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Ornis Hungarica 2021. 29(2): 81–92.
DOI: 10.2478/orhu-2021-0021

Seasonal and age-specific dynamics of the Griffon Vulture's home range and movements in the Eastern Rhodopes

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Received: October 11, 2021 – Revised: November 09, 2021 – Accepted: November 10, 2021

Arkumarev, V., Dobrev, D., Stamenov, A., Delchev, A. & Stoychev, S. 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. DOI: 10.2478/orhu-2021-0021

Abstract The spatial ecology of the Eurasian Griffon Vulture *(Gyps fulvus)* has been a subject of scientific interest for long due to its conservation status, critical ecosystem role, gregarious lifestyle and complex foraging behavior. The trans-border Eastern Rhodope Mountain in Bulgaria and Greece holds an increasing population of the species and one of the largest on the Balkan Peninsula. We used high-frequency GPS data from 13 Griffon Vultures from this population to study their movements, home range size and its seasonal or age specific dynamics. The overall foraging home range (95% kernel) was 3,204 km^2 and the core area of activity (50% kernel) was 256.5 km^2. We found high seasonal variation of the home range size. Vultures were foraging over larger areas in the summer and spring but their activity was limited to four times smaller areas in winter. We found no age specific variation in the home range sizes but the non-adult vultures showed tendency to conduct exploratory movements far from the breeding colony. Our results can be used for planning conservation efforts in the areas of high importance for the species.

Keywords: *Gyps fulvus*, GPS-tracking, foraging, movement, raptor conservation

Összefoglalás Az eurázsiai fakó keselyű *(Gyps fulvus)* térökológiája régóta a tudományos érdeklődés tárgya a faj védettségi állapota, kritikus ökoszisztéma-szerepe, közösségi életmódja és összetett táplálkozási viselkedése miatt. A határokon átnyúló, Bulgáriában és Görögországban található Kelet-Rodope-hegységben a faj populációja növekvő, és az egyik legnagyobb a Balkán-félszigeten. Ebből a populációból 13 egyed nagyfrekvenciás GPS-adatait használtuk fel mozgásuk, mozgáskörzetük és szezonális vagy korspecifikus dinamikájuk tanulmányozására. A teljes táplálkozási terület (95% valószínűségi elterjedés) 3204 km^2, a fő tevékenységi terület (50% valószínűségi elterjedés) 256,5 km^2 volt. A mozgáskörzet méretében nagy szezonális ingadozást találtunk. A keselyűk nyáron és tavasszal nagyobb területeken kerestek táplálékot, ehhez képes télen tevékenységük negyedannyi területre korlátozódott. Nem találtunk korspecifikus eltérést a mozgáskörzet méretében, de a fiatal keselyűk hajlamosak voltak felfedező mozgást végezni a költőkolóniától távol is. Eredményeink felhasználhatóak a faj szempontjából kiemelt jelentőségű területek védelmi intézkedéseinek tervezésére.

Kulcsszavak: fakó keselyű, GPS-követés, táplálkozás, mozgás, ragadozómadár-védelem

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Introduction

The Eurasian Griffon Vulture *(Gyps fulvus)* is a large long-lived scavenger with a breeding distribution extending from Portugal in the west to the Himalayas in the east (Ferguson Lees & Christie 2001). It is listed as 'Least Concern' by the IUCN and is the most common vulture species in Europe (BirdLife International 2021). The Iberian Peninsula holds over 85% of its European population (Botha *et al.* 2017, Del Moral & Molina 2018). In the Balkan Peninsula, the species has undergone a decline during the 20th century (Andevski 2013). However, over the past 30 years it showed recovery in Serbia, Bulgaria and Croatia (Dobrev *et al.* 2021a). Its population in Bulgaria has steadily increased as a result of intensive conservation actions and successful reintroduction programs (Demerdzhiev *et al.* 2014, Kmetova-Biro 2021, Dobrev *et al.* 2021a). The adult and immature Griffon Vultures are mostly resident, while some juveniles are migratory and winter in the Middle East and Africa (del Hoyo *et al.* 1994, McGrady & Gavashelishvili 2006, Arkumarev *et al.* 2019).

The Griffon Vulture is an obligate scavenger, exclusively feeding on carcasses of livestock and wild ungulates (Cramp & Simmons 1980), thus providing critical ecosystem services (Pain *et al.* 2003, Grilli *et al.* 2019). It relies on food resources, which are spatially and temporally unpredictable. Therefore, vultures evolved various adaptations to increase their foraging efficiency and minimize the energy costs related to flight (Spiegel *et al.* 2013a, Duriez *et al.* 2014). The social foraging strategy reduces the uncertainty regarding food location (Harel *et al.* 2017). Vultures almost exclusively use soaring-gliding flight supported by thermal updrafts to travel long distances in search of carcasses minimizing the energy costs (Ruxton & Houston 2004). Griffon Vultures forage over wide range of open habitats and have large home ranges (García-Ripollés *et al.* 2011). However, their ranging movements are affected by the availability of food and they tend to concentrate near predictable food sources (Deygout *et al.* 2010, Monsarrat *et al.* 2013, Dobrev *et al.* 2021b). In the Balkans, vultures largely depend on extensively grazed livestock and supplementary feeding stations, which shape their home ranges (Azmanis 2009, Arkumarev *et al.* 2021a). The spatial ecology of the Griffon Vulture has been a subject of scientific interest for long due to its conservation status, critical ecosystem role and complex foraging behavior. GPS-based telemetry has been used as an effective tool to study the movements of vultures and other raptors and to identify the most frequently used foraging areas, the threats in these areas and to inform the conservationists (Alarcon & Lambertucci 2018). The movement ecology is now providing the knowledge needed to incorporate movements of species into management planning (Allen & Singh 2016). Vulture movement data is used to assess the effectiveness of protected areas, the risk of collision with human-made infrastructure, detect poisoning incidents and identify mortality hotspots and priority areas for conservation (Alarcon & Lambertucci 2018). Studies on the Griffon Vulture's movements were already conducted in Spain (García-Ripollés *et al.* 2011), Israel (Bahat *et al.* 2001), Crete (Xirouchakis *et al.* 2021), on the Balkans (Peshev *et al.* 2021), Bulgaria (Peshev *et al.* 2018), Serbia (Hribsek *et al.* 2021), Eastern Alps and Croatia (Genero *et al.* 2020). However, the increasing Griffon Vulture population in the trans-border Rhodope Mountains in Bulgaria and Greece has not yet been studied. The growing number of planned new energy infrastructure in the area

(Kafetzis *et al.* 2017) requires detailed studies on vulture's movements and foraging. We determined the home range size of adult and non-adult vultures from the Eastern Rhodopean population and studied the seasonal foraging dynamics.

Material and Methods

Between 2017 and 2019, 13 Griffon vultures were trapped and equipped with solar-powered GPS/GSM transmitters in the Eastern Rhodopes, Bulgaria. Vultures were captured using a walk-in trap, located at a vulture feeding station. At the time of transmitter deployment, 7 birds were adults (>6 calendar years) and 6 birds were non-adults (2–5 calendar years) (Clark 2004, Zuberogoitia *et al.* 2013). However, as two non-adults aged into adults over the course of the study our final dataset included 141 non-adult bird months and 171 adult bird months. The vultures were fitted with 57 g high-resolution GPS/GSM and accelerometer (ACC) tags (E-Obs GmbH; Munich, Germany). Transmitters were attached with a backpack or leg-loop harness configuration with 11.2 mm Teflon ribbon (Anderson *et al.* 2020). The transmitter harness, rings and wing tag did not exceed 3% of the bird's body mass in accordance with the recommended limits to avoid adverse effects (Bodey *et al.* 2018). The transmitters were programmed to acquire a GPS fix and ACC data every 5 min during the day (between 03:00 and 19:00 UTC) with dormancy periods during the night. In winter due to insufficient solar charging GPS fixes were acquired once every 20 min. All data were stored in and accessed from Movebank (www. movebank.org, Kranstauber *et al.* 2011). Prior analyses, the data were inspected and visualized to check for outliers. Using the Movebank data filters, we removed erroneous GPS fixes (Walter *et al.* 2011).

Between May 2017 and March 2021 we received 1,638,251 GPS locations, on average 94.650±67.350 per individual. However, to estimate the Griffon Vulture's foraging home range we removed all stationary points by filtering the GPS locations with recorded ground speed <3 km/h. We conducted all further analyses with the remaining 415,434 GPS locations. We estimated vultures' foraging home range by applying the kernel density approach (Kenward 2001). We used iterative plug-in bandwidth selection (Amstrup *et al.* 2004, Gitzen *et al.* 2006). Data processing and estimations were completed in R v4.0.2 (R Core Team 2020) using package 'plugdensity' (Herrmann 2011). Fixed 99%, 95%, 75% and 50% kernel density contours were calculated to estimate home ranges. The 50% isopleth contour was defined as the vulture's core area and the 95% isopleth contour as the foraging home range. We also calculated the overall foraging range as the Minimum Convex Polygon (MCP) encompassing all GPS locations (Worton 1989). We pooled the data of all individuals for defining the foraging home range of the entire population. Furthermore, we defined the home ranges for each of the two age groups and for each season. The seasons were defined by the winter and summer solstices and spring and autumn equinox dates. The differences among the age groups and the seasonal home range size were assessed using one-way ANOVA and LSD post-hoc tests. For the aim of these comparisons and to comply with the sample independence rule, we excluded the adult home ranges of the two individuals, which aged into adults during the study.

We calculated the daily travelled distances for each tracked vulture by summing the distance between all successive GPS points for the day (Spiegel *et al.* 2013a). This parameter was considered as a proxy of vulture's foraging effort. Means are presented ± Standard Deviation (SD). The statistical processing of the data was carried out using the program Statistica 10 for Windows and R v4.0.2 (StatSoft Inc. 2010, R Core Team 2020). Spatial data were mapped and processed using QGIS software v3.12 (QGIS Development Team 2020).

Results

We tracked 13 Griffon Vultures for 1,093±244 tracking days (range 692 – 1,398). The average number of GPS fixes per day was 89.5±24.3. The overall foraging range, calculated as MCP, was 98,785 km^2. The foraging home ranges based on 95% and 75% kernel contours were 3,204 and 924.2 km^2, respectively. The core area (50% kernel) of the population in the Eastern Rhodopes was 256.5 km^2 *(Figure 1)*.

We found significant seasonal variation in the size of the core area ($F_{3,52}$ = 20.001, P = 0.002) of the Griffon Vulture activity *(Figure 2)*. The post-hoc analyses revealed that in summer it was larger than in autumn (P = 0.01) and winter (P = 0.0002), but not significantly larger than in spring (P = 0.10). The core area in summer was 249.1±169.5 km^2 and in winter only 64.2±54.2 km^2. It was 173.4±117.7 km^2 in spring and 127.1±117.3 km^2 in autumn

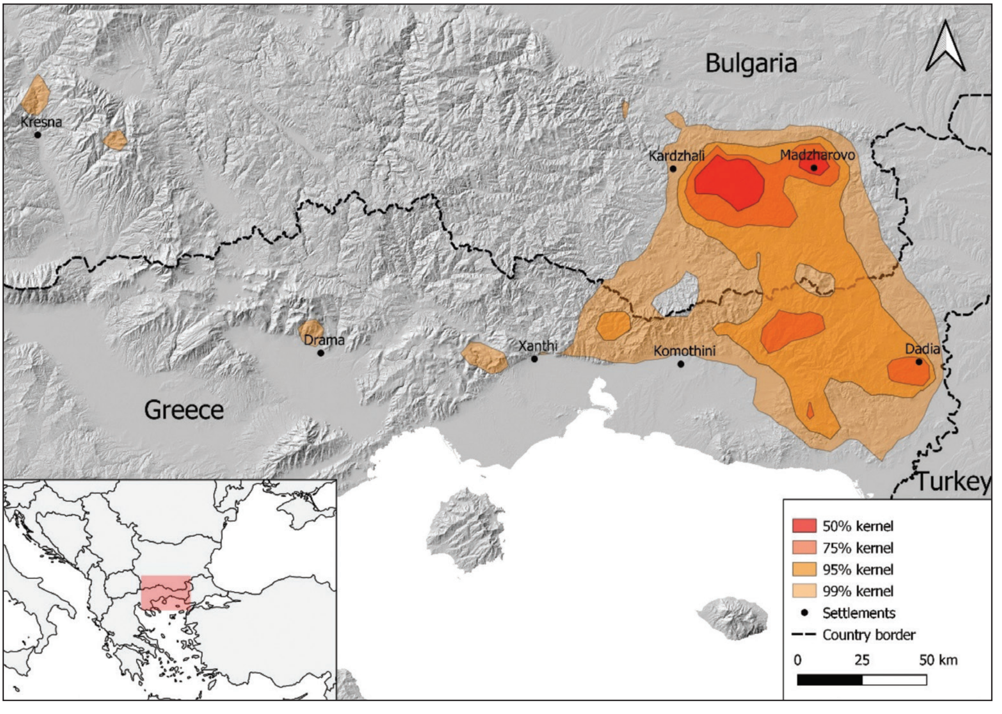

Figure 1. Home range of the Griffon Vulture population from the Eastern Rhodopes
1. ábra A fakó keselyű populáció mozgáskörzete a Keleti-Rodopéból

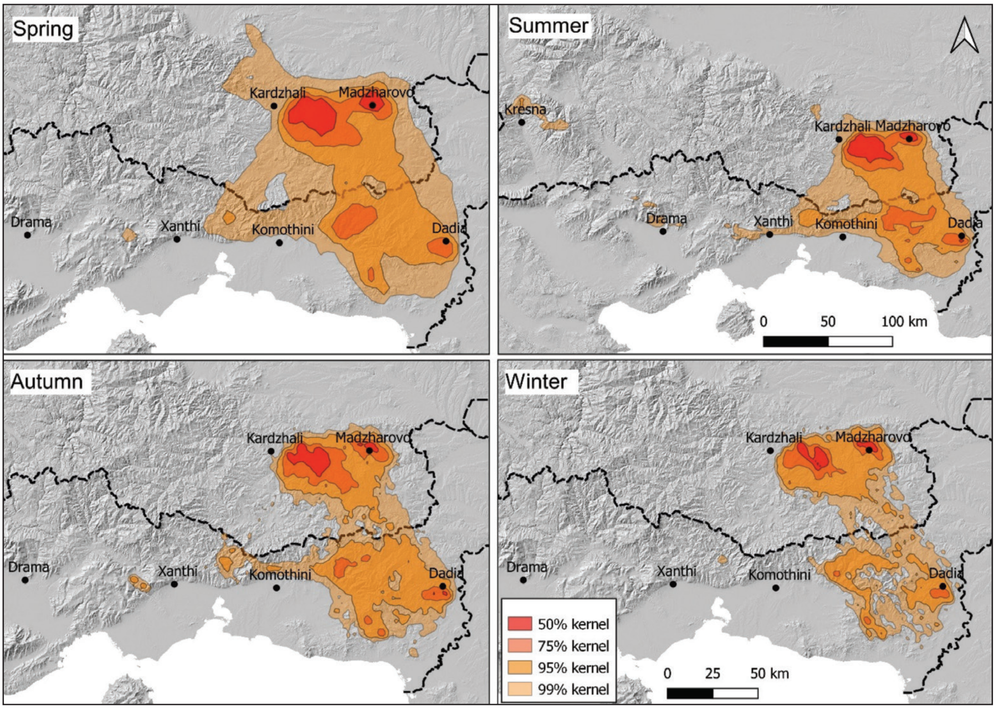

Figure 2. Seasonal variation in the home ranges of the Griffon Vulture population in the Eastern Rhodopes

2. ábra A fakó keselyű populáció mozgáskörzetének évszakonkénti változása Kelet-Rodope területén

(Figure 2). We found also significant difference in the 95% kernel home range among the seasons ($F_{3,52}$ = 5.93, P = 0.001). The home range (95% kernel) was similar in size in spring and summer – 2,383.6±1737 km^2 and 2,687.6±1,949.7 km^2, respectively (P = 0.57). However, in autumn and winter it was significantly smaller than in summer (P = 0.009; P = 0.0006) – 1,241.6±850.9 km^2 and 764.8±592.6 km^2, respectively. No significant differences

Table 1. Home range (95% kernel), core area (50% kernel) size and daily travelled distances of Griffon Vultures per season and age groups

1. táblázat A fakó keselyű mozgáskörzete és napi megtett távolsága évszakonként és korcsoportonként

Age	Season	50% kernel (km²)	95% kernel (km²)	Distance travelled per day
Adult	Spring	167.3±80	2,016.3±1,233.4	91.3±62.8 km
	Summer	223.3±94.8	2,097.3±1,059.4	122.1±66.4 km
	Autumn	123.3±97.9	1,030.1±578.4	45.3±43.6 km
	Winter	70.8±50.5	746.5±435	34.9±39.2 km
Non-adult	Spring	182.5±157.8	2,934.5±2,180.7	78.3±62 km
	Summer	287.8±236.2	3,573.1±2,552	111.1±65.5 km
	Autumn	132.9±141.3	1,558.8±1,067.9	48.2±46.8 km
	Winter	54.5±57.9	792.3±769.9	41.9±40.4 km

were found in the size of the core area or the home range (95% kernel) between the adult and non-adult Griffon Vultures ($F_{1,13}$ = 0.056, P = 0.82; $F_{1,13}$ = 2.31, P = 0.16). Furthermore, no significant differences were found between the two age groups among the seasons *(Table 1)*.

Vultures travelled on average 75 ± 64.5 km per day. The longest recorded distance for a day was 369.7 km. Adult and non-adult individuals travelled similar daily distances – 76.3 ± 65.6 and 72.5±62.3 km, respectively. Vultures travelled longer distances in summer (118.2 ± 66.3 km) and spring (87.5±62.8 km) than in autumn (46.4±44.8 km) and winter (37.2±39.7 km) *(Table 1)*.

Discussion

In our study, we used spatial data from 13 Griffon Vultures to determine the foraging home range size of the population inhabiting the trans-border Eastern Rhodope Mountain. We found that the core of the home range encompasses the species breeding sites along the Arda river valley in Bulgaria, the central feeding station and two small feeding stations, and the Boynik ridge. Along that ridge occur most of the vulture feedings on natural carcasses found in the field (Arkumarev *et al.* 2021a). The Griffon Vultures frequently visited also the central feeding station near the village of Dadia, which is managed by the Management Body of Dadia-Soufli-Lefkimi Forest National Park (DSLFNP). Vultures foraged also along the Filiouri river and the villages of Esochi and Ragada in Greece where they also frequently find carcasses (Arkumarev *et al*. 2021a). The Kompsatos river valley, northeast from Komothini, was mostly visited by the vultures from spring to autumn. It is a mountainous area with rugged terrain where high numbers of sheep and goats are raised. Three small supplementary feeding stations provide additional food to vultures there since 2019. However, in winter most of the livestock is moved to the lowlands which can explain the exclusion of this area from the vulture's foraging range during this period. The areas near the country border are used by the vultures mostly to move between the main foraging areas in Bulgaria and Greece. Vultures rarely feed in this border area and mostly fly through (Arkumarev *et al*. 2021a). In the east, vultures follow Byala reka river valley and cross the border over the lower parts of Maglenik ridge to reach the central feeding station in DSLFNP. The same area is used as a main movement corridor by the Cinereous Vultures *(Aegypius monachus)* breeding in DSLFNP but foraging also in Bulgaria (Noidou & Vasilakis 2011, Arkumarev *et al.* 2020). Vultures also use the thermal updrafts over the ridges Irantepe and Maglenik to gain height and glide towards the main foraging areas in Greece along the Filiouri river valley. Less frequently, vultures follow the Varbitsa river valley and cross the border over Gyumyurdzhinski Snezhnik ridge to reach the foraging areas along the Kompsatos river valley in Greece. The foraging home range of the species encompasses mostly low mountainous areas with high numbers of livestock where the main husbandry practices are extensive grazing or semi-intensive grazing. The population in the Eastern Rhodopes feeds mostly on livestock carcasses found in the field (Arkumarev *et al.* 2021a, 2021b).

The size of the home range in our study is similar to the figures reported by Peshev *et al.* (2021) derived from GPS tracking of exogenous vultures (reintroduced and wild immatures) which have visited the Eastern Rhodopes. We consider that as a result of the social and gregarious lifestyle of the species the exogenous birds which arrive in the area are foraging and roosting together with the local groups of vultures, hence using the same areas. Looking at a broader scale, we found considerable variations in the home range estimations and daily travelled distances among the different populations on the Balkans, in Italy, France, Spain and Israel (Bahat & Kaplan 1995, Xirouchakis & Andreou 2009, García-Ripolles *et al.* 2011, Monsarrat *et al.* 2013, Genero *et al.* 2020, Hribsek *et al.* 2021, Peshev *et al.* 2021, Xirouchakis *et al.* 2021). These differences could be a result of different tracking methods and intensity, analytical approach, age and season variations. Despite that, it might also reflect the differences in the availability and fragmentation of suitable foraging habitats, presence of supplementary feeding stations and availability of natural food in the inhabited areas. The foraging home ranges of the Cape Vultures *(Gyps coprotheres)* and White-backed Vultures *(Gyps africanus)* in Africa are over 5 times larger than those of the Griffon Vultures in Europe (Phipps *et al.* 2013, Kane *et al.* 2016). Furthermore, the White-backed Vultures and the Lappet-faced Vultures *(Torgos tracheliotus)* travel longer daily distances and have larger daily displacement than the vultures in Europe (Spiegel *et al.* 2013b). Tucker *et al.* (2019) reported that birds travel much longer distances in areas with homogenous environments e.g. in Africa. The patchy, fragmented habitats and the availability of supplementary feeding stations in Europe might play an important role in shaping the foraging range of vultures.

We found high seasonal variation in the size of the home range and the daily distances travelled by the vultures. In spring and summer vultures forage over larger areas. The favorable weather conditions in terms of daily temperatures and formation of thermal updrafts allow vultures to travel far from the roosting and breeding cliffs. Previous study on the same population revealed that the daily temperatures, precipitation and wind speed are the main factors influencing vulture's foraging behavior and the probability to find food (Arkumarev *et al.* 2021a). During that period some non-adult vultures were undertaking long distance travels reaching other colonies on the Balkans. One individual visited the reintroduction site near Sliven in the Balkan Mountain. Another individual made a trip to Serbia and then to Kresna gorge where supplementary feeding station operates and a breeding colony was established as result of a reintroduction program (Peshev *et al.* 2018). In summer, some non-adults visited also the area near Drama and the Nestos river gorge west of Xanthi, Greece where the breeding colony has vanished but recently showed signs of recovery (Dobrev *et al.* 2021). These foraging trips of the non-adult vultures show the connectivity of the different Griffon Vulture populations on the Balkans, which are well documented also in other studies (Peshev *et al.* 2021). However, the adult Griffon Vultures we tracked did not undertake any long trips outside the main foraging and breeding areas in the Eastern Rhodopes. Immature vultures in other species are known to have larger home ranges due to their exploratory behavior and lack of attachment to breeding sites (Yamac & Bilgin, 2012, Kruger *et al.* 2014, Lopez-Lopez *et al.* 2014). However, we did not find significant difference in the home range size between the immature and adults Griffon Vultures in the Eastern Rhodopes. Similar results were reported for the Grands Causses in France where the increase of the population was followed also by increase of the number of supplementary feeding station (Monsarrat *et al.* 2013). Thus, the authors suggest that when the food availability in the area is high, the intraspecific competition is relatively low, which presumably decreases the need for the young vultures to forage over larger areas than adults. Our results are in line with this hypothesis considering that the availability of food, both natural and provided at supplementary feeding stations, in the Eastern Rhodopes currently exceeds the needs of the population (Arkumarev *et al.* 2021a). In winter, when the breeding season starts, the adult Griffon Vultures travelled shorter daily distances. In that time of the year the adults prepare the nests for the breeding, attend more time at the nest and start the incubation (Xirouchakis 2010). The immature vultures travelled slightly longer distances probably because they are not attached to a particular site and invest more time and efforts in foraging. In winter, the Griffon Vultures increase their reliance on the food provided at the supplementary feeding stations near the breeding cliffs (Arkumarev *et al.* 2021a). The unfavorable flight conditions and the decreased amount of natural carcasses in the landscape turn the feeding stations into preferred source of food (Arkumarev *et al.* 2021a). The higher attendance at the feeding stations probably increases the intraspecific competition. As adults are dominant during feeding, the immature birds are probably forced to search for additional sources of food, hence to travel longer distances. In spring and summer, Griffon Vultures travelled long daily distances as a result of the improving weather condition. In addition, the adults raise their chicks in that period and have to increase the foraging time and efficiency to find enough food for themselves and the growing hatchlings (Xirouchakis & Mylonas 2007).

Implications for conservation

Our study defined the foraging areas of the Griffon Vulture population in the trans-border Eastern Rhodope Mountain. It may serve as a baseline for planning and applying direct conservation measures to mitigate the threats and hence to increase the survival of the individuals of this increasing population. The construction and operation of wind farms is among the main threats for the vulture species and other soaring birds. The Greek part of Thrace, which falls within the Griffon Vulture home range, is designated as a priority area for development of wind farms (Kafetzis *et al.* 2017). Hundreds of wind turbines have been already erected in the area and proposals for the construction of new wind farms are underway. Systematic field studies have confirmed that the wind farms cause mortality of Griffon, Cinereous Vultures and many other birds of prey species (Carcamo *et al.* 2011, Doutau *et al.* 2011, author's unpubl. data). A comprehensive collision risk model suggested that 5 – 11% of Thrace's Cinereous Vulture population may collide annually with the wind turbines in the area (Vasilakis *et al.* 2016). Proposals for construction of wind farms have also been made in the Bulgarian part of the mountain. Here we provide valuable information for the movement patterns and important foraging areas of the Griffon Vulture population in the Eastern Rhodopes. We urge the policy makers to consider this and other relevant studies when planning the development of wind farms in the area to minimize the collision risk and avoid vulture mortality incidents.

Acknowledgements

This research was financed by the National program "Young scientists and Postdoctoral candidates" funded by the Bulgarian Ministry of Education and Science. The fieldwork and data collection were conducted in the frame of the LIFE project "Conservation of Black and Griffon Vultures in the cross-border Rhodope Mountains" (LIFE14 NAT/NL/000901) funded by the European Union and supported by Rewilding Europe, Segre Foundation and WWF-Greece. We would like to express our gratitude to Vera Alekseeva, Nikolay Terziev, Hristo Hristov, Desislava Kostadinova and Sylvia Dyulgerova for assisting in the vulture trapping and tagging.

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