restocked griffons in Sardinia, a Mediterranean island with the only autochthonous population of griffons in Italy [22][23]. Finally, in the light of our findings we will provide realistic recommendations on the deployment of wind turbines in the flight zone of a griffon vulture colony.

Materials and methods

Released Griffon Vultures, study area and resource availability

Between 2016 and 2021, 64 griffons were released in North-West Sardinia, within the LIFE Under Griffon Wings project (LIFE14 NAT/IT/000484), to increase the size of the local population, which had declined across 20th century. The initiative was authorized by the National Institute for Environmental Protection and Research (ISPRA) and the Sardinian Regional Department for the Environment.

Released griffons came from wildlife rehabilitation centers in Spain (n = 57), captive breeding programs (n = 7), or from Sardinia, after having been found and rehabilitated at a local wildlife center (n = 10). Release strategies included hard release, with no acclimatization (n = 12), as well as soft release with a 3 months (n = 48) or 14 months (n = 14) acclimatization period. Before being released, griffons were fitted with PIT tags and with an engraved metal ring around one tarsus and an orange plastic ring with a black alphanumeric code on the other tarsus, containing the official identifier from ISPRA. Rings were useful for long-distance identification. Moreover, remiges and rectrices were bleached, to provide individual recognition until their moult.

Environmental conditions at all release sites were comparable, with vegetation being constituted mostly by holm oak (*Quecus ilex*), cork oak (*Quercus suber*) and *Pinus* sp., as well and pastures used for extensive livestock rearing. In the study area cattle and sheep are kept all year round in extensive pastures, with no seasonal movements. Moreover, wild ungulates populations are relatively limited, with wild boar (*Sus scrofa*) present all over the areas with a density lower than 15 animals/100 hectares and a small population of about 300 fallow deers localized around the aviary in Porto Conte (*Dama dama*)[24]. In the study area 37 farm feeding stations were progressively implemented since 2016, providing approximately 20 tons of livestock carrion every year, in a radius of less than 50 km from colonies [25].

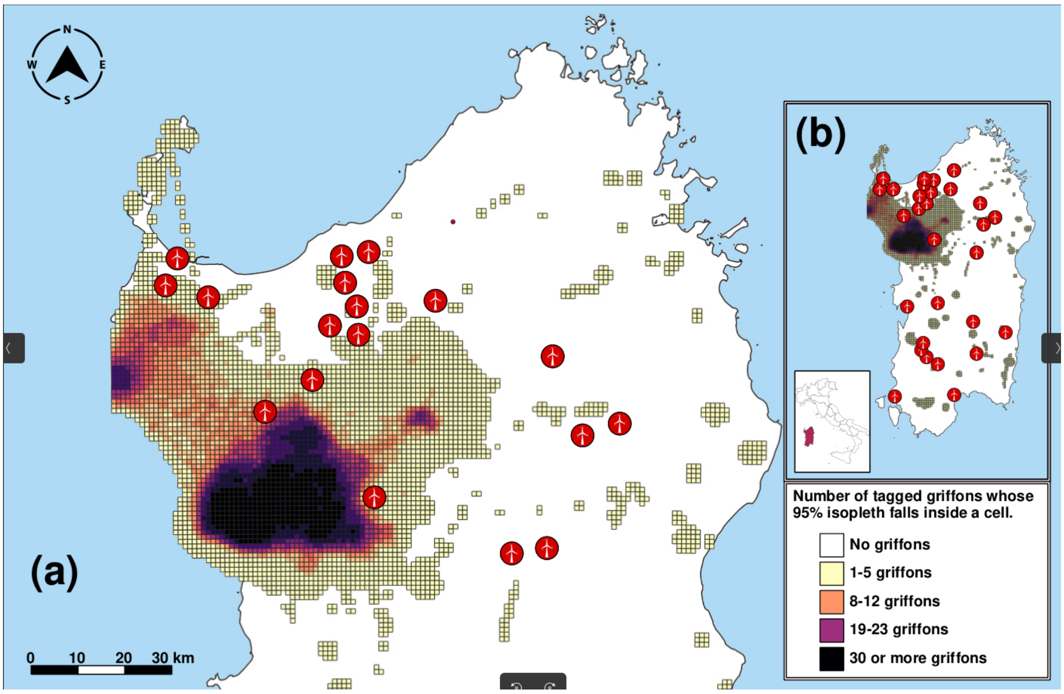

Figure 1: Spatial distribution of areas covered by griffons, and wind farms, in Sardinia. Each cell of the grid (1km x 1km) represents the number of areas where individual vultures moved on a regular basis, delimited by 95% isopleths occurrence distributions. Darker areas were used by a higher number of griffons. Panel (a) shows a detail of North Sardinia, whereas panel (b) shows an overview of Sardinia. Individual occurrence distributions are available in the Supplementary Information (Appendix S1)

Livestock herding is widespread, with around 563,421 sheep (weighting approx. 55 kg, 8% mortality rate) and 17,487 cattle (weighting approx. 500 kg, 3% mortality rate) in the area where griffons move (Fig. 1). Empirical evidence indicates that carrion is often left on pastures, due to difficulties associated with their recovery. Given these numbers, and by assuming that 10% of livestock carcasses are left in the field and detected by griffons, every year around 94 tons of carrion would be available to them. By assuming that: *i*) that griffons can exploit soft tissues only (corresponding to approx. 27% of the whole carrion), *ii*) that 316-338 adult griffons live in the study area and that 55 chicks were born in 2022 [26], *iii*) that each adult griffon needs around 500g of meat per day and each breeding pair needs approx. 75 kg of food to rear a chick [27], then the whole population of griffons would consume between 61 and 66 tons of carrion per year. Therefore, the total biomass of 94 tons, provided by feeding stations and by carrion left on the field, would be sufficient to sustain the entire population.

Data collection and pre-processing

43 griffons were equipped with solar-powered GPS/GSM and VHF transmitters. Devices were mounted with a leg-loop harness made from teflon, assembled in three strings (a cord of rounded silicone 2mm + tubular teflon ribbon 025" and 0.44"), according to the recommendation of the Vulture Conservation Foundation (https://4vultures.org/). We used GPS/GSM devices from Ecotone (Ecotone Telemetry, Sopot, Poland; cDuck model, n = 2; Crex n = 25; Saker, n = 7; Skua, n = 5; all weighting 33 grams) and Ornitela (Ornitela, Vilnius, Lithuania; Ornitela 3G_50g, n = 4; weight 50 grams). The weight of GPS and harness did not exceed 3% of total body mass [28].

GPS/GMS devices acquired GPS locations at different rates, from dawn to dusk. However, in autumn and winter the frequency of data acquisition was lower, due to scarce solar charging caused by lower levels of solar radiation and diminished daylength (Fig. S1). When a griffon was still for more than 24 hours, field technicians checked if it was dead, and in case the carcass was subjected to necropsy.

Between September 2017 and June 2022, we collected a total of 130,218 observations, from 37 griffons (see the following section and Appendix S2 and Fig. S2) that had acquired on average 3038.5 ± 2525.1 GPS positions each (mean ± standard deviation), over a tracking time of 582.7 ± 462.1 days. As some individuals acquired GPS positions every 2 hours, we used this figure for all individuals, and then interpolated missing data with the Euclidean distance method. This approach interpolated locations also at night, when griffons do not fly and usually spend the time at roosting sites. Therefore, before using interpolated data, we graphically inspect them to check their plausibility, and found that nocturnal GPS locations were plausible as they fell around roosts or nesting sites.

To quantify the overlap between the range distribution of griffons and existing wind farms in Sardinia, we requested data about wind energy facilities to the Industrial secretariat of Regione Sardegna. The position of each wind turbine was provided in the shapefile format.

Statistical analysis

Estimation of the occurrence distribution

To identify the area and environmental resources used by griffons we estimated their occurrence distribution. This represents the uncertainty surrounding the observed trajectory of moving individuals over a certain time [9]. We decided to estimate the occurrence distribution because griffons are a long-lived species, where juveniles and adults have different movement patterns [29], changing across their lifetime [30] and can travel long distances [31]. Therefore, as data were collected only for 2-3 years, they could have been characterized by a low effective sample size and therefore estimators for the range distributions could have been unreliable [32].

As our GPS locations showed a significant temporal autocorrelation (Appendix S3), we fitted dynamic Brownian Bridge Movement Models [33]. The dynamic Brownian Bridge Movement Model was chosen as this method can effectively identify flyways [34], and it has already been successfully applied to gregarious vultures of the genus *Gyps* [35]

Resource utilization function

The occurrence distribution did not allow us to test for habitat selection, as use-availability approaches require the use of the range distribution [9][38]. However, it allowed us to test which environmental features were associated to the use of landscape patches, through resource utilization functions [39].

We tried to predict the intensity of utilization of landscape patches, at a 250 m resolution, from *i*) their roughness and *ii*) aspect, *iii*) the percentage of the patch that was covered by trees, the distance of each patch *iv*) from the nearest supplementary feeding station and *v*) from the nearest roosting or nesting site, *vi*) the distance of each patch from the coastline, *vii*) the number of farms occurring on each patch and the *viii*) latitude and *ix*) longitude of the centroid of each habitat patch.

Roughness and aspect were selected because they are associated to the generation of orographic updrafts, important for soared flight [40]. In the study area, orographic updrafts are usually caused by Western winds, coming from the Mediterranean Sea and hitting the coastline, where griffons have their colonies (Fig. 1). Roughness and aspect were generated from a Digital Elevation Model, freely available from Amazon AWS Terrain Tiles (https://registry.opendata.aws/terrain-tiles/).

The percentage covered by trees was also included to predict space use, as *Gyps* vultures detect carrion through eyesight [29] and tree cover could undermine their foraging success. Therefore, we expected them to select less those habitat patches where foraging was not possible. This value was measured through the MODIS/Terra Vegetation Continuous Fields (https://lpdaac.usgs.gov/products/mod44bv006/)

As some studies emphasized that griffons concentrate foraging movements around colonies and roost, especially when supplementary food is nearby [14][18][21], we also included distance from colonies and the nearest farm feeding station as covariates. The distance from farm feeding stations was also deemed to capture traditional foraging patterns of gregarious *Gyps* species, where individuals use interdependent foraging [41] and feeding stations are likely to be regularly selected. Moreover, we also used the number of farms occurring on a habitat patches, as a proxy for carcass availability. The location of colonies was obtained from long-term population monitoring programs [25], while the location of supplementary farm feeding stations has been recorded during the LIFE Under Griffon Wings project. The location of livestock farms was provided by the Regional Veterinary Epidemiological Observatory (Regional Department of Health, Veterinary services, Region of Sardinia).

The distance from the coastline was also included, as griffons are soared fliers which are well-known to avoid flying over the sea, unless necessary [42]. The coastline was obtained from official administrative boundaries downloaded from the Italian National Institute for Statistics (https://www.istat.it/it/archivio/222527), after having checked its plausibility against a satellite image of the study area.

We predicted space utilization through regression random forests [43]. The random forest algorithm averages multiple regression trees and was used as we had no prior expectations about the functional forms of our covariates, and about their possible interactions. Moreover, random forests allow to control for spatial trends in the data by including the latitude and longitude of observations as covariates, as we did with the centroids of each cell of the occurrence distribution. We did not use multilevel modelling [44], as our considerable amount of data allowed for individual models, which for large samples attain a higher degree of accuracy than partial pooling [45]. Instead, we fitted one random forest to each individual, and then calculated the total decrease in node impurities, through the residual sum of squares, and the R2, to assess the overall predictive accuracy of our models. Finally, we used partial dependence plots to highlight the relationship between each covariate and space utilization by griffons, as well as interaction s between covariates. Statistical analyses were carried out with the statistical software R [46] and a completely reproducible software code, and a dataset, are available at the following link (`https://osf.io/urbpv/`).

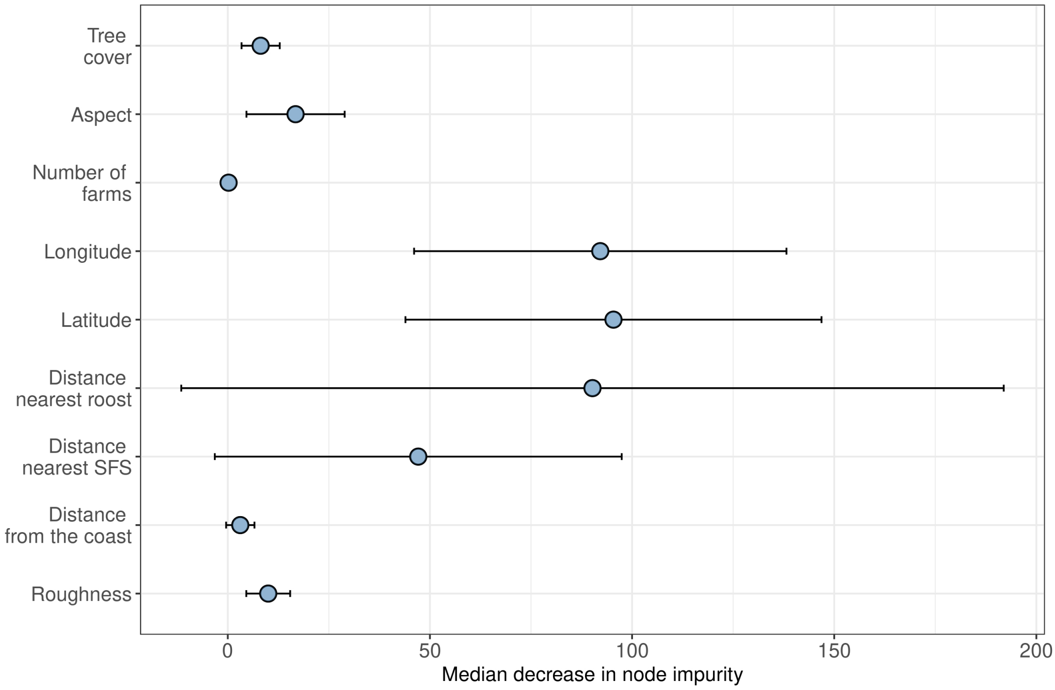

Figure 2: Importance of the various predictors, expressed as the decrease in node impurities through the residual sum of squares. This value tells how well the tree can split variables (the higher the better). Values were averaged for all 37 random forests: points represent median increase in node purity, and error bars standard deviation.

Results

During the time of the study, griffons moved across an area of 956.3 ± 677.7 km^2 (95% isopleth) but restricted most of their activities over an area of 73.8 ± 48.2 km^2 (50% isopleth). There were no clear differences in the size of covered areas between male and female vultures (Fig. S3). The size of both the 95% and the 50% isopleth increased with the length of data acquisition, indicating that griffons in our sample have not stabilized their movements yet (Fig. S4).

The occurrence distribution of griffons highlighted two areas with a very high spatial utilization (Fig. 1). These corresponded to colonies and roosting sites around Bosa, the stronghold of the species in Sardinia (approx. 69 territorial pairs, distributed over approx. 9 cliffs) and Punta Cristallo (approx. 5 territorial pairs at one single cliff)[26].

As for wind farms, the most recent available data referred to those that had been built, or authorized, until 2019 (Fig. S5). Overall, we found 29 sites, with 37 different wind farms and 649 turbines. Most wind farms occurred in Northwest and Southwest Sardinia, and some of them (n = 6) were located within the occurrence distribution of griffons, with two of them just outside the most used area, including one on the flyway between Punta Cristallo and Bosa (Fig. 1).

Covariates predicted a significant amount of the occurrence distribution (R2 = 0.91 ± 0.12, Fig. S6). The median increase in node purity, indicates that the distance from the nearest roost/colony, and the distance from the nearest supplementary feeding station were, by far, the most important predictors (Fig. 2). For most griffons, the areas used the most occurred within 5 km from roosting sites or colonies and within 10 km from the nearest farm feeding station (Fig.3).

However, some individuals (n = 6) also had a non-monotonic relationship between space utilization and distance from roosts and colonies, increasing again their space utilization at distances greater than 5 km. And some other individuals (n =4) had a non-monotonic relationship with distance from supplementary feeding stations increasing again their space utilization at distances greater than 20 km.

There was no clear interaction between these two variables (Appendix S4), and the effect of supplementary feeding stations over space utilization did not vary according to their distance from colonies.

Among the other covariates, the only one which seemed to be slightly more important was the aspect of each habitat patch. Although considerable heterogeneity occurred between different individuals, space utilization was more common for patches whose terrain had between 180 and 300 degrees from North, being oriented westward. The distance from the coastline, tree cover in each habitat patch and terrain slope did not seem to be important for predicting space utilization and did not have any clear pattern (Fig. S7).

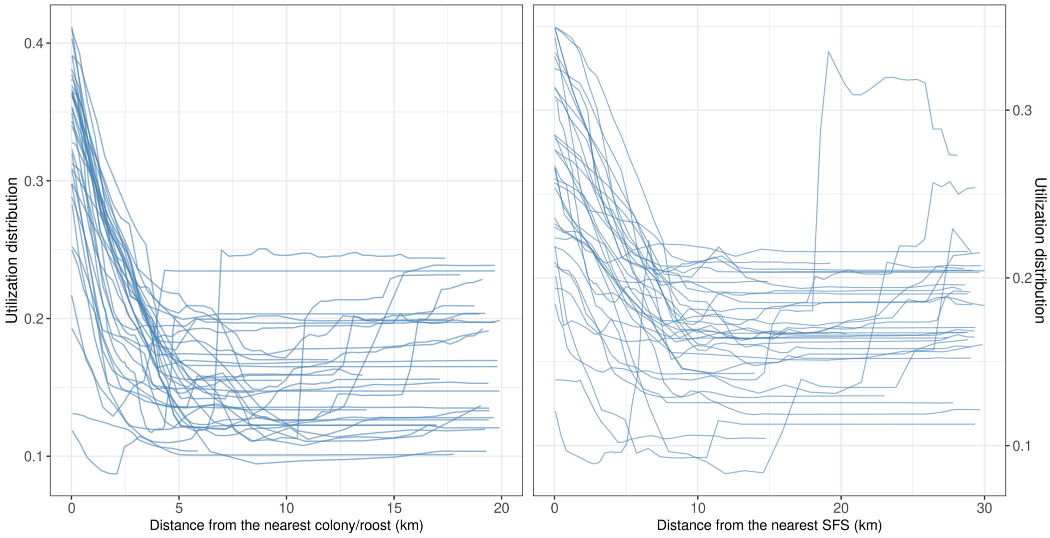

Figure 3: Partial dependence plot, showing how the intensity of the occurrence distribution varied in function of the distance from roosts/colonies (panel on the left) and the distance from the nearest farm feeding stations (SFS, panel on the right).

Discussion and conclusions

To the best of our knowledge this study was the first one assessing through high-resolution GPS telemetry space utilization by griffons in a Mediterranean island well disconnected from mainland and characterized by both supplementary feeding and the availability of undisposed carrion. Moreover, this information was used to provide, for the first time, concrete indications on wind energy zonation in a Mediterranean island inhabited by vultures.

Overall, we found that griffons living in Sardinia cover smaller areas compared to those living in mainland Europe, like in the Iberian Peninsula, but also to those living in islands like Crete (Table S1). Even if these differences could be partly due to methodological differences, as areas from kernel density estimates are generally larger than those from Brownian Bridge models, differences were sometimes quite impressive. In some cases, areas identified by our 95% isopleth were one order of magnitude smaller. Indeed, the area covered by our 95% isopleth (956.3 ± 677.7 km^2) was also considerably smaller than that covered by griffons living in the Balkans, (1,431.22 ± 1,472.12 km^2) according to Peshev *et al*.

The fact that griffons in Sardinia move across relatively small areas could be motivated by the proximity of trophic resources to roosts and colonies, and perhaps also to long-term mechanisms that reduced vagrancy in the Sardinian population.

As for the spatial distribution of roosting sites and trophic resources, these two factors were by far the most predictive of space utilization by griffons, with most vulture movements occurring within 5 - 10 km from colonies and roosts. In this area, farm feeding stations provide griffons with nearly 20 tons of carrion per year, approx. 21% of total biomass available. Griffons are gregarious [11] and their colonies grow through time, becoming subjected to strong density dependent competition for optimal breeding sites [48] before experiencing increased emigration. Considering that cliffs in Punta

Cristallo and around Bosa are still capable of hosting new breeding pairs and given the considerable availability of trophic resources around existing roosts and colonies, where griffons can rely on highly efficient group foraging, griffons may have limited reasons to expand their distribution.

Another explanation might also lie in the fact that in Sardinia griffons could have progressively lost their migratory habits, that implied sea crossings, due to selective pressure [49]. Although most of the GPS-tagged griffons from this study were wild-caught individuals recovered in Spain (n = 64), griffons are gregarious and have complex interdependent behaviour [11]. Therefore, by not having contacts with movement-prone individuals, they may have adapted their movements to those of the sedentary local population. From a conservation viewpoint our findings have three clear implications.

First, since griffon movements concentrate around nesting/roosting sites and feeding stations, wind farms should not be built in these highly utilized areas. This recommendation aligns with Carrete *et al*. [6], who showed that distance from roosts and aggregations was a major predictor of collisions between griffons and wind turbines, and that setback distances are a crucial tool to reduce mortality. According to our findings, we believe that a setback distance for wind farm development, of at least 15 km from the most used areas (Fig. 4) should be enforced as soon as possible. Moreover, provided that a careful zonation of wind farms remains the most desirable management option, mitigation measures like selective stopping protocols, where wind turbines are halted whenever griffons fly around them [50], should be enforced on a compulsory basis. This measure should be implemented particularly along flyways connecting the two most utilized areas at the Southernmost and Northernmost portion of the study area (Fig. 1). Considered the presence of extensive animal husbandry, and the fact that wind farms areas can be used as pastures, monitoring carrion occurring on the field would also be important: vultures are blind towards the rotating blades of wind turbines when they forage [7], and the presence of carrion around them could result into the death of multiple foraging individuals. These measures are needed, as wind farms have already been built around the area the most used by griffon vultures, well within the occurrence distribution of the species.

The second point is the need to understand how to regulate wind energy development, considered that griffons are expected to progressively disperse across the island. To enlarge the occupancy area a new release site is now being created in Southeast Sardinia, within the LIFE Safe for Vulture project (LIFE19 NAT/IT/000732). Moreover, supplementary feeding stations will be constructed to create a corridor between Southeast and Northwest Sardinia, across which griffons could move. Even if we did not monitor feeding events [16], the intensity to which griffons use habitat patches also depends upon their distance from supplementary feeding stations. It is crucial that these are not placed in areas where wind farms occur, or where their development has already been authorized. Considered that no updated map of wind turbines is publicly available for Sardinia, it will be crucial to rapidly map wind energy facilities across the island, and to use models based on thermal uplifts [51] or landscape connectivity [52] to predict the main routes that will be used by griffons and to optimize mitigation measures.

Finally, by identifying under which weather conditions, and at which time of the year, griffons perform exploratory sallies [53] and then select specific landscape patches [54], it would also be possible to tailor mitigation measures across specific temporal windows, optimizing their efficacy. Absent any zonation, mitigation and mapping of wind energy development, by considering that up to approx. 6,700 turbines could be built by 2030 (https://www.anev.org/wp-content/uploads/2022/07/Anev_brochure_2022.pdf) and that the last available data refer to 2019, the griffon population in Sardinia could experience frequent mortality events, which could in turn lead to severe density-dependent dynamics undermining its viability [55].

Acknowledgements

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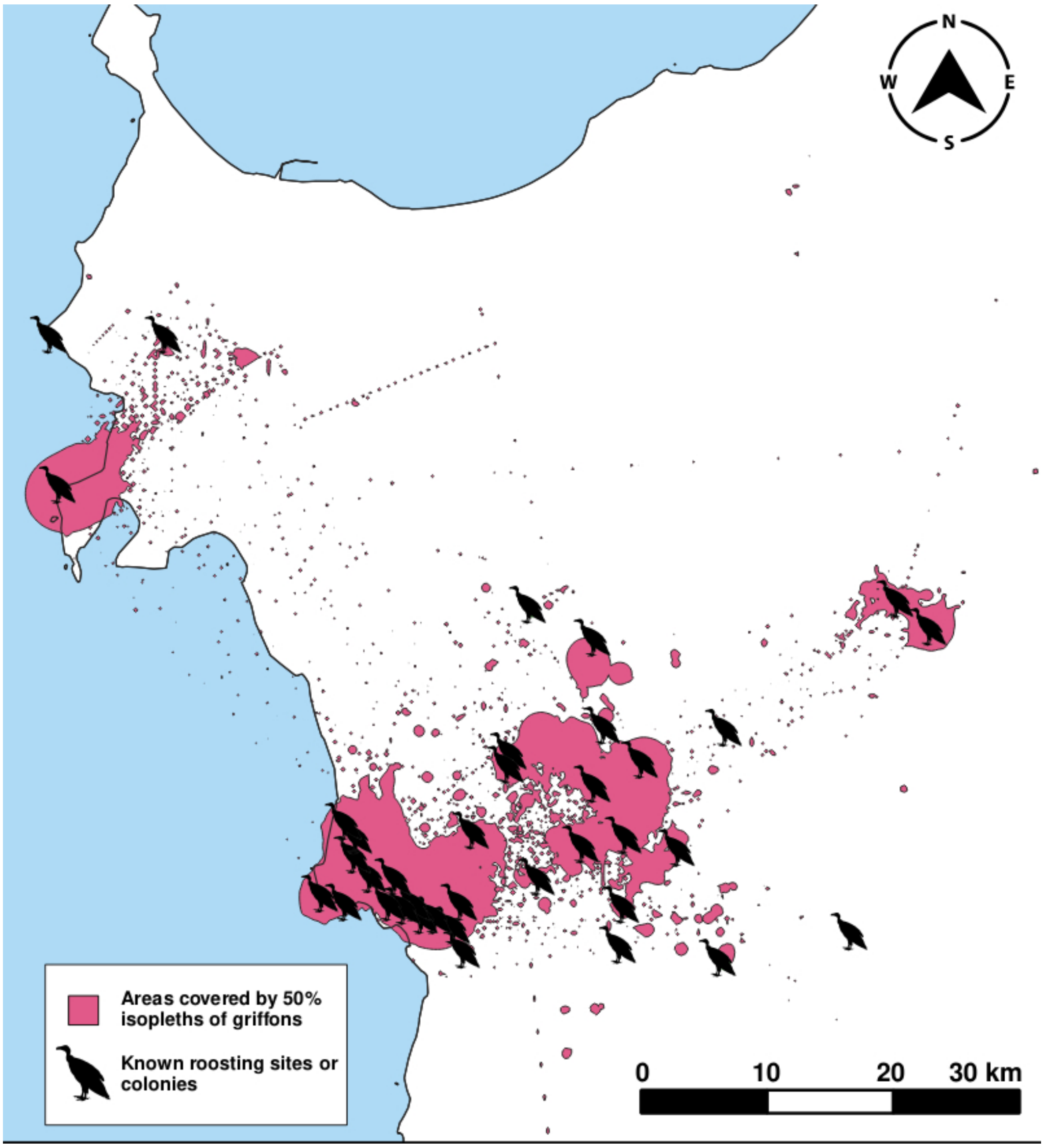

Figure 4: Map representing those parts of the study area used the most by griffons (in pink, polygons obtained by merging 50% isopleths of the various individuals), as well as known roosts and colonies. Small patches of highly utilized areas represents flyways used by griffons to move between roosts/colonies.

Under Griffon Wings project (LIFE14/NAT/IT/000484) and the Life Safe for Vultures project (LIFE19 NAT/IT/000732).

Conflict of Interest

The authors declared no conflict of interest.

Authors' contribution

Fiammetta Berlinguer, Jacopo Cerri and Marco Apollonio conceived the ideas and designed methodology; Fiammetta Berlinguer, Davide De Rosa, Ilaria Fozzi and Mauro Aresu collected the data; Jacopo Cerri analysed the data; Jacopo Cerri and Fiammetta Berlinguer led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Data availability statement

Data available via the Open Science Framework Repository, `https://osf.io/urbpv/`.

Supplementary figures

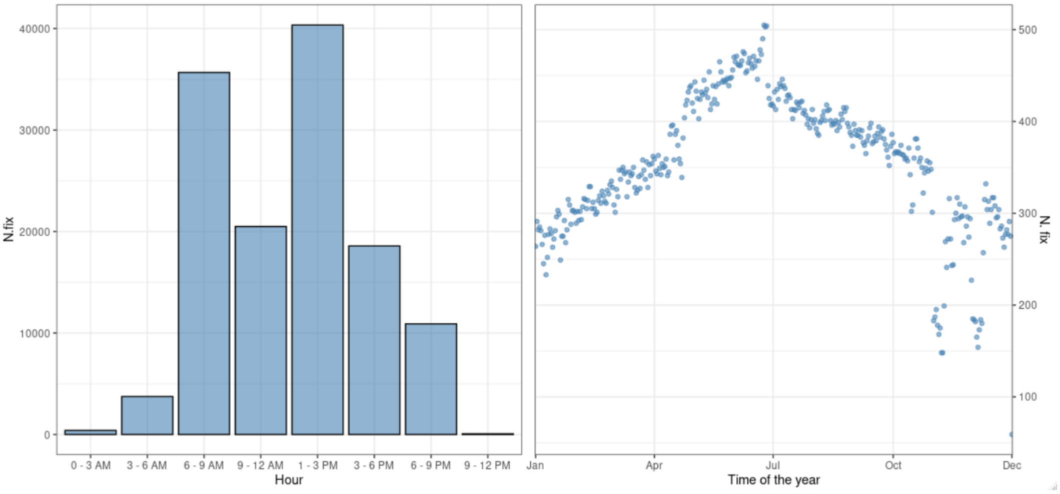

Figure S1: Overview of temporal distribution of GPS positions, across the various times of the day (panel on the left), and during the course of the year (panel on the right).

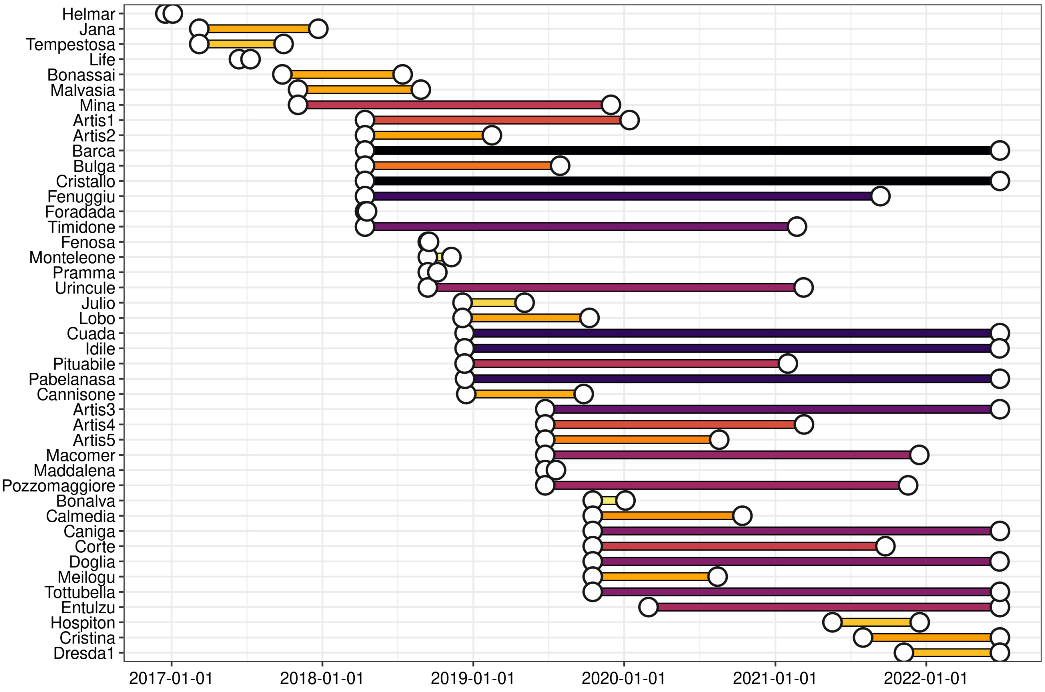

Figure S2: Duration, in days, of GPS position acquisition of the various griffons equipped with GPS/GSM tags.

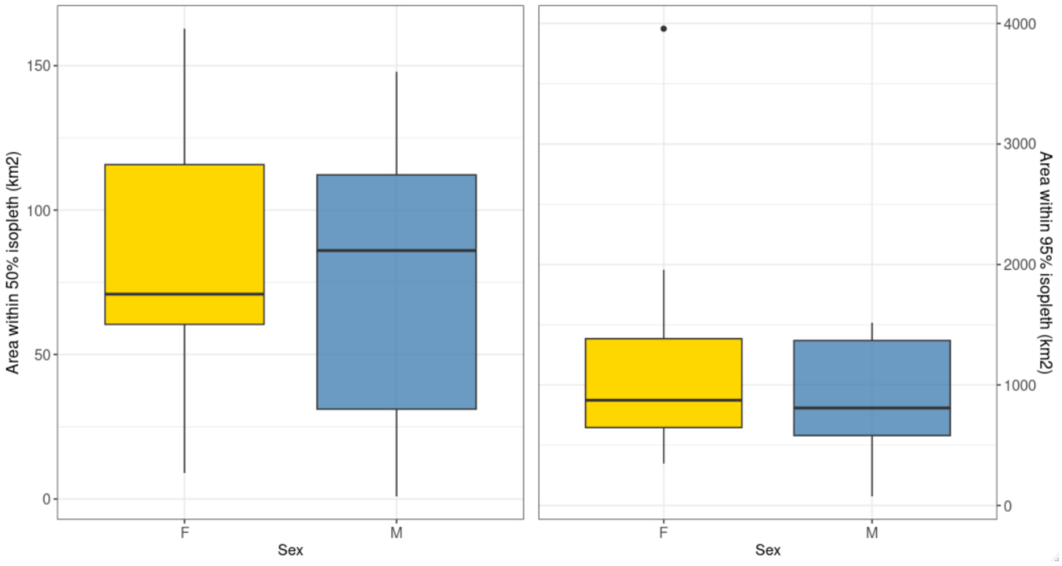

Figure S3: Differences in the size of the area delimited by the 95% isopleth and the 50% isopleth of the occurrence distribution, between male (Sex = M) and female (Sex = F) griffons.

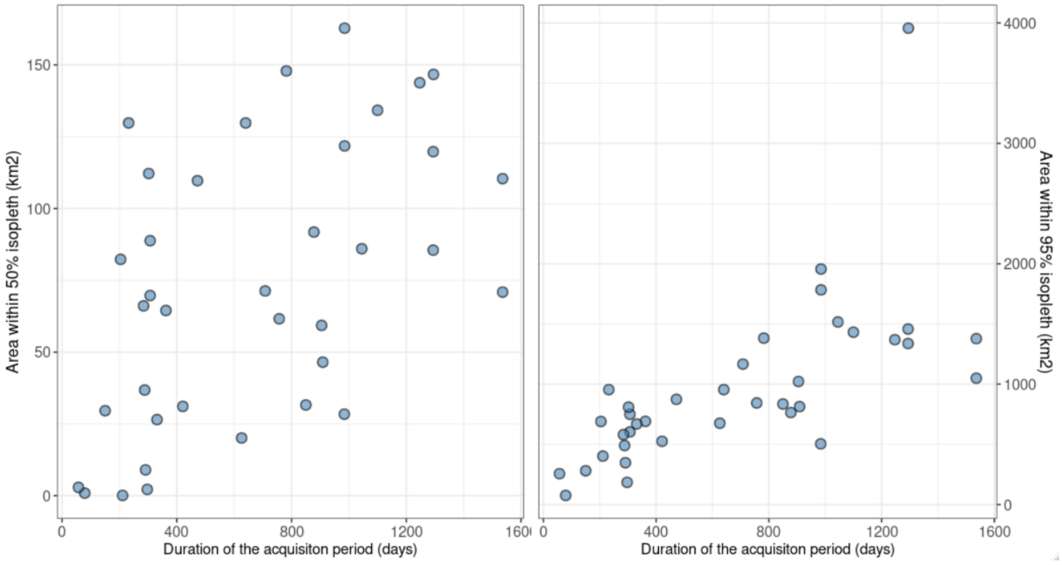

Figure S4: Variation in the size of the area delimited by the 95% isopleth and the 50% isopleth of the occurrence distribution, according to the duration of the acquisition period (in days).

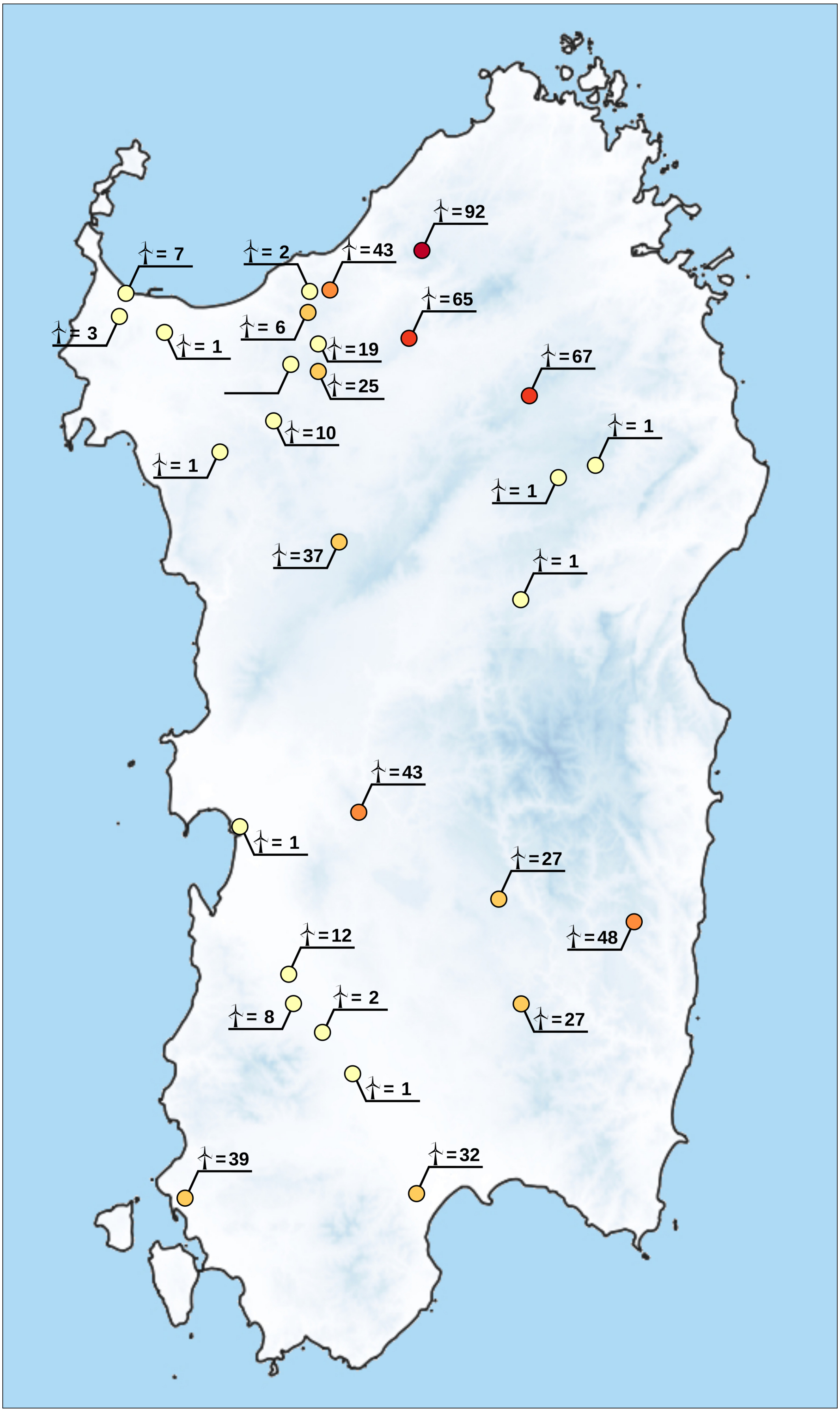

Figure S5: Distribution of wind farms that were built, or authorized, in Sardinia, until 2019. For each site, the number of turbines is reported.

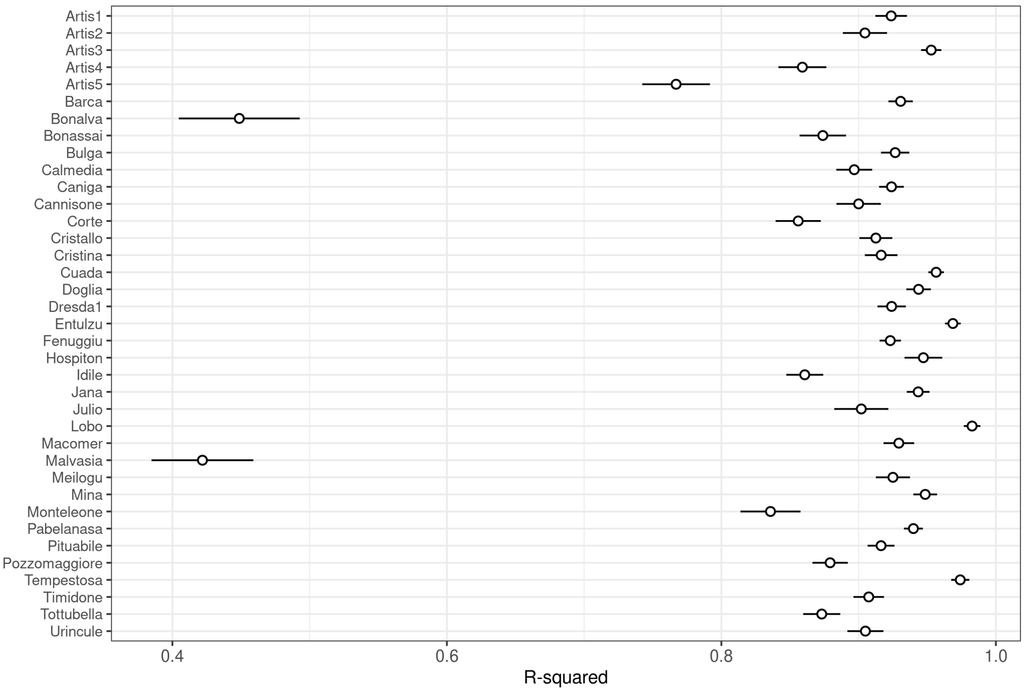

Figure S6: Overview of the R2 of regression trees in the random forest, for the various griffons. The median value of R2 is represented as a dot, whereas horizontal bars represent the standard deviation of the distribution.

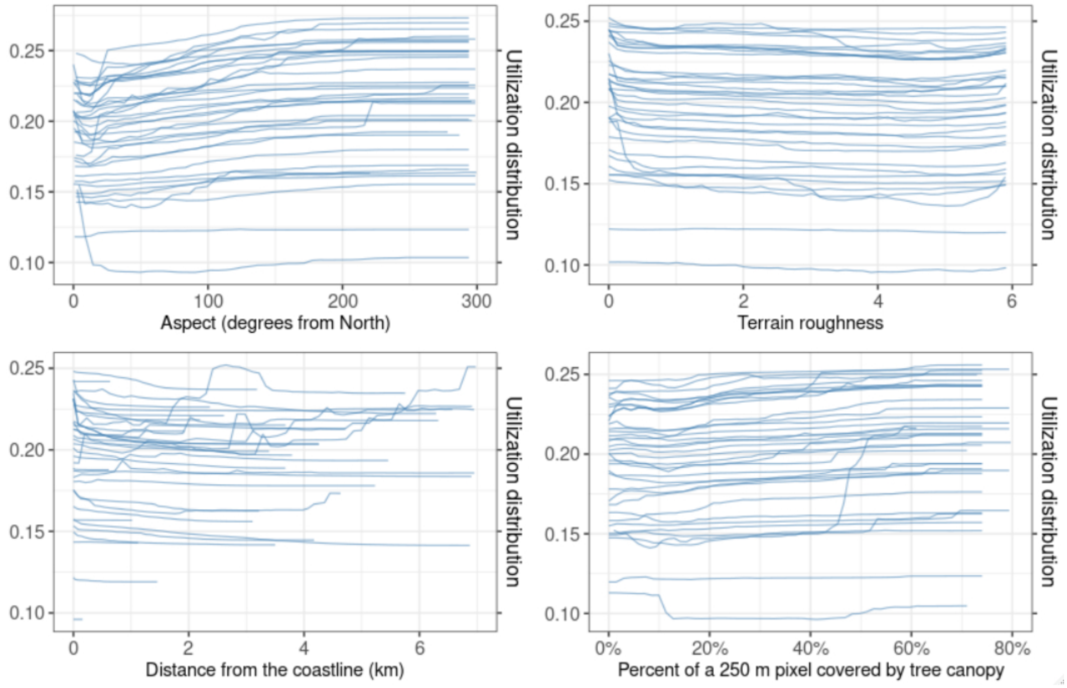

Figure S7: Partial dependence plot, showing how the intensity of the occurrence distribution varies in function of the terrain aspect, the terrain roughness, the distance from the coastline and the percent of each habitat patch that was covered by forest canopy.

References

1. Plaza, P. I., & Lambertucci, S. A. (2022). Mitigating GHG emissions: A global ecosystem service provided by obligate scavenging birds. Ecosystem Services, 56, 101455. https://doi.org/10.1016/j.ecoser.2022.101455
2. Berlinguer, F., *et al.* (2021). Help from the sky: Can vultures contribute to Cystic Echinococcosis control in endemic areas?. PLoS Neglected Tropical Diseases, 15(7), e0009615. https://doi.org/10.1371/journal.pntd.0009615
3. Terraube, J., *et al.* (2022). Population estimates for the five European vulture species across the Mediterranean: 2022 update. The Vulture Conservation Foundation, Koninklijke Burger's zoo b.v. Antoon van Hooffplein 1, 6816 SH Arnhem. Netherlands. https://4vultures.org/blog/new-report-on-vulture-population-estimates-in-europe-is-now-available/
4. Arrondo, E., *et al.* (2020). Landscape anthropization shapes the survival of a top avian scavenger. Biodiversity and Conservation, 29, 1411-1425. https://doi.org/10.1007/s10531-020-01942-6
5. Gauld, J. G., *et al.* (2022). Hotspots in the grid: Avian sensitivity and vulnerability to collision risk from energy infrastructure interactions in Europe and North Africa. Journal of Applied Ecology, 59(6), 1496-1512. https://doi.org/10.1111/1365-2664.14160
6. Carrete, M., *et al.* (2012). Mortality at wind-farms is positively related to large-scale distribution and aggregation in griffon vultures. Biological Conservation, 145(1), 102-108. https://doi.org/10.1016/j.biocon.2011.10.017
7. Martin, G. R., *et al.* (2012). Visual fields, foraging and collision vulnerability in *Gyps* vultures. Ibis, 154(3), 626-631. https://doi.org/10.1111/j.1474-919X.2012.01227.x
8. Xirouchakis, *et al.* (2021). Home range size, space use and resource selection of griffon vultures in an insular environment. Journal of Zoology, 314(2), 116-131 https://doi.org/10.1111/jzo.12868
9. Alston, J. M., *et al.* (2022). Clarifying space use concepts in ecology: range vs. occurrence distributions. BioRxiv, 2022-09. https://doi.org/10.1101/2022.09.29.509951
10. Cortés-Avizanda, A., *et al.* (2016). Supplementary feeding and endangered avian scavengers: benefits, caveats, and controversies. Frontiers in Ecology and the Environment, 14(4), 191-199. https://doi.org/10.1002/fee.1257
11. van Overveld, T., *et al.* (2020). Integrating vulture social behavior into conservation practice. The Condor, 122(4), duaa035. https://doi.org/10.1093/condor/duaa035
12. Shepard, E., *et al.* (2019). Wind prevents cliff-breeding birds from accessing nests through loss of flight control. Elife, 8, e43842. https://doi.org/10.7554/eLife.43842
13. Arkumarev, V., *et al.* (2021). Seasonal dynamics in the exploitation of natural carcasses and supplementary feeding stations by a top avian scavenger. Journal of Ornithology, 162, 723-735. https://doi.org/10.1007/s10336-021-01865-1
14. Dobrev, D. D., & Popgeorgiev, G. S. (2021). Habitat preferences of the Eurasian Griffon Vulture (*Gyps fulvus*) in Bulgaria to support species management. Ornis Fennica, 98(3), 116-127 https://www.ornisfennica.org/pdf/latest/21DobrevPopgeorgiev.pdf
15. Duriez, O., *et al.* (2012). Intra-specific competition in foraging Griffon Vultures *Gyps fulvus*: 2. The influence of supplementary feeding management. Bird Study, 59(2), 193-206. https://doi.org/10.1080/00063657.2012.658640
16. Fernández-Gómez, *et al.* (2022). Vultures feeding on the dark side: current sanitary regulations may not be enough. Bird Conservation International, 32(4), 590-608. https://doi.org/10.1017/S0959270921000575
17. Fernández-Gómez, L., *et al.* (2022). Food subsidies shape age structure in a top avian scavenger. Avian Conservation and Ecology, 17(1). https://doi.org/10.5751/ACE-02104-170123
18. Fluhr, J., *et al.* (2017). Assessing the risk for an obligate scavenger to be dependent on predictable feeding sources. Biological Conservation, 215, 92-98. https://doi.org/10.1016/j.biocon.2017.07.030
19. Genero, F., *et al.* (2020). Spatial ecology of non-breeding Eurasian Griffon Vultures *Gyps fulvus* in relation to natural and artificial food availability. Bird Study, 67(1), 53-70. https://doi.org/10.1080/00063657.2020.1734534
20. Monsarrat, S., *et al.* (2013). How predictability of feeding patches affects home range and foraging habitat selection in avian social scavengers?. PloS one, 8(1), e53077. https://doi.org/10.1371/journal.pone.0053077
21. Zuberogoitia, I., *et al.* (2013). Foraging movements of Eurasian griffon vultures (*Gyps fulvus*): implications for supplementary feeding management. European Journal of Wildlife Research, 59, 421-429. https://doi.org/10.1007/s10344-012-0687-2
22. Aresu, M., *et al.* (2021). Assessing the effects of different management scenarios on the conservation of small island vulture populations. Bird Conservation International, 31(1), 111-128. https://doi.org/10.1017/S0959270920000040
23. Aresu, M., *et al.* (2022). Modelling the effect of environmental variables on the reproductive success of Griffon Vulture (*Gyps fulvus*) in Sardinia, Italy. Ibis, 164(1), 255-266 https://doi.org/10.1111/ibi.13012
24. Berlinguer, F., *et al.* (2021). LIFE "Safe For Vultures" – Report Year 2021. Action A.2. Assess the current and potential food availability for vultures in Sardinia. https://www.lifesafeforvultures.eu/report/assess-the-current-and-potential-food-availability-for-vultures-in-sardinia.pdf

25. Berlinguer, F., *et al.* (2020). Azione D.2 – Monitoraggio del successo riproduttivo. Quinto report – Anno 2020. http://www.lifeundergriffonwings.eu/export/sites/default/.galleries/doc-notizie/Azione-D.2_report-2020.pdf
26. Berlinguer, F., *et al.* (2022). Life Safe for Vultures. Azione D.5 – Monitoraggio del successo riproduttivo. Secondo Report, Anno 2022. https://www.lifesafeforvultures.eu/report/azione-d5-monitoraggio-del-successo-riproduttivo.pdf
27. Donázar, J., & Fernández, C. (1990). Population trends of the Griffon Vulture *Gyps fulvus* in northern Spain between 1969 and 1989 in relation to conservation measures. Biological Conservation, 53(2), 83-91. https://doi.org/10.1016/0006-3207(90)90001-6
28. Bodey, T. W., *et al.* (2018). A phylogenetically controlled meta-analysis of biologging device effects on birds: Deleterious effects and a call for more standardized reporting of study data. Methods in Ecology and Evolution, 9(4), 946-955. https://doi.org/10.1111/2041-210X.12934
29. Bildstein, K. L. (2022). Vultures of the World. In Vultures of the World. Cornell University Press https://www.cornellpress.cornell.edu/book/9781501761614/vultures-of-the-world/
30. Acácio, M., *et al.* (2023). A lifetime track of a griffon vulture: The moving story of Rehovot (Y64). Ecology, e3985 https://doi.org/10.1002/ecy.3985
31. Delgado-González, A., *et al.* (2022). Apex scavengers from different European populations converge at threatened savannah landscapes. Scientific Reports, 12(1), 1-10. https://doi.org/10.1038/s41598-022-06436-9
32. Silva, I., *et al.* (2022). Autocorrelation-informed home range estimation: A review and practical guide. Methods in Ecology and Evolution, 13(3), 534-544. https://doi.org/10.1111/2041-210X.13786
33. Kranstauber, B., *et al.* (2012). A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. Journal of Animal Ecology, 81(4), 738-746. https://doi.org/10.1111/j.1365-2656.2012.01955.x
34. Palm, E. C., *et al.* (2015). Mapping migratory flyways in Asia using dynamic Brownian bridge movement models. Movement Ecology, 3(1), 1-10. https://doi.org/10.1186/s40462-015-0029-6
35. Kane, A., *et al.* (2022). Understanding continent-wide variation in vulture ranging behavior to assess feasibility of Vulture Safe Zones in Africa: Challenges and possibilities. Biological Conservation, 268, 109516. https://doi.org/10.1016/j.biocon.2022.109516
36. Kmetova–Biro, E., *et al.* (2021). Re-introduction of Griffon Vulture (*Gyps fulvus*) in the Eastern Balkan Mountains, Bulgaria–completion of the establishment phase 2010-2020. Biodiversity Data Journal, 9.https://doi.org/10.3897%2FBDJ.9.e66363
37. Zvidzai, M., *et al.* (2020). Multiple GPS fix intervals show variations in the manner African White-backed Vultures *Gyps africanus* utilise space. Ostrich, 91(4), 343-355.https://doi.org/10.2989/00306525.2020.1832153
38. Northrup, J. M., *et al.* (2013). Practical guidance on characterizing availability in resource selection functions under a use–availability design. Ecology, 94(7), 1456-1463. https://doi.org/10.1890/12-1688.1
39. Marzluff, J. M., *et al.* (2004). Relating resources to a probabilistic measure of space use: forest fragments and Steller's jays. Ecology, 85(5), 1411-1427.. Practical guidance on characterizing availability in resource selection functions under a use–availability design. Ecology, 94(7), 1456-1463. https://doi.org/10.1890/03-0114
40. Shepard, E. L., *et al.* (2013). Energy landscapes shape animal movement ecology. The American Naturalist, 182(3), 298-312. https://doi.org/10.1086/671257
41. Harel, R., *et al.* (2017). Social foraging and individual consistency in following behaviour: testing the information centre hypothesis in free-ranging vultures. Proceedings of the Royal Society B: Biological Sciences, 284(1852), 20162654. https://doi.org/10.1098/rspb.2016.2654
42. Bildstein, K. L., *et al.* (2009). Narrow sea crossings present major obstacles to migrating Griffon Vultures *Gyps fulvus*. Ibis, 151(2), 382-391. https://doi.org/10.1111/j.1474-919X.2009.00919.x
43. James, G., *et al.* (2013). An introduction to statistical learning (Vol. 112, p. 18). New York: springer. https://doi.org/10.1007/978-1-0716-1418-1
44. Ripari, L., *et al.* (2022). Human disturbance is the most limiting factor driving habitat selection of a large carnivore throughout Continental Europe. Biological Conservation, 266, 109446.https://doi.org/10.1016/j.biocon.2021.109446
45. Liu, S. (2017). Person-specific versus multilevel autoregressive models: Accuracy in parameter estimates at the population and individual levels. British Journal of Mathematical and Statistical Psychology, 70(3), 480-498. https://doi.org/10.1111/bmsp.12096
46. R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/
47. Peshev, H., *et al.* (2021). New insight into spatial ecology of Griffon Vulture (*Gyps fulvus*) on the Balkans provides opportunity for focusing conservation actions for a threatened social scavenger. Biodiversity Data Journal, 9. https://doi.org/10.3897%2FBDJ.9.e71100
48. Zuberogoitia, I., *et al.* (2019). Factors affecting population regulation of a colonial vulture. Ibis, 161(4), 878-889. https://doi.org/10.1111/ibi.12687
49. Sanz-Aguilar, A., *et al.* (2015). Age-dependent survival of island vs. mainland populations of two avian scavengers: delving into migration costs. Oecologia, 179, 405-414. https://doi.org/10.1007/s00442-015-3355-x

50. Ferrer, M., *et al.* (2022). Significant decline of Griffon Vulture collision mortality in wind farms during 13-year of a selective turbine stopping protocol. Global Ecology and Conservation, 38, e02203. `https://doi.org/10.1016/j.gecco.2022.e02203`
51. Eisaguirre, J. M., *et al.* (2020). Novel step selection analyses on energy landscapes reveal how linear features alter migrations of soaring birds. Journal of Animal Ecology, 89(11), 2567-2583. `https://doi.org/10.1111/1365-2656.13335`
52. D'Elia, J., *et al.* (2019). Applying circuit theory and landscape linkage maps to reintroduction planning for California Condors. Plos one, 14(12), e0226491. `https://doi.org/10.1371/journal.pone.0226491`
53. Jacobsen, T. C., *et al.* (2020). A novel method for detecting extra-home range movements (EHRMs) by animals and recommendations for future EHRM studies. Plos one, 15(11), e0242328. `https://doi.org/10.1371/journal.pone.0242328`
54. Hooven, N. D., *et al.* (2023). Influence of natal habitat preference on habitat selection during extra-home range movements in a large ungulate. Ecology and Evolution, 13(2), e9794. `https://doi.org/10.1002/ece3.9794`
55. Tsiakiris, R., *et al.* (2021). Models of poisoning effects on vulture populations show that small but frequent episodes have a larger effect than large but rare ones. Web Ecology, 21(2), 79-93. `https://doi.org/10.5194/we-21-79-2021,2021`
56. Arkumarev, V., *et al.* (2021). Seasonal and age-specific dynamics of the Griffon Vulture's home range and movements in the Eastern Rhodopes. Ornis Hungarica, 29(2), 81-92. `https://doi.org/10.2478/orhu-2021-0021`
57. Gangoso, L., *et al.* (2021). Avian scavengers living in anthropized landscapes have shorter telomeres and higher levels of glucocorticoid hormones. Science of the Total Environment, 782, 146920. `https://doi.org/10.1016/j.scitotenv.2021.146920`
58. García-Ripollés, C., *et al.* (2011). Ranging behaviour of non-breeding Eurasian Griffon Vultures *Gyps fulvus*: a GPS-telemetry study. Acta Ornithologica, 46(2), 127-134. `https://doi.org/10.3161/000164511X625892`
59. Hribšek, I., *et al.* (2021). First description of movement and ranging behavior of the Griffon vulture (*Gyps fulvus*) from Serbia using GPS satellite tracking. Archives of Biological Sciences, 73(2), 185-195. `http://dx.doi.org/10.2298/ABS201210013H`
60. Martin-Díaz, P., *et al.* (2020). Rewilding processes shape the use of Mediterranean landscapes by an avian top scavenger. Scientific Reports, 10(1), 2853. `https://doi.org/10.1038/s41598-020-59591-2`
61. Morant, J., *et al.* (2023). Large-scale movement patterns in a social vulture are influenced by seasonality, sex, and breeding region. Ecology and Evolution, 13(2), e9817. `https://doi.org/10.1002/ece3.9817`
62. Stoynov, E., et al. (2017). Ranging Behaviour of the Griffon Vulture *Gyps fulvus* in Kresna Gorge and South-western Bulgaria. Technical Report on Action A1 of the LIFE11 NAT/BG/363, Fund for Wild Flora and Fauna, Blagoevgrad. `https://www.researchgate.net/profile/Emilian-Stoynov/publication/314239249_Ranging_Behaviour_of_the_Griffon_Vulture_Gyps_fulvus_in_Kresna_Gorge_and_South-western_Bulgaria/links/58bd3913a6fdcc2d14e61bc5/Ranging-Behaviour-of-the-Griffon-Vulture-Gyps-fulvus-in-Kresna-Gorge-and-South-western-Bulgaria.pdf`

Appendices

Due to their lenght, Appendix 1, 2, 3, and 4 are available from the Supplementary Information at: `https://osf.io/urbpv/`

Authors	**doi**	*Location*	**Method**	**Area covered**
Arkumarev et al. (2021a)[56]	`https://doi.org/10.2478/orhu-2021-0021`	Bulgaria, Greece, North Macedonia	Kernel Density Estimator (plug-in bandwidth selection)	• Adults - 95% isopleth: Spring – 2,016.3 ± 1,233.4 km^2 Summer – 2,097.3 ± 1,059.4 km^2 Autumn - 1,030.1 ± 578.4 km^2 Winter – 746.5 ± 435 km^2 • Adults - 50% isopleth: Spring – 167.3 ± 80 km^2 Summer – 223.3 ± 94.8 km^2 Autumn - 123.3 ± 97.9 km^2 Winter – 70.8 ± 50.5 km^2 • Non-adults - 95% isopleth: Spring – 2,934.5 ± 2,180.7 km^2 Summer – 3,573.1 ± 2,552 km^2 Autumn – 1,558.8 ± 1,067.9 km^2 Winter – 792.3 ± 769.9 km^2 • Non-adults - 50% isopleth: Spring – 182.5 ± 157.8 km^2 Summer – 287.8 ± 236.2 km^2 Autumn – 132.9 ± 141.3 km^2 Winter – Winter – 54.5 ± 57.9 km^2
Arrondo et al. (2020)[4]	`https://doi.org/10.1007/s10531-020-01942-6`	Spain	Kernel Density Estimation	• 95% isopleth: Northern Spain – 8,386.4 ± 8,358.2 km^2 Southern Spain – Southern Spain – 11,249.8 ± 5,956 km^2

Table S1 Overview of existing studies, carried out in Europe, quantifying the extent of areas covered by griffon vultures (in continues on the next page).

Authors	**doi**	*Location*	**Method**	**Area covered**
Fluhr et al. (2017)[18]	`https://doi.org/10.1016/j.biocon.2017.07.030`	France (Grands Causses and Pyrenees)	Movement-based Kernel Density Estimation	• 95% isopleth (Summer): Grands Causses: 1,551 ± 842 km^2 Pyrenees: 2,378 ± 969 km^2 • 50% isopleth (Summer): Grands Causses: 181 ± 105 km^2 Pyrenees: 213 ± 160 km^2
Gangoso et al. (2021)[57]	`https://doi.org/10.1016/j.scitotenv.2021.146920`	Spain	Kernel Density Estimation	• Males - 95% isopleth: North Spain – 6,709.52 ± 8,386.43 km^2 South Spain – 9,888.89 ± 6,152.36 km^2 • Males - 50% isopleth: North Spain - 451.53 ± 551.50 km^2 South Spain - 467.45 ± 557.36 km^2 • Females - 95% isopleth: North Spain - 10,886.63 ± 8,803.21 km^2 South Spain - 13,600.34 ± 5,985.50 km^2 • Females - 50% isopleth: North Spain - 830.44 ± 570.62 km^2 South Spain - 937.62 ± 571.51 km^2
García-Ripollés et al. (2013)[58]	`https://doi.org/10.3161/000164511X625892`	Spain	Kernel Density Estimation	• 95% isopleth: 6,557.5 ± 8,629.6 km^2 • 50% isopleth: 8,13.5 ± 1,190.0 km^2

Table S1 Overview of existing studies, carried out in Europe, quantifying the extent of areas covered by griffon vultures (in continues on the next page).

Authors	**doi**	*Location*	**Method**	**Area covered**
Genero et al. (2020)[19]	https://doi.org/10.1080/00063657.2020.1734534	Austria, Croatia, Italy	Kernel Density Estimation, fixed bandwidth	• 95% isopleth 4,642.5 ± 2,835.6 km^2 • 50% isopleth 875.2 ± 461.4 km^2
Hribšek et al. (2021)[59]	http://dx.doi.org/10.2298/ABS201210013H	Serbia	Kernel Density Estimation	• 95% isopleth: 2,102.44 km^2 • 50% isopleth: 76.56 km^2
Kmetova-Biro et al. (2021)[36]	https://doi.org/10.3897%2FBDJ.9.e66363	Bulgaria (Eastern Balkan Mountains)	Dynamic Brownian Bridge Movement Model	• 95% isopleth: 281.88 ± 91 km^2 • 50% isopleth: 6.6 ± 2.28 km^2
Martin-Diaz et al. (2020)[60]	https://doi.org/10.1038/s41598-020-59591-2	Spain	Spain	• 95% isopleth (Summer): 6,897.46 ± 3,966.52 km^2 • 50% isopleth (Winter): 2,128.17 ± 1,000.83 km^2
Monsarrat et al. (2013)[20]	https://doi.org/10.1371/journal.pone.0053077	France (Grands Causses)	Movement-based Kernel Density Estimation	• 95% isopleth (Summer): 1,272 ± 752 km^2 • 50% isopleth (Winter): 473 ± 237 km^2
Morant et al. (2022)[61]	https://doi.org/10.1002/ece3.9817	Iberian peninsula	Kernel Density Estimation	• 95% isopleth (Annual): 5,027 ± 2,123 km^2 • 50% isopleth (Monthly): 4,889 ± 1,753 km^2
Peshev et al. (2021)[47]	https://doi.org/10.3897/BDJ.9.e71100	Bulgaria, Greece, North Macedonia	Dynamic Brownian Bridge Movement Model	• 95% isopleth: 1,431.22 ± 1,472.12 km^2 • 50% isopleth: 50% isopleth: 30.04 ± 37.58 km^2

Table S1 Overview of existing studies, carried out in Europe, quantifying the extent of areas covered by griffon vultures (in continues on the next page).

Authors	**doi**	*Location*	**Method**	**Area covered**
Stoynov et al. (2017)[62]	https://www.researchgate.net/profile/Emilian-Stoynov/publication/314239249_Ranging_Behaviour_of_the_Griffon_Vulture_Gyps_fulvus_in_Kresna_Gorge_and_South-western_Bulgaria/links/58bd3913a6fdcc2d14e61bc5/Ranging-Behaviour-of-the-Griffon-Vulture-Gyps-fulvus-in-Kresna-Gorge-and-South-western-Bulgaria.pdf	Bulgaria, Greece, Macedonia, Turkey	Kernel Density Estimation	• 95% isopleth: 8,796.2 ± 22,096.98 km^2 • 50% isopleth: 666.1 ± 1,441.9 km^2
Xirouchakis et al. (2021)[8]	https://doi.org/10.1111/jzo.12868	Crete	Kernel Density Estimation , reference bandwidth chosen under the assumption that the sample data come from a bivariate normal distribution	• 95% isopleth: 1,560 ± 140 km^2 • 50% isopleth: isopleth: 373 ± 36 km^2

Table S1 Overview of existing studies, carried out in Europe, quantifying the extent of areas covered by griffon vultures (in continues on the next page).

Authors	doi	Findings	Method
Arkumarev et al. (2021)[56]	`https://link.springer.com/article/10.1007/s10336-021-01865-1#article-info`	• Vulture's reliance on feeding stations was lowest in summer (19.82 ± 7.8%) and highest in winter when 56.5 ± 16.1% of the feedings were at the SFS. • Griffon Vultures travelled longer daily distances in days feeding in the wild compared to days when they were not feeding or were visiting SFS • Our study indicates that in habitats with high abundance of natural food (free-range livestock and game), vultures tend to actively forage and use feeding stations as supplemental sources of food, mostly during long periods of adverse weather or in winter when foraging conditions are worse and natural food is less abundant.	Analysis of accelerometer data, coupled with field inspections.
Fluhr et al. (2017)[18]	`https://doi.org/10.1016/j.biocon.2017.07.030`	• They investigated the degree of routine movement behaviour in a population of Eurasian Griffon vultures (Gyps fulvus) that mostly feed on livestock carrion provided at Supplementary Feeding Stations (SFS) • Only 10% of the SFS included within an individual's home range were periodically visited for some time, with a period ranging from 1 to 6 days. • The closer a SFS to the nest and the higher the frequency of food supply, the more likely was a vulture to visit this SFS periodically. • Vultures also tended to repeatedly visit some series of SFS more often than expected if they would forage at random, but the levels of routine remained relatively low. • Our results suggest that the management of supplementary food through a network of numerous small SFS does not substantially disrupt the natural foraging behaviour of vultures, whereas large, frequently replenished SFS tend to artificially increase their level of routine.	Recent methodologies (Fourier, Wavelet and conditional entropy-based analyses) applied on GPS telemetry

Table S2 Overview of existing studies, carried out in Europe, exploring the effect of supplementary feeding stations over space use and movements of griffon vultures. (It continues on the next page).

Authors	doi	Findings	Method
Genero et al. (2020)[19]	https://doi.org/10.1080/00063657.2020.1734534	• Average foraging range size and the time spent by the birds in Italy were comparable to those recorded in Croatia and Austria, where the vultures depend on unpredictable food resource. • A significant difference in terms of foraging range size was recorded among seasons. In winter it seems to be smaller as a consequence of reduced movements performed by the individuals due to harsh climate conditions. • Our results suggest that the creation of a feeding station in Forgaria does not seem to have affected the spatial ecology of the Eurasian Griffon Vulture.	The effect of each independent variable (area and season) over the dependent variables (i.e. 95% KDE, 50% KDE, 50/95 KDE ratio and time spent at the various sites). With GLMMs and t-test.
Dobrev and Popgeorgiev (2021)[14]	https://www.ornisfennica.org/pdf/latest/21DobrevPopgeorgiev.pdf	• At a cliff scale, the height and length of the cliff, the distance to the nearest conspecific colony and the distance to the nearest feeding site were the best predictors for the species habitat preference. • Occupied cliffs → median distance < 5 km • Unoccupied cliffs → median distance 15-20km	Univariate modeling of occupied and unoccupied cliffs
Duriez et al. (2011)[15]	https://doi.org/10.1080/00063657.2012.658640	• Young vultures have better access to food resources at supplementary feeding sites where carcasses are fewer and less predictable, and placed further from colonies. • At heavy feeding sites adults arrived sooner than young, so they had better access to viscera of high energy content, while young individuals could only eat later on the scraps. • At light feeding sites young vultures arrived earlier and in larger proportions. Intra-specific competition was strong and adults were generally dominant over younger birds. • Young birds foraged preferentially at light feeding sites where the competition was lower, allowing a better access to high-quality food.	Focal and scan sampling at feeding sites

Table S2 Overview of existing studies, carried out in Europe, exploring the effect of supplementary feeding stations over space use and movements of griffon vultures. (It continues on the next page).

Authors	doi	Findings	Method
Fernández-Gómez et al. (2022)[17]	`http://www.ace-eco.org/vol17/iss1/art23/`	• In the years of the Tolerance legislation scenario (from 2014 onwards), with more available food, the proportion of immature vultures decreased at random carcasses and, to a lesser extent in predictable feeding sites. In other words, new food sources in the form of random carcasses (available after farmers were permitted to abandon the remains of livestock) would be exploited preferably by adult birds. • Conversely, immature birds still tend to concentrate in landfills. It is well established that immature raptors use different foraging strategies relative to adults, tending to congregate in areas whereresources are more abundant, predictable, and clumped (Hiraldo et al. 1995, Carrete et al. 2006, van Overveld et al. 2018). • In particular, we show age-specific resource exploitation patterns, with adult birds profiting more from more randomly distributed resources and immatures depending on low- quality feeding sites such as landfills.	Observations of carrion deployed at fields and inspection of naturalistic photographic data.
Monsarrat et al. (2013)[20]	`https://doi.org/10.1371/journal.pone.0053077`	• Analyses of home range characteristics and feeding habitat selection via compositional analysis showed that feeding stations were always preferred compared to the rest of the habitat where vultures can find unpredictable resource. • Feeding stations were particularly used when resources were scarce (summer) or when flight conditions were poor (winter), limiting long-ranging movements. • When flight conditions were optimal, home ranges also encompassed large areas of grassland where vultures could find unpredictable resources, suggesting that vultures did not lose their natural ability to forage on unpredictable resources, even when feeding stations were available • During seasons when food abundance and flight conditions were not limited, vultures seemed to favour light over heavy feeding stations, probably because of the reduced intraspecific competition and a pattern closer to the natural dispersion of resources in the landscape	GPS data, Kernel HR estimation and compositional analysis

Table S2 Overview of existing studies, carried out in Europe, exploring the effect of supplementary feeding stations over space use and movements of griffon vultures. (It continues on the next page).

Authors	doi	Findings	Method
Xirouchakis et al. (2021)[8]	https://doi.org/10.1111/jzo.12868	• Foraging adults were restricted to the vicinity of the breeding colonies and favoured sites away from urban zones. In contrast, immature griffon vultures selected pastoral zones in marginal areas with mild winters and rugged terrain. • The lack of significant effects on space use by food availability suggests that carrion is spaced rather uniformly within the vultures' winter range. • Moreover, given the spatial restrictions of the island and the non-overlapping winter home ranges between adult and immature birds, one could argue that the species' movements are influenced more by competition over carrion rather than carrion availability itself. • Adults foraged in remote places away from human settlements most likely being able to locate carrion from free-ranging flocks apart from that originating from anthropogenic sources. • Immature vultures frequented areas with a high density of dirt roads, showing their strong dependence on rural regions where waste management sites are regularly stocked with livestock carcasses and offal by the farmers. Compared to adults, immature vultures are less selective regarding their foraging habitat, favouring areas with predictable resources (Gangoso et al., 2013; McGrady et al., 2018). On Crete, immature birds were radio-located near waste management sites and supplementary feeding stations (i.e. 'light' and 'heavy' conditions; Cortés-Avizanda et al., 2010; Monsarrat et al., 2013). • The existence of predictable food sources in combination with suitable roosting sites and favourable flight conditions were the main factors differentiating the space-use pattern between the two age classes.	Examination of HR overlap and resource-selection-functions with used/availability design
Zuberogoitia et al. (2013)[21]	https://doi.org/10.1007/s10344-012-0687-2	• Using these re-sighting records, we tested whether birds randomly moved long distances whilst searching for food, or if vulture re-sightings were restricted to a few feeding sites within a limited area. • Movements out of the main foraging nuclei were statistically less frequent than would be expected if adult vultures accessed all resources at a similar rate. • Our results suggest that vultures' home ranges are largely restricted to zones close to breeding areas and that artificial feeding may only be a valid method of improving breeding parameters when the feeding station is placed within the foraging area of adults. • Vulture restaurants attract non-territorial subadults in large numbers	Re-sightings of ringed individuals

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