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First description of movement and ranging behavior of the Griffon vulture (*Gyps fulvus*) from Serbia using GPS satellite tracking

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Abstract: Understanding the movement pattern and ranging behavior of the Griffon vulture population in Serbia is of great importance for prioritizing conservation action. In 2011, an immature vulture was the first bird to be equipped with a satellite transmitter in Serbia. Our study aims to define the vulture's foraging areas, home ranges, core and basic areas, and to investigate movement patterns across different years and seasons by analyzing satellite telemetry data. We tracked the movements of the vulture for over three years and obtained satellite tracking data for 34 bird-months (1976 GPS fixes) between October 2011 and July 2014. We determined that the overall foraging area of the vulture across the entire study period was 11654.34 km^2. The overall area used by the vulture was larger during spring and summer than during winter periods. Combined ranges across all years identified one basic area and its associated core area around the Uvac colony and nearby feeding site; we identified three core areas in its proximity. This study showed that areas of traditional stock-raising practices are important vulture foraging areas and that supplementary feeding sites have a vital role. Our maps can be used for future planning of vulture conservation measures.

Keywords: Griffon vulture *Gyps fulvus*; necrophagous species; ranging behavior; seasonal movements; conservation

INTRODUCTION

The Griffon vulture *Gyps fulvus*, an Old World vulture also known as the Eurasian griffon, is a cliff-nesting vulture species, characterized by a long lifespan, delayed maturity and low reproductive rate [1,2]. This obligate scavenger species is specialized in feeding almost exclusively on the carcasses of medium- and large-sized ungulates [3]. The species is found from Central Asia, India, the Middle East, Turkey, the Crimean Peninsula, the Caucasus, formerly North Africa, in Europe across the Mediterranean, including Sardinia, Crete, Cyprus, Mallorca, and the Kvarner Archipelago and the Iberian Peninsula in the west [4]. The Mediterranean basin is the core range of the species in Europe [5-7]. The species is globally assessed as of "Least Concern"[8], although some local populations are under higher risk and they are still in decline in many parts of southeastern Europe (the Balkans and Caucasus region), the Middle East and North Africa [7-10]. Conservation actions have contributed to the species recovery and populations have significantly increased in Europe [4], with more than 90% of the European population found in Spain [11]; however, populations on the Balkan Peninsula still show negative trends. Thus, it has already disappeared from several Balkan countries, including Albania, Bosnia and Herzegovina and Montenegro, while in others, such as continental Greece and North Macedonia, its populations are small and threatened. Stable populations can only be found in Croatia, the island of Crete, in recent years in Bulgaria and in Serbia [12].

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In the Balkan region, the species mainly persists in areas supported by supplementary feeding [13,14]. Currently, its population in Serbia is increasing [15]. However, this is only a fraction of the population that once inhabited Serbia. Several factors have contributed to its decline in Serbia, of which the most important were food shortage and the use of poisons during the 20th century [13,16]. During the 1990s, it faced extinction, with only ten breeding pairs remaining in 1992 [16].

Since the Griffon vulture depends on carrion, it has a vast foraging range [2,17,18]. It is known to travel extensively while foraging to find sparsely distributed food resources [9]. During foraging, birds fly over a wide range of open areas, from lowlands, steppes and semi-deserts to mountain slopes and plateaus [1]. The species is described as a partial migrant whose juveniles and sub-adults disperse from breeding areas and perform long-distance flights for foraging [2,19-22], in contrast to adult birds, which are largely sedentary [1,23-25]. Data collected from traditional ringing and radio-tracking studies confirmed that the range of juveniles is extensive [2,19,20,24-28].

Satellite telemetry has proved to be a highly effective method for investigating the movement ecology of different raptor species, including vultures [21,29-31]. It has provided assessments of home ranges and movements throughout the species distribution range, with studies conducted in the Caucasus [21], Spain [2] and Bulgaria [32]. GPS tracking provides precise data on the home range, dispersal and migration of the birds. It allows for the identification of the most frequently used foraging areas, as well as the detection of previously unknown roosting and breeding sites [32]. Information on the ranging behavior and spatial parameters is important for the long-term conservation of vulture species [2].

The spatial ecology of the Griffon vulture in Serbia is known only from the data collected from sightings of wing-tagged birds that showed that the birds were from Serbia, especially juveniles, with an extensive range [33]; however, detailed knowledge of the ranging behavior and home range of the Griffon vulture in Serbia is scarce. This paper presents data from a three-year-long Platform Transmitter Terminal (PTT) satellite-tracking of one immature Griffon vulture from the Uvac colony in Serbia. The aims of the study were to define the home-range, core and basic areas and patterns of seasonal movements, and to identify and characterize the changes in the foraging area across different seasons. Furthermore, we identified important feeding grounds and sites visited by the vulture that could prioritize future conservation actions.

MATERIALS AND METHODS

Ethics Statement

All precautions and necessary care were taken to reduce potential discomfort or harm to the bird. The handling time was kept to a minimum to reduce stress of the bird. The weight of the transmitters and the method of fitting the device were carried out according to standard protocols and recommendations. A permit for equipping the vulture with the satellite transmitter, marking and taking DNA samples was provided by the Ministry of Environmental Protection and Spatial Planning of the Republic of Serbia (2009-2011).

Study area

The study area on the Balkan Peninsula is characterized by a moderate continental climate. This part of western Serbia is mountainous with peaks averaging around 1000 m, and with the highest over 1600 m a.s.l. A mountain climate is present at altitudes above 1000 m, but in canyons the climate is slightly altered by elements of sub-Mediterranean climate. The average annual precipitation ranges between 800-1100 mm, with more than 50% during October-March. The average duration of the snow cover in the lowlands is 50 days, and in the mountains more than 90 days [34,35]. An overview of mean, minimum and maximum temperatures, the amount of precipitation, amount of snow and number of days with snow cover and rain is given in the Supplementary Table S1.

There are four active Griffon vulture colonies in Serbia (Fig. 1), all located in limestone gorges on steep cliffs in the mountainous parts of western and southwestern Serbia [13,15]. The Trešnjica colony is situated in western Serbia, located in the Trešnjica

Fig. 1. Active and former colonies of the Griffon vulture and supplementary feeding sites in Serbia.

River Gorge, while other three colonies are situated in southwestern Serbia. The Trešnjica colony is located 83 km north of the Uvac colony [15,34]. The Uvac and the Radoinja colonies are located in the Uvac River Gorge, 15 km apart, and the Mileševka colony is located in the Mileševka River Gorge, 10 km south of the Uvac colony. The Uvac colony (43°25'07"N, 19°55'39"E) extends over two artificial lakes: Sjenica (972 m a.s.l.) and Zlatar (876 m a.s.l.) in the Uvac River Gorge, and is the largest colony of this species in Serbia, with a population of up to 100 breeding pairs [15]. There are three active feeding stations at the Trešnjica colony, at the Uvac colony (the biggest one) and at the Mileševka colony. All three are in proximity of cliffs with nests [15].

Equipment and satellite tracking

One immature Griffon vulture from the Uvac colony was captured in October 2011 and fitted with an Argos 65 g solar-powered GPS/PTT transmitter produced by North-Star (King George, Virginia, USA). The bird was previously marked as a nestling at the Uvac colony in June 2009, with a wing tag and with metal and PVC rings. Besides morphometric data, feather samples were taken, and a molecular method of sex determination was carried out. It was determined to be a male bird, which we called Konstantin. It was captured again on October 20, 2011, as a 2-year-old immature bird (i.e., in its third calendar year (CY)) and was fitted with a satellite transmitter. The transmitter was fixed to the bird's back using a Teflon® harness sewn with a cotton ribbon, designed to ensure that the harness would fall from the bird at the end of the tag's life. The mass of the equipment, including the harness, metal ring and tag, was less than 3% of the bird's body mass, which was 8.6 kg, and corresponds to the recommended limits [2,36].

Argos/GPS transmitters contain a GPS receiver that records locations at preset intervals from the GPS satellite network. The data were then relayed to the ground-based Argos processing centers [37]. We used only GPS fixes (locational information that the GPS system provides for a specific point). The GPS tracker was set to acquire five location fixes per day, roughly every 2 h from 09:00-17:00, and actively collected daily data during the three-year period from late October 2011 to July 2014. All data points were grouped based on the year, month and season. Seasons were defined as "Spring" (March 20-June 20), "Summer" (June 21-September 22), "Autumn" (September 23-December 20) and "Winter" (December 21-March 19). We calculated the foraging range using the minimum convex polygon (MCP), encompassing all location fixes for a specific season/year. Since the MCP can be greatly influenced by a single outlying data point, we also used the kernel density (KD) approach to calculate the home range (95% isopleths), core area (75% isopleths) and basic area (50% isopleths) [32,36,38,39]. All parameters were calculated separately for each year, the season of each year, and for all fixes combined across all years. Additionally, we partitioned the annual cycle into a non-breeding season (NBS) (August-January) and a breeding season (BS) (February-July). All analyses were performed using the Geospatial Modelling Environment (v0.7.3.0) software (in dependencies with ArcGIS 10.2.2 [40] and R package "ks" v. 1.11.7 [41]) and graphically presented using QGIS (v3.4.12) [42]. Data on land use (pasture coverage) were obtained from the Copernicus

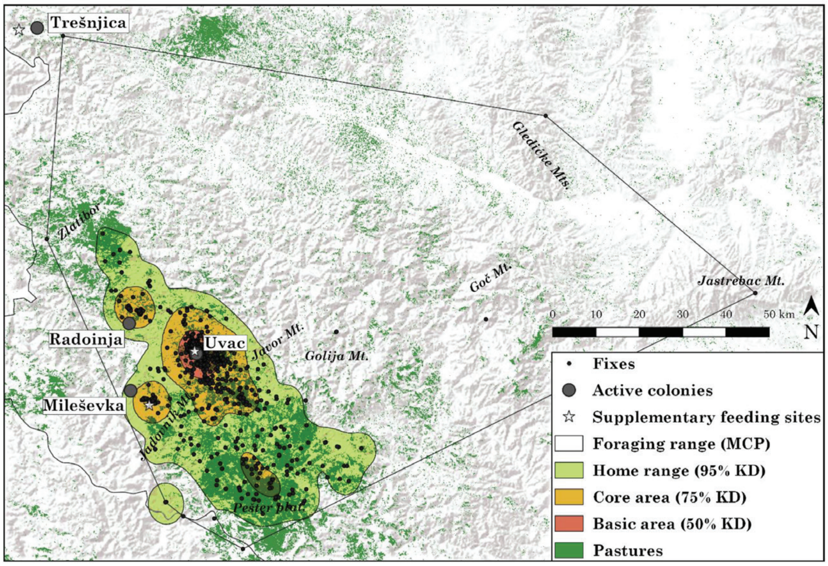

Fig. 2. Total (inter-annual) home range, core and basic areas of the Griffon vulture with marked active colonies, supplementary feeding sites, pasture areas and important geographical features.

raster dataset (100 m resolution) [43]. The Wilcoxon signed-rank test was used to analyze differences in foraging and home ranges between 2012 and 2013 (paired by season) as those were the only two years with all seasons included. Daily movement distances were calculated as the total distance between multiple location fixes of a single day. Differences in median daily distances between years (paired by season or home range estimates for 2012 and 2013 only) were analyzed with the Wilcoxon signed-rank test. Analyses were performed in R software (v3.6.3) [44]. In this study, we considered two age classes: immature (≤5 CYs) and adult (≥6 CYs) [45].

RESULTS

Satellite tracking data were obtained for 34 bird-months (1976 GPS fixes) between October 2011 and July 2014, of which 27 months of movements were considered immature (79.4%) and seven months of movements, adult (20.6%). We removed unreliable fixes from the data sets. A total of 45 erroneous data points that were not consistent with the bird's movements in terms of distance covered and time elapsed between consecutive fixes or false fixes based on impossible coordinates were excluded. Most of the location fixes (99.59%) had an accuracy of <100 m, with only eight data points with lower or unknown accuracy and these points were additionally checked for validity as defined previously and were all retained in the final data set. There were gaps in the data collected due to suboptimal performance of the Argos/GPS transmitter, probably caused by unfavorable weather conditions such as heavy cloud cover, or the geomorphological specificity of the terrain which incapacitated the solar-powered battery required to activate the device on certain days. Thus, we experienced location fixes on 695 days instead of the 1015 days covered by the study period. The total number of gaps was 61, with an average gap duration of 5.1 days, and minimal and maximal gap durations of 1 and 85 days, respectively. Similarly, not all five fixes per day were possible for the same reasons mentioned above, so the majority of the days had two, three or four fixes (24%, 30% and 28%, respectively) while 15.5% and 2.5% of days had one or five fixes, respectively.

Combined ranges across all years identified one basic area and its associated core area around the Uvac colony and a nearby feeding site, but also identified three other core areas near the Radoinja colony, the Mileševka colony and its feeding site, as well as the Pešter plateau (Fig. 2). Land use in the combined home range across all years consisted mostly of pastures (1306.98 km^2 or 62.2%). The combined foraging range was around 152 times greater than the basic area, 19.5 times greater than the core area and about 5.5 times greater than the home range. The northwesternmost point of these data points in 2012 is the area of the Trešnjica colony, while more eastern points are in the areas of Gledićke (2012), Goč (2013) and Jastrebac (2014) mountains in central Serbia (Fig. 2).

We found some differences in estimates of ranges and areas between years (Table 1) (Fig. 3). All estimated parameters in 2011 were extremely small and based only on 33 fixes and therefore hard to interpret; for this reason, they were not considered. In the other three years, the foraging range (MCP) was largest in 2012 and smallest in 2013, while the basic area (50%

Table 1. Home range estimates for the Griffon vulture across years.

Year	Number of analyzed fixes	Basic area (50% KD isopleths, km^2)	Core area (75% KD isopleths, km^2)	Home range (95% KD isopleths, km^2)	Foraging range (MCP, km^2)
2011	33	1.86	5.98	21.04	17.19
2012	663	67.50	211.76	1038.75	7356.42
2013	739	85.26	287.05	1578.94	3832.70
2014	496	43.18	112.01	549.37	4177.75
All years	1931	76.56	590.85	2102.44	11654.34

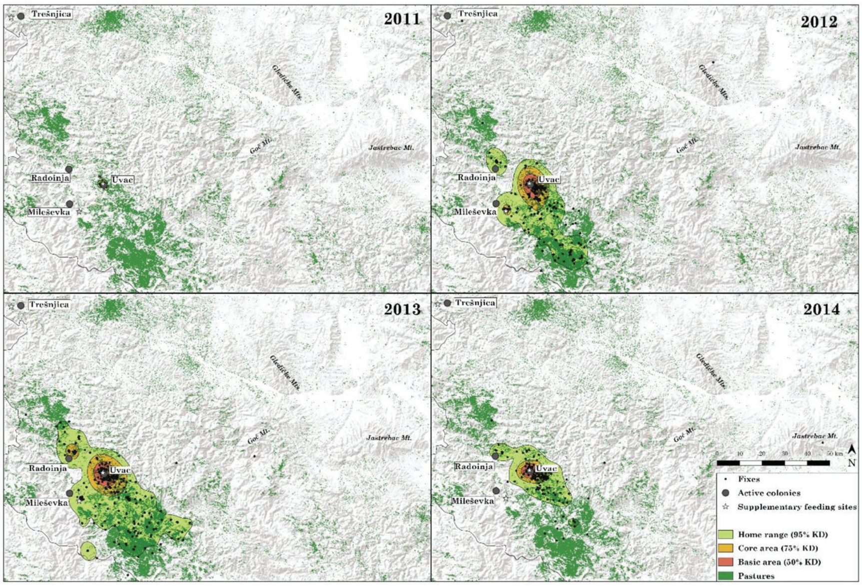

Fig. 3. Home range, core and basic area estimate for the Griffon vulture across years.

KD), core area (75% KD) and home range (95% KD) were largest in 2013 and smallest in 2014 (Table 1). Depending on the year, the foraging range was about 45-109 times greater than the basic area, 13-37 times greater than the core area and 2.5-7.5 times greater than the home range. Examination of data points on the map showed that these striking differences in the estimated area were due to several isolated and distant fixes, especially in 2012 and 2014 (Fig. 3).

The seasonal dynamics of the estimated ranges and areas also exhibited some variations (Table 2) (Fig. 4). The autumn of 2011 and summer of 2014 did not have fixes across whole periods so the estimated areas are underestimated and we therefore did not take them into consideration. The smallest foraging range and the smallest basic area, core area and home range were recorded during the winter of 2011/2012 and autumn of 2013. During the spring and summer, all parameters were much larger. The largest foraging range was in the spring of 2014, followed by the spring and summer of 2012, and the spring and summer of 2013. The home range, core area and basic area were largest in the summer and spring of 2013, followed by the summer and autumn of 2012

Table 2. Home range estimates for the Griffon vulture across seasons.

Year	Number of analyzed fixes	Basic area (50% KD isopleths, km^2)	Core area (75% KD isopleths, km^2)	Home range (95% KD isopleths, km^2)	Foraging range (MCP, km^2)
Autumn 2011	33	1.86	5.98	21.04	17.19
Winter 2011/12	93	9.42	20.49	67.99	107.37
Spring 2012	227	88.07	250.22	800.05	2979.13
Summer 2012	250	105.33	359.53	1470.77	2403.86
Autumn 2012	89	112.65	299.11	815.75	554.6
Winter 2012/13	63	88.13	215.57	727.84	919.88
Spring 2013	247	179.21	551.19	1804.25	1734.37
Summer 2013	308	118.79	460.12	1668.83	1912.63
Autumn 2013	119	12.05	28.19	74.49	132.54
Winter 2013/14	156	30.32	76.14	298.15	387.47
Spring 2014	259	68.03	198.03	676.36	4034.86
Summer 2014	87	31.36	101.16	319.52	258.11

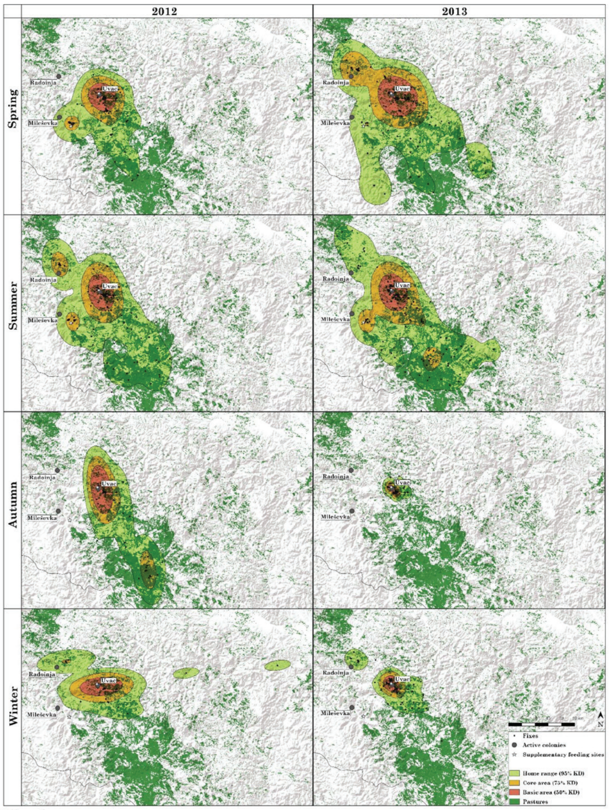

Fig. 4. Home range, core and basic area estimate for the Griffon vulture across seasons of 2012 and 2013.

(Table 2). Again, the observed discrepancies between the foraging range and other estimated parameters arose from several isolated and distant data points (Fig. 4). The Wilcoxon signed-rank test did not reveal significant differences between years in any of the analyzed parameters (MCP: Z=1.13, P=0.125; 50% KD: Z=0.16, P=0.875; 75% KD: Z=0.00, P=1.000; 95% KD: Z=0.00, P=1.000).

The difference in size of foraging areas between the breeding season period (BS) and the non-breeding season period (NBS) was not significant (Z=-0.489, P=0.625). For the BS, the MCP 100% was 7886.82 km^2, home range (95% KD) 1075.36 km^2, core area (75% KD) 198.3 km^2 and basic area (50% KD) 66.73 km^2; for the NBS, the MCP 100% was 4063.12 km^2, home range (95% KD) 1143.89 km^2, core area (75% KD) 152.64 km^2 and basic area (50% KD) 52.61 km^2.

We only had enough data points for the years 2012 and 2013 to analyze the daily movements meaningfully. The median daily distances in 2012 and 2013 were 2.9 km (a range of 0-122.4 km) and 6.6 km (a range of 0-80.3 km). The maximum distance covered in a particular day was 122.4 km in 2012, and 80.3 km in 2013. The median daily distances varied across seasons (Table 3) with the largest values observed during the summer of 2013 but without statistically significant differences between years (Z=-1.15, P=0.250). The median daily distance within the different estimated areas varied between years, with somewhat longer but not significantly different distances in 2013 (Z=-1.15, P=0.250) (Table 3).

Table 3. The median daily distances traversed by the Griffon vulture across seasons and home range estimates.

Year	Season	Number of analyzed days	Age of the vulture in calendar years	Median daily distance (min-max), km
2012	winter	34	4	1.1 (0–46.3)
	spring	70	4	2.7 (0–122.4)
	summer	94	4	6.1 (0–86.1)
	autumn	11	4	4.1 (0–44.0)
2013	winter	21	5	2.3 (0–34.0)
	spring	75	5	8.6 (0–80.3)
	summer	85	5	17.9 (0–77.0)
	autumn	34	5	3.4 (0.4–23.4)
2012	50% KD	188		2.8 (0–8.5)
	75% KD	196		2.8 (0–26.8)
	95% KD	205		3.1 (0–80.0)
2013	50% KD	188		4.5 (0–18.2)
	75% KD	208		5.7 (0–31.1)
	95% KD	214		6.4 (0–80.3)

DISCUSSION

Herein we present the first detailed insight into the ranging behavior and spatial parameters of the Griffon vulture in Serbia by tracking one individual fitted with a satellite transmitter for almost three years. The immature vulture was equipped with a satellite transmitter in its third CY and tracked until it reached adult age and started breeding in its sixth CY. Based on the collected data from this one individual, we were able to identify its foraging range, home range, core and basic areas, and to analyze its movement patterns, which will serve as a starting point for future ranging behavior research of this species in Serbia.

The bird ranged mostly and extensively over the Uvac Gorge area and the surrounding mountains

Zlatar, Javor, Golija, over Jadovnik and Mileševka Gorge, as well as over the Pešter Plateau and Zlatibor area. Combined ranges across all years identified one basic area and its associated core area around the Uvac colony and nearby feeding site. This basic area near the supplementary feeding site at the Uvac colony (with a distance of less than three km) also includes common roosting sites of Griffon vultures, and in its proximity was also the birth nest of this particular bird, which it often visited. We identified three additional core areas near the Mileševka colony and feeding site, the Radoinja colony and the Pešter plateau; this is in concordance with findings that vulture feeding sites and the most commonly used roosting sites are usually within 15 km of each other, and that the covered area is in the radius of 14-15 km around the main colony [2,27,28,32].

We found inconsistent differences in estimates of the foraging and home ranges between years. The foraging range was largest in 2012 and smallest in 2013. This can partly be explained by the presence of several distant points in 2012 and 2014 that resulted in a large foraging range, which increased bias in overestimating the area surface [46]. A more reliable estimation of important areas was obtained from the basic area (50% KD), core area (75% KD) and home range (95% KD), which yielded a consistent pattern of larger areas in 2013 in comparison to 2012 or 2014. However, it should be noted that data points for 2014 were gathered only for the spring and partly for the summer of 2014, not for the whole year, so those combined home ranges for that year were probably underestimated.

Although 2014 had fewer data points, it was also the vulture's sixth CY when it reached sexual maturity and started nesting, as confirmed by visual observation. This could potentially contribute to smaller home ranges in 2014, as it is known that some species such as the Cape vulture *Gyps coprotheres*, have smaller ranges during breeding seasons because they have dependent offspring [9]. Also, this is consistent with the findings of [47], who showed that adult Griffon vultures stayed close to colonies and regularly visited feeding sites stocked with food.

The main foraging area of our bird was the local area nearby the Uvac Gorge and over neighboring mountains Zlatar, Javor, Golija, Jadovnik, and very frequently over the area of the Pešter Plateau and Zlatibor area, the most significant livestock region in western Serbia. These areas are centers of traditional and contemporary livestock raising and pasturing in Serbia [48]. Similar foraging behavior was found in [2,49], where vultures ranged mainly in areas where similar traditional stock raising and pasturing practices are common. Our results showed that the bird relied on and regularly visited supplementary feeding sites, especially the one at the Uvac colony. The northwesternmost point in 2012 was the area of the Trešnjica colony, the location of another supplementary feeding site about 83 km north of the Uvac colony. Based on scientific monitoring reports and previous observations of birds with wing-tags, it is known that the Griffon vulture frequently travels between these two feeding sites. Other more easterly points are set in the areas of Gledićke (2012), Goč (2013) and Jastrebac (2014) mountains in central Serbia, where it is likely to find either naturally occurring food and/or thermals.

It was found that especially during unfavorable periods, vultures regularly search for stocked, predictable food resources, probably due to poor flight conditions or low natural food availability [45]. Over the last decades, there was a steady decline in traditional stock-raising and pasturing practices (nomadic farming was interrupted and changes in livestock husbandry occurred), which resulted in a reduced availability of naturally occurring food for vultures, especially during the winter period, when it is most needed [48].

The winter period also coincides with the beginning of the breeding season [50,51] and is the most critical period for vultures because the availability of food determines how many birds will start breeding [34]. The prolongation of snow cover affects flight conditions and increases travel cost due to lack of thermals requiring more energetic flight, which results in a reduced foraging area [52,53], and it is almost impossible for vultures to find carcasses under snow cover [34]. Additional food contributes to increased survival, especially of juvenile birds as previous studies suggested [50,51]. Supplementary feeding thus proved to be a crucial resource, especially in the winter period [34].

Foraging and home ranges of the Griffon vultures are expected to vary between different seasons, as shown in [32], with travel distance in the spring-summer period being about three times longer than during the autumn-winter period. Our study showed similar findings with the larger foraging ranges in spring and summer during all study periods. It is well known that unfavorable weather conditions affect flight performance during autumn, and especially in winter, the consequence of which is the reduction of foraging range [52-54]. This was especially evident in the winter of 2011/2012 when the basic, core, home and foraging ranges were smallest due to bad weather conditions during that winter. According to the data obtained from the Republic Hydrometeorological Institute of Serbia, in that particular area there were more days under snow cover during the winter 2011/2012 than the following years. Smaller basic, core, home and foraging ranges were also noticeable during the autumn of 2013 and winter of 2013/2014. In Italy, the spring core area (equivalent to the basic area in our study) was significantly smaller than in summer [49], while in Croatia the largest core area was recorded during the autumn, but no significant difference between seasons was detected [49]. These results also suggest that vultures tended to stay more within their respective areas in autumn than in spring and/or summer when flight conditions are less favorable [49,54]. Our results are in accordance with studies from Bulgaria [32] and France [45], as we also observed smaller foraging ranges, home ranges and basic areas during winter and autumn. The overall MCP area in our study was similar to those that were reported in Bulgaria [32], while the basic area (50% KD) and the home range area (95% KD) were similar to those ranges from Bulgaria [32] and Spain [2].

We also found no significant differences in the sizes of the foraging range, home, core and basic areas between the breeding and non-breeding season, although ranges for the breeding period were slightly larger. However, the power of our data for such a comparison was limited because we had data for only one bird, and these data included one incomplete season for the adult period and two seasons for the immature period of this Griffon vulture. In the study using an integrated radio-tracking methodology from Greece, the overall area used by Cinereus vultures *Aegypius monachus*, was bigger in the NBS than in the BS, with no statistically significant differences between adults and immatures; however, adult individuals had home ranges and core areas larger than those of juveniles [55].

The movement of this immature bird was in contrast to the behavior expected for juveniles and immature *Gyps* vultures. From the data obtained after the re-sighting of birds with wing-tags, it was concluded that immature Griffon vultures can travel long distances. Thus, birds from Serbia were observed in the neighboring countries of Bosnia and Herzegovina, North Macedonia, Greece, Bulgaria, Montenegro, Albania, Romania, Hungary and Croatia, and also in very distant locations such as Israel, Turkey, Iraq, Saudi Arabia, France, Estonia, Poland, Ukraine and Russia [33]. From 1993-2016, 243 Griffon vultures were marked mostly at the Uvac colony, of which 227 were nestlings. We collected 803 findings of our tagged birds from abroad and about 80% of all sightings were of immature birds (3-5 CY old). It was estimated that between 45% and 90% of juveniles left native colonies and migrated. After a period of wandering, when they reached sexual maturity (≥6 CY), most of the birds returned to their native colonies [33]. Most re-sighting data of birds with wing-tags we collected from Bulgaria and Greece, where immature Griffon vultures from Serbia are often observed, especially at the feeding sites [33]. The Griffon vultures GPS/GPRS tracking data on the Balkan Peninsula revealed that vultures visit regions where colonies and feeding sites exist [56]. The map of vulture distribution in the Balkans revealed that besides western Serbia, vulture areas exist in Bulgaria, Greece and North Macedonia [56]. These areas are Vrachanski Balkan in western Bulgaria, Sinite Kamani and Kotel Mountain in the eastern part of the Balkan mountains, the Kresna Gorge and Pirin National Park in southwestern Bulgaria, eastern Rhodopes Studen Kladenets and Madjarovo on the Bulgarian side, Kompsatos Gorge and Dadia on the Greek side, further in northern Greece Kaymakchalan, in southwestern Greece Tzumerka, Central Greek Mountains, Akarnanika and Boumistos Mountains, Kleisura and Missolonghi and in North Macedonia Mariovo, Vitachevo feeding site and Chatino colony and Demir Kapia [56].

The maximum distance covered on a single day was 122.4 km in 2012 and 80.3 km in 2013, similar to distances reported in a study from Bulgaria [32] but greater than those reported in Spain [2]. Previously it was found that the vultures' average maximum distance traveled in a single day was 207.97±17.44 km [57], which confirms their capability to search for food across vast areas. Further, larger foraging ranges are expected in immature *Gyps* vultures than in adults [9]. The median distances in our study suggest that the bird mostly made short-distance flights. The biggest median daily distance that our vulture travelled was 17.9 km during the summer of 2013. The median daily distances in our study were overall smaller, but still in the range of those reported in studies carried out in Bulgaria [32] and Spain [2]. Also, longer daily flight distances were performed during spring and summer.

While our study is based only on one bird, it still provides a first detailed insight into the spatial and seasonal movements of the Griffon vulture in Serbia. These results are important for further understanding of movement patterns and recognition of the commonly used foraging areas. The species' annual and seasonal movement ecology during the pre-breeding and breeding phase and knowledge about their migratory routes are fundamental for understanding and planning conservation actions [58]. Though limited, our study provides valuable information and could be used as a basis for new conservation and management strategies on a larger scale, such as new supplementary feeding sites, or to address various threats to the species (unsecured power lines, poisoning, construction of wind parks in nearby areas, low overflights of various aircraft above colonies, etc.). Ongoing research, based on the monitoring of several more birds with GPS satellite tracking, will provide additional information about ranging behavior at the population level, and this data could provide insight into the different threats that vultures face during foraging in mainly human-dominated landscapes, and identify activities that can have a long-term negative effect on the population. Finally, better insight into the usage of the foraging area, home and core ranges provides a better foundation for future planning of reintroduction programs to areas that the vultures once inhabited.

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Supplementary Material

The Supplementary Material is available at: http://www.serbiosoc.org.rs/NewUploads/Uploads/Hribsek%20et%20al_6045_Supplementary%20Material.pdf