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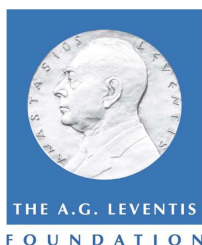
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Characterizing Eurasian black vulture's (*Aegypius monachus*) flight movement corridors in Thrace: a need for conservation on a landscape-level scale

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Abstract

As habitat degradation and fragmentation increase across vulture ranges in Thrace (NE Greece) due to large scale wind farm development plans, characterizing Eurasian black vulture's flight movement corridors for conservation finds new urgency. In this paper we use high accuracy time-specific location data and a continuous-time stochastic movement model (Brownian bridge movement model, BBMM) to describe and analyze vultures' daily foraging flight routes (DFFRs). The BBMM quantifies the probability of use along a DFFR by estimating a probability density or utilization distribution (UD). We first apply the model for each DFFR (232 cases) of each collared vulture (*n*= 6) and then we represent the flight movement corridors of each vulture by one UD. Next, we seek to characterize the network of flight movement corridors used by the entire sampled population, which we refer to as a *population-level flight movement corridor*. Our analysis clearly delineated where *flight movement corridors* occurred relative to proposed development and provided guidance for on-the-ground conservation efforts. Vulture *flight movement corridors* were characterized by a series of core areas where vultures spent most of their time, connected by movement corridors through which vultures moved quickly. Our analyses suggest that management strategies that differentiate between core areas and movement corridors might be appropriate. Because some corridor segments were used by more vultures than others, proportional level of use may provide a reasonable metric by which routes can be prioritized for conservation. Although, the 33% proportional level of use criterion that was applied in this paper is not the most conservative for the species, it resulted that 73% of the proposed wind turbine sites (1277) overlapped with the high conservation priority population-level flight movement corridors. Our Eurasian black vulture movement corridors might be of equal importance for other vulture species, like the Eurasian griffon vulture *Gyps fulvus*, that roams over the same area in larger numbers and has quite similar foraging behavior. The objective set by the Greek state to succeed installation of 480 typical WTs (930 MWe) in Wind Priority Area (WPA 1) can probably be achieved by sensitive siting of wind farms in only the very low use areas (<10%). In these last areas at least 474 wind turbines with a capacity exceeding 500 MW are planned to be constructed. These numbers correspond only to 27% of the investor demand for wind turbine installation and more than 52% of the planned capacity in the area by the Greek state.

Key words: Brownian bridge movement model (BBMM); global positioning system (GPS); foraging flight routes; movement corridors; Black Vulture, *Aegypius monachus*; wind farm development; utilization distribution (UD); Thrace, NE Greece.

INTRODUCTION

Habitat fragmentation is one of the major biodiversity conservation issues facing the world today (MacDonald 2003, Bennett 2003, Fahrig 2003). This fragmentation may be natural (caused by natural catastrophes) or human-induced (large scale wind farm development plans, highways or other) and may occur on many scales. However, when habitat fragmentation is discussed in conservation terms, it is generally regarded as referring to anthropogenic alterations on a landscape scale. To combat the negative consequences of anthropogenic habitat fragmentation, the conservation of biologically valuable land has been promoted as a way to ensure species viability. The concept of corridors as a conservation measure has been highly successful in attracting the interest of decision makers, land managers and the community and a variety of 'wildlife corridors', 'movement corridor' 'landscape linkages', 'dispersal corridors', 'green belts', 'greenways' and other forms of linking features have been proposed, included into conservation plans, or are now under active construction or management (Bennett 2003, Sawyer et al. 2009). McEuan (1993) defined a wildlife corridor as "a linear landscape element which serves as a linkage between historically connected habitats, and is meant to facilitate movement between these natural areas". Bennett (2003) argued that this first definition ignored other types of connecting habitats, such as stepping stones or habitat mosaics; other types of movements, such as daily foraging or migratory movements; and other ways that movements can facilitate continuity and connectivity in a landscape level. Bennett (2003) suggested that populations, communities and natural ecological processes are more likely to be maintained in landscapes that comprise an interconnected system of habitats, than in landscapes where natural habitats occur as dispersed ecologically-isolated fragments. He emphasized on 'connectivity' rather than 'corridors' and insisted that landscape patterns that promote connectivity for species, communities and ecological processes are a key element in nature conservation. However, corridors were recognized as one type of connecting habitats that along with other habitat configurations can enhance continuity and connectivity and this way serve conservation of biodiversity in general, and species in particular (MacDonald 2003, Bennett2003).

Vultures like most animals tend to occupy one or more certain areas (core areas) within their range with higher frequency than other areas and it is possible that their behaviour will differ in the core and outer areas of their range (Hodder et al. 1998, Vasilakis et al. 2008). The core areas are usually interconnected with the aforementioned movement corridors. Core areas and movement corridors can be of outmost importance for species survival and its management constitutes a great challenge for conservation practitioners and decision makers.

The Eurasian black vulture *Aegypius monachus*, although like other raptorial scavengers depends upon food resources that are unpredictable in space and time, and must travel extensively to forage successfully (Mundy 1982; Maretsky and Snyder 1992) exhibits central-place forager ranging behaviour (Carrete and Donàzar 2005) and tends to occupy certain areas within its range with higher frequency than other (Vasilakis et al. 2008). For this species these centers of high activity or use can represent important breeding, foraging and roosting grounds or include important surveillance sites but also areas where vultures gain kinetic energy for locomotion

(Vasilakis et al. 2008) where simply favorable conditions for deflection updrafts, thermals, orographic lifts, wave lifts or dynamic soaring prevail.

In this paper we use high accuracy time-specific movement data and a novel continuous-time stochastic movement model (Brownian bridge movement model, BBMM; Horne et al. 2007) to characterize Eurasian black vulture's flight movement corridors by describing and analyzing vultures' daily foraging flight routes (DFFRs). We attempt to: (1) identify the network of flight movement corridors for a sampled population, (2) identify corridor segments used as core areas vs. those used primarily for movement, and (3) prioritize corridors for conservation based upon their proportional levels of use (use radio raking movement data to validate the model output).

Study area

The study area (ca 8000 km^2) is located in Rhodope and Evros Prefecture (Thrace, NE Greece), it includes the Dadia-Lefkimi-Soufli Forest National Park (Dadia NP; 26°00′-26°19′N, 40°59′-41°15′E, Catsadorakis and Källander 2010) and part of south Bulgaria, and is part of the southeastern tip of the Rhodope mountain range, with altitudes between 10 and 1200 m. It is characterized by alternating small and large valleys, steep and shallow slopes, as well as an intricate hydrological network, and is covered at low altitudes by extensive oak and pine forests, and at high altitudes by beech and oak forests. Many other habitats, such as cultivated fields, pastures and rocky slopes, are present also in significant amount (Poirazidis et al. 2010). This same area is internationally acknowledged as of high ornithological interest, hosting habitats of European importance mainly for large birds of prey (Poirazidis et al. in press) and aquatic birds. The area is a biodiversity hotspot (Kati et al. 2004, Poirazidis et al. 2010) and has a long history of conservation research (Schindler et al. in press). The endangered and probably isolated population (Vasilakis et al. 2011) of Eurasian black vulture is of special importance and focus of conservation management efforts (Poirazidis et al. 2004, Skartsi et al. 2008, Vasilakis et al. 2008, Poulakakis et al, 2008). A large part of the above mention area has been declared as a Wind Priority Area (WPA 1) by the Greek state. 50% of the WPA 1 is covered by seven Natura 2000 sites, five of which constitute SPAs (Special Protection Areas) and two of them National Parks. Since 2003, 9 wind farms (WFs) with 163 wind turbines (WTs) have been installed and are currently in operation. This number is expected to increase drastically in order to fulfil the objective of 480 typical WTs (930 MWe) set by the Greek state. Thus a big concern has been raised about the possible impacts of this development on the avifauna of the area.

MATERIALS AND METHODS

Selection, capture, collaring of vultures and data collection

Vultures were trapped outside the breeding season (October – December 2007 and 2008), using a walk-in cage with a sliding-door (Elorriaga et al. 2004). An effort was made to select immature and sub-adult (Forsman 1999) individuals that were expected to forage in longer distances than juveniles and adults (Vasilakis et al. 2008). The vultures were aged with accuracy at hand (De La Puente and Elorriaga 2004),

measured and marked (Skartsi et al. 2003). In 2007 four GPS Plus[1] transmitters (155 gr) were attached to vultures as backpacks (Bögel 1994) but one of them did not worked properly and the second did not provided suitable data, consequently were excluded from analysis. These transmitters were programmed to collect one location every 1 h during the day light hours and one location during the night two days randomly selected per month. In 2008 four more Televilt Tellus GSM GPS transmitters (200 gr) were attached to vultures as backpacks. These transmitters were programmed to collect one location every 45 minutes during the day light hours and one location during the night every day. Additionally, these transmitters were programmed to collect locations two days (randomly selected) per month every 10 minutes during the day light hours and one location at night. In all cases the backpack/body weight ratio was less than the limit of 3% that is suggested for birds that migrate or depend greatly on flight (Kenward 2001).

Estimating daily foraging flight routes

We used the Brownian bridge movement model (BBMM; Horne et al. 2007) to estimate a utilization distribution (UD) for each individual daily foraging flight route (DFFR) collected from GPS-collared vulture. The BBMM requires (1) the sequence of time-specific location data, (2) the estimated error associated with the location data, and (3) grid-cell size for the output UD. We used a sequence of GPS locations (i.e., the DFFR path) that occurred every day. We defined the start of DFFR as locations occurring after the vulture departing from a known roosting place and crossing the border of the Dadia NP and the end of DFFR as locations occurring before vulture returned to a known roosting place in the Dadia NP and stay immobile. There were cases that the vulture departed from the Dadia NP and roosted over night out from it or the opposite. These cases were also analyzed considering as last location of the DFFR the one before the animal started to be immobile. Missing observations or fix-rate bias (Nielson et al. 2009) were not a concern, because 99% of our GPS fix attempts were successful. Nonetheless, we took precautions to ensure that occasional missing observations were accounted for by restricting the BBMM calculations to sequential locations. We used an estimated location error of 20 m because more than 98,5% of our GPS locations were three-dimensional (3-D) fixes, which typically have, 20 m error (Di Orio et al. 2003). We used a grid-cell size of 50 X 50 m that was intended to provide high-resolution mapping, while maintaining a reasonable processing time.

　　　　The BBMM is a continuous-time stochastic movement model, where the probability of being in an area is conditioned on the distance and elapsed time between successive locations, the location error, and an estimate of the animal's mobility, referred to as the ''Brownian motion variance'' (BMV; Horne et al. 2007). Assuming that odd-numbered locations are independent observations from Brownian bridges connecting even-numbered locations; the BMV can be estimated by maximizing the likelihood of observing the odd locations (Horne et al. 2007). The two assumptions associated with the BBMM are that location errors correspond to a bivariate normal distribution and that movement between successive locations is random. The assumption of normally distributed errors is appropriate for GPS telemetry, but the assumption of conditional random movement between successive

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[1] VECTRONIC Aerospace GmbH, http://www.vectronic-aerospace.com/html/gps_plus.html

locations may become less likely as time between locations increases (Horne et al. 2007). Given that our locations were only 1 h and 45 minutes apart, and Horne et al. (2007) successfully applied the BBMM to migratory data collected at 7-h intervals and as well as that Sawyer et al. (2009) successfully applied the BBMM to migratory data collected at 2.5 h intervals, we considered the assumption of conditional random movement to be reasonable. In addition to that, visual inspection of the DFFR with location 10 minutes apart (16 cases) reveal that consecutive interlocation distance covered under certain condition (e.g vulture gliding) were almost equal (Figure 2a) indicating that constant movement rate, a prerequisite for conditioned random walk (Horne et al. 2007), holds for the time interval contained within our location data. Furthermore, the location data with 10 minutes interlocation time interval (16 sampling days with 54 location) were used to estimate a UD for each individual DFFR and then re-sampled at time intervals of 40 minutes, and 1hour to evaluate the ability BBMM to deliver reliable UD as time between locations increases and consequently the assumption of conditional random movement between successive locations may become less likely. In the re-sampling posses we follow the DFFR definition (see above). Due to the fact that vultures spent considerable amount of time at specific points (e,g roosting sites, nests, surveillance points) before boost a foraging trip it was possible to regress the departure time and this way from a sampling day with 54 locations taken at 10 minutes to produce multiple sets of location data for the same DFFR with inter-location time interval of 1 h or 40 minutes. Further, on this sets of data the BBMM was applied and the model out put was compared with initial model prediction (Figure 2). We used the programmed by Sawyer et al. (2009) BBMM calculations in the R language for statistical computing (R Development Core Team 2007). Data were mapped using ArcGIS software (ESRI).

Estimating population-level flight migration corridors

Application of the BBMM resulted in a UD for each DFFR of each collared vulture. For vultures that had >1 DFFR (*n*=6 vultures), the cell values of all their UDs were summed and then their cumulative cell values were re-scaled to sum to 1, such that the flight movement corridors of each vulture to be represented by one UD. Next, the network of flight movement corridors used by the entire sampled population, which was referred as a *population-level flight movement corridor*, was characterized following this same re-scaling procedure with the UDs of all vultures. Analyzing the UD values from the affirmation *population-level flight movement corridor*, it was discovered that the distribution of values was very much skewed towards the Dadia NP, and some pixels over the vulture colony (roosting sites or nests sites from were the vultures started or ended a DFFR) appeared to have very high values. This happened because pixels over roosting sites or nests sites and the pixels around them were given by the model higher probability of use and because the procedure of summing the UD for each DFFR and then later the UD of the flight movement corridors of each vulture were further very much enlarged the pixel values of these areas. This finding reflected the facts that this species exhibits central-place forager ranging behaviour (Carrete and Donàzar 2005) and tends to occupy certain areas within its range with higher frequency than other (Vasilakis et al. 2008). Wanting to characterize the *population-level flight movement corridor* this artifact had to be removed and this was done first by applying a low pass neighbourhood filter based on focal functions with weighted kernel neighbourhoods, which smoothes the data by

reducing local variation and removing noise, and then by further excluding extreme values in a radius of 1 km around the nests or roosting sites (Vasilakis et al. 2008). Next, the resulted UD values of the *population-level flight movement corridor* were categorized into 25% quartiles, so that the top 25% were classified as high use and the lowest 25% were low use. Although the amount of time an animal spends in a particular area is the most common metric in resource use studies, it is not particularly effective at capturing rare events, such as visiting watering, seeking mates, or quick movement bouts (Buskirk and Millspaugh 2006). The *population-level flight movement corridors* estimated by the BBMM are unique in that they reflect two metrics of movement behavior: time spent in an area and rate of movement. Both metrics were considered by recognizing that high-use areas represent areas where vultures spend the most time and move slowly (e.g., stop moving at surveillance sites or soaring over a source of updraft lift), while moderate-use areas represent areas where vultures spend the least time and move quickly (gliding to the next source of updraft lift). Thus, we assumed that high-use areas represent core areas, presumably used for feeding or gaining height or resting habitat, whereas moderate-use areas located between stopover sites represent movement corridors (Figure 3a). The analysis used in this paper implicitly assumed that behavioral state (i.e., stopover or movement) could be inferred from movement rates. The validity of this assumption depends on the frequency of the movement data, the type of behaviors to be distinguished, and how likely those behaviors are to be associated with different movement rates. In this paper, movement data were collected at frequent (10 min, 45 min, 1 h) time intervals and attempted to differentiate between two coarse-scale behavioral states (i.e., stopover or soaring sites vs. fast movement) that were probably characterized by more or less pronounced differences in movement rates.

To prioritize movement corridors, it was assumed that corridor segments used by a larger proportion of the population had higher conservation priority than those used by a small proportion of the population. The proportion of the sampled population that used each coridor segment was determined by calculating how many of the individual movement flight corridors (99% UD) occurred within each 50 X 50 m cell of the estimated population-level movment corridor. Thus, cell values ranged from 1 to a possible maximum value equal to the total number of marked vulture (*n*=6). Movement corridor used by >33% of the sampled population can be considered to have higher conservation priority than others. The 33% criterion was a subjective decision intended to reflect corridor used by more than one marked vultures. It is recognized that other criteria could be used, but in the absence of a metric directly related to fitness, proportional use can be considered an intuitive metric to prioritize movement corridors.

RESULTS

We estimated utilization distributions (UDs) for 232 DFFR collected from 6 radio-collared vultures (Table 1). Taking into account only the transmitters (4 out of 6) that were programmed to collect data every day it came out that the number of DFFR per month ranged from 5-12 and that the vultures did a DFFR going out from Dadia NP on 16-40% of the monitoring days. Although, these transmitters worked for 5-6 months from mid-October to mid-April, mainly winter months when unsuitable

fight weather conditions prevailed, it came out that they moved out from the Dadia NP often, conducting 9 DFFRs per month on the average (Table 1).

Table 1. Monitoring days and number of daily foraging flight routes (DFFRs) that were included in the analysis.

Vulture ID	Monitored days (MD)	Nr of DFFR	Nr of DFFR per Month	Percentage of MD (%)
T3H-2021	186	74	12	39.7
T3H-2022	174	28	5	16.0
T3H-2023	140	39	8	27.8
T3H-2024	189	65	11	34.3
Total	**689**	**206**	**9**	**29.8**
Collar03664*	24	15	1	62.5
Collar03668*	24	11	1	45.8
Grand Total	**-**	**232**	**6**	**37.7**

* These transmitters were programmed to collect location every 1 h two days randomly selected per month.

The Brownian motion variance (BMV, is expressed in m^2) of individual DFFRs of the vultures collared with the transmitters that were programmed to collect one location every 45 minutes during the day light hours every day, was 1087614.826 ±68021.361 (mean ±SE; $n=205$ DFFRs), and for the days that these transmitters were programmed to collect locations every 10 minutes it was 394296.125± 99446.328 (mean ±SE; $n=16$ DFFRs), while for vultures collared with the transmitters that were programmed to collect one location every 1 h it was 1652381.607 ± 250605.819 (mean ±SE; $n=27$ DFFRs). The BMV indicates a highly mobile animal with large variability in the estimated DFFRs motion variance (Figure 1).
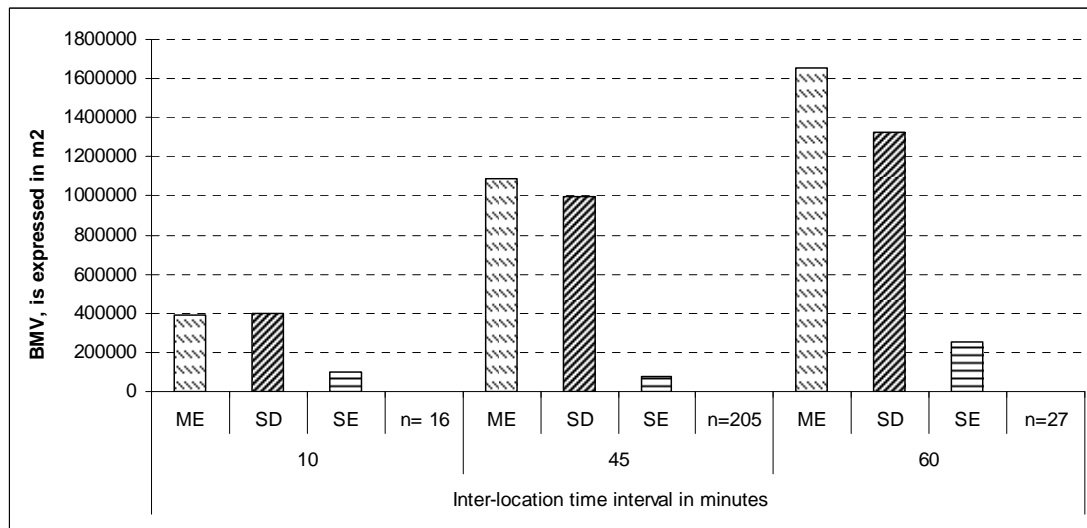

Figure 1. The average (ME) Brownian motion variance (BMV is expressed in m^2) of individual daily foraging flight routes (DFFRs) of the vultures collared with the transmitters programmed to collect locations at different time intervals. (ME: arithmetic mean; SD: standard deviation; SE: standard error; n: the number of DFFRs).

The DFFR with locations collected every 10 minutes were re-sampled at time intervals of 40 and 60 minutes and the BBMM were used to predict with these new data sets the vulture flight movement corridor (Figure 2). Although, when the initial data set of 37 locations (10 minutes interval) were re-sampled, the resulted locations

for the analyses were much fewer (10 and 7 locations respectively), it appeared that the model could detect the main stream of the vulture flight movement corridor.

The population-level flight movement corridor represents a probabilistic measure of where both the going and coming back segment of a DFFR occurred over the study period for the sampled vultures. Population-level flight movement corridor was characterized by stopover sites or revisited sites (core areas), where vultures spent most of their time, connected by movement corridors through which vultures moved quickly (Figures 2, 3a).
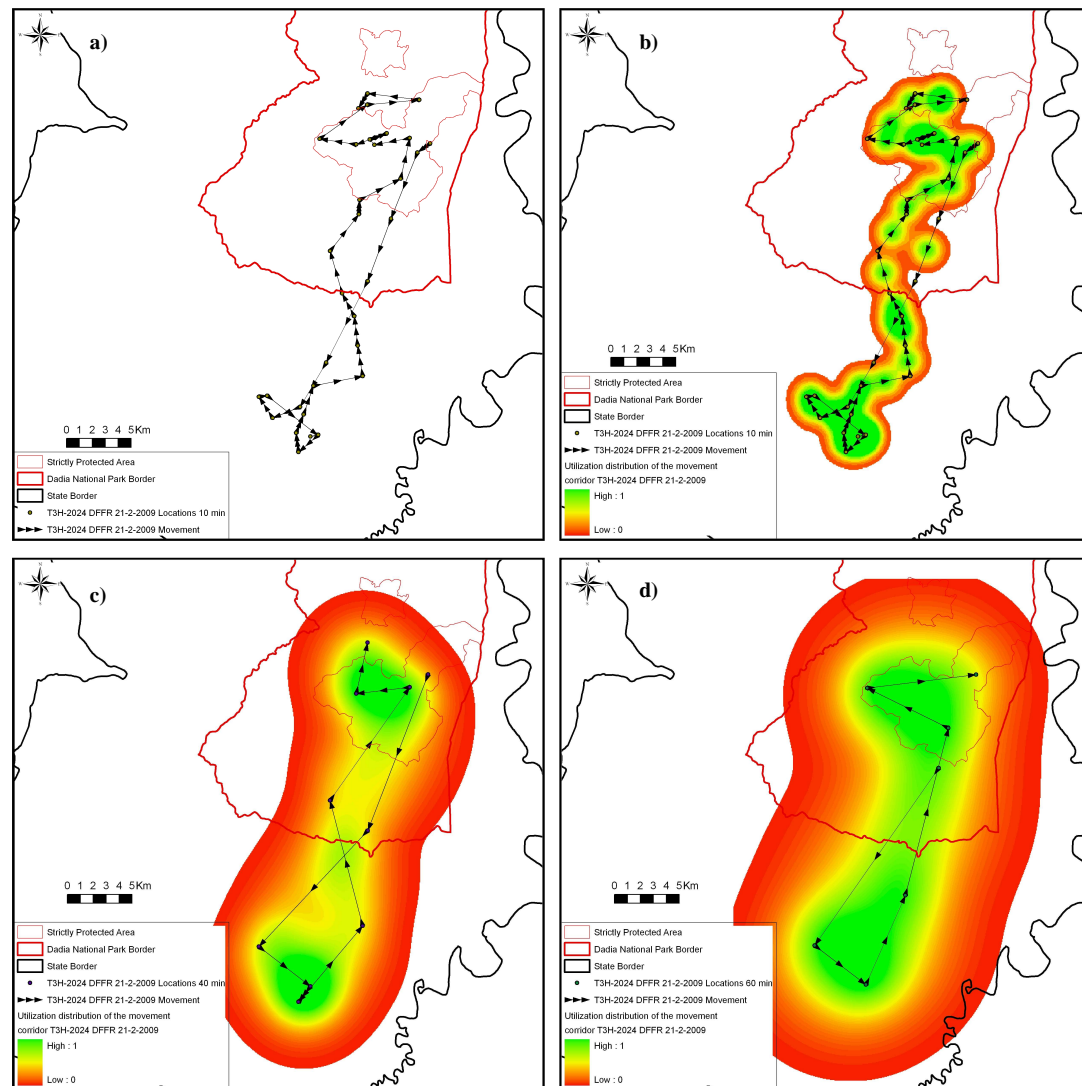

Figure 2. Utilization distribution (UD) estimated for an individual vulture (*Aegypius monachus*; GPS no. T3H-2024 DFFR 21-2-2009) during a daily foraging flight route; a) Indicates the original location data collected every 10 minutes and the direction of the vulture movement. b) The UD resulted when the Brownian Bridge Movement Model (BBMM) was fitted to the aforementioned data. High-use areas (green color) correspond with stop-over sites where the vulture spent most time (i.e., roosting or soaring). Moderate-use area (in yellow) located between stop-over sites correspond with corridor segments through which vulture moved quickly in one or both directions. Low-use areas (in orange) reflect the uncertainty in the entire route. c) Indicates a sub set of the initial locations collected every 40 minutes and the resulted UD when the BBMM was fitted to these locations. d) Indicates a sub set of the initial locations collected every 60 minutes and the resulted UD when the BBMM was fitted to these locations.
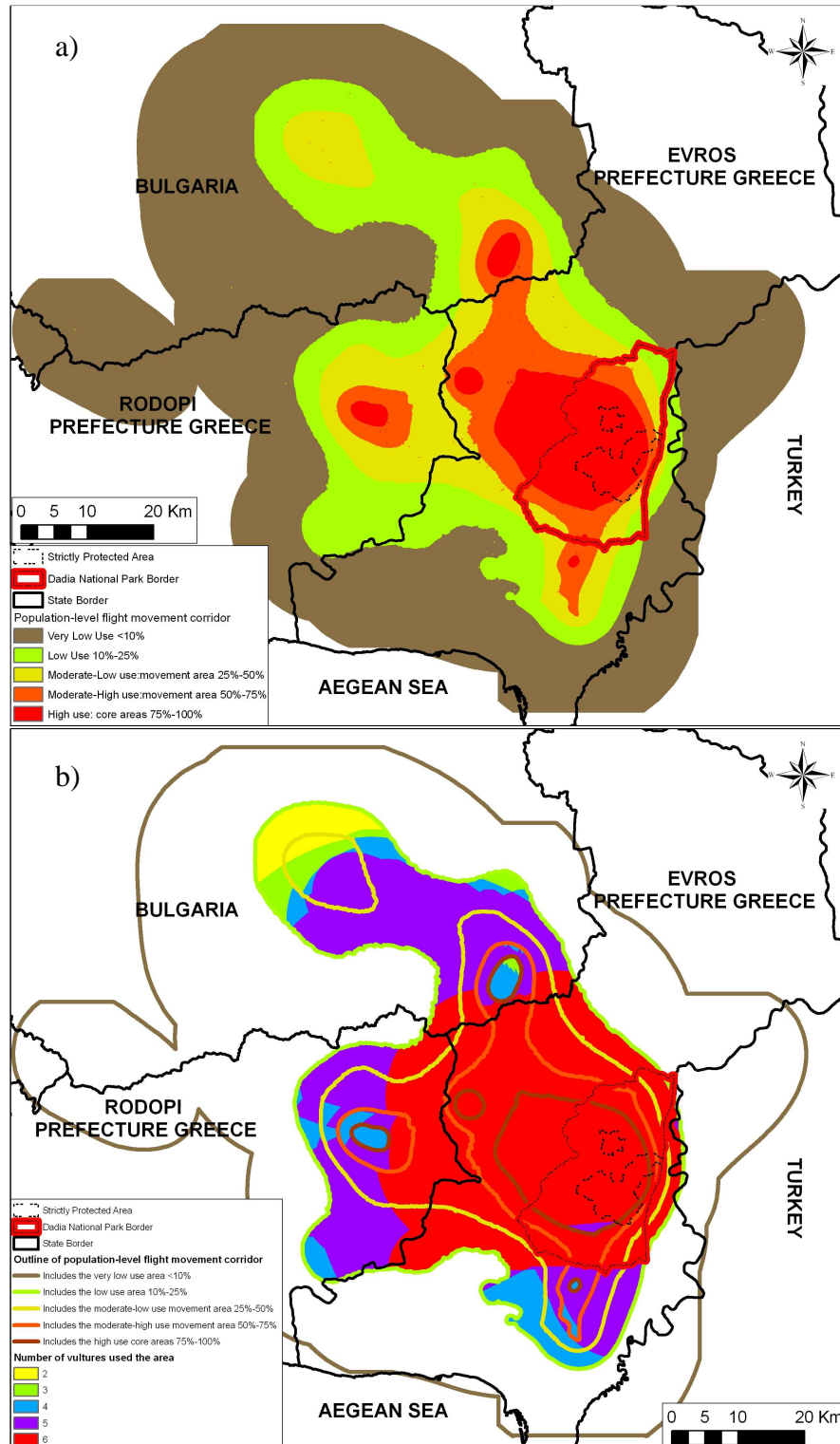
Figure 3. a) Estimated population-level flight movement corridor and relative amounts of use for Eurasian black vulture *Aegypius monachus*, in Thrace. High-use areas represent core areas presumably used for foraging or include important surveillance sites or areas where vultures gain kinetic energy for locomotion, whereas moderate-use areas represent movement flight corridors. (b) Indicates the number of individual vultures that used the area across the Eurasian black vulture population-level flight movement corridor. There were areas that although used by the entire sampled population they were used less intensively and fell within the low used areas (10%-25%). If flight movement corridor used by >33% of the sampled population (2 individuals) is considered to have higher conservation priority than others, then also the low used areas (10%-25%) as well as the moderate-low use, the moderate-high use and the high use areas had to be kept free of wind farms.
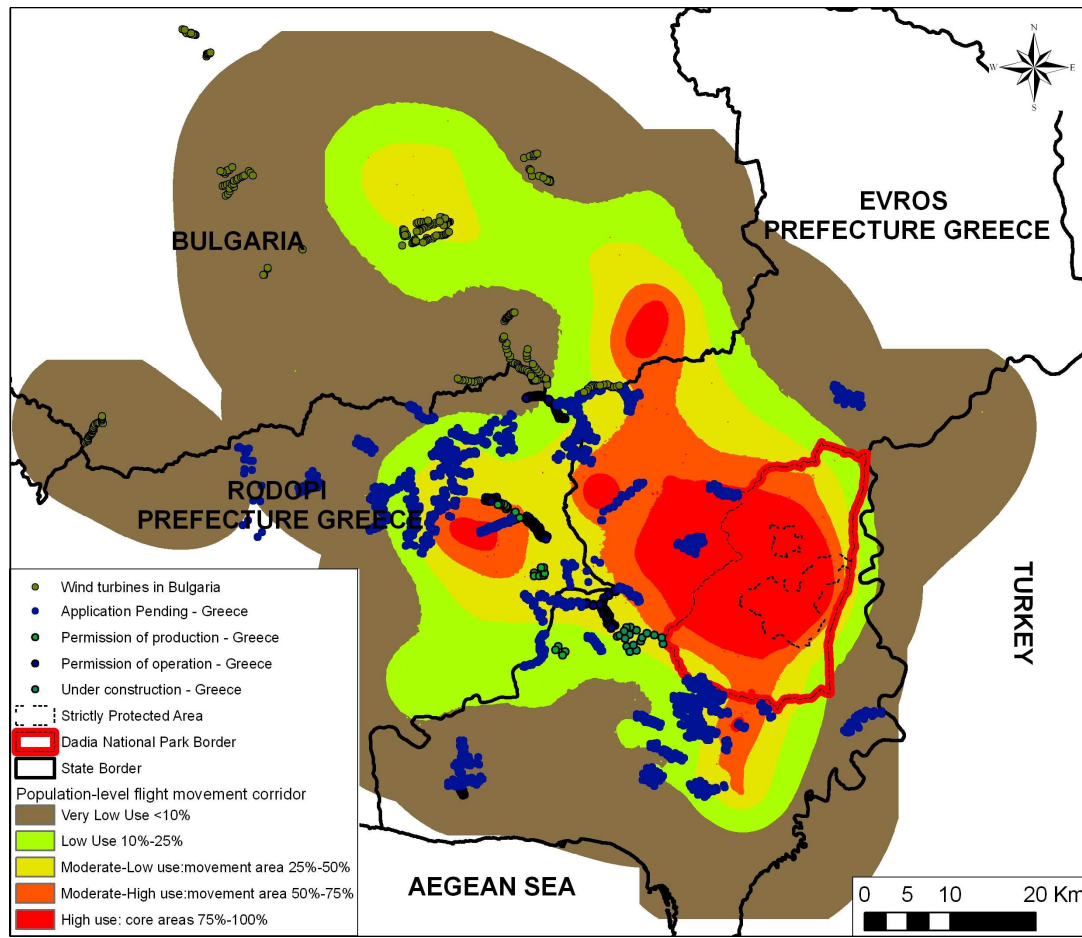
Figure 4. Estimated population-level flight movement corridor and relative amounts of use for Eurasian black vulture *Aegypius monachus*, in Thrace. The dots indicate wind turbines within wind power plant with various status (operating, permission of production, permission of operation, under construction or application pending).

Table 2. Description of the relative amounts of use for Eurasian black vulture *Aegypius monachus*, in Thrace population-level flight movement corridor, area that was included in the associated buffers and numbers of wind turbines (WT), their capacity and operational status.

Description	Probability of use	Area in km²	Bulgaria Planed WT	Application Pending Number of WT	Application Pending Capasity in MW	Permission of production Number of WT	Permission of production Capacity in MW	Permission of operation Number of WT	Permission of operation Capacity in MW	Under construction Number of WT	Under construction Capacity in MW	Total Number of WT	Total Capacity in MW	Percentage of wind turbines (%)	Percentage of MW 9%)
Very Low Use <10%	10	4448	124	301	441	0	0	49	43	0	0	474	484	27	21
Low Use 10%-25%	15	1272	32	435	583	5	4	31	40	3	6	506	634	29	28
Moderate-Low use:movement area 25%-50%	25	865	64	436	797	10	4	77	52	7	14	594	867	34	38
Moderate-High use:movement area 50%-75%	25	484	0	95	180	21	11	0	0	1	2	117	193	7	8
High use: core areas 75%-100%	25	414	0	60	109	0	0	0	0	0	0	60	109	3	5
Total	**100**	7483	220	1327	2110	36	20	157	136	11	22	1751	2287	100	100

Core areas corresponded with high-use areas some of which are used for breeding and others presumably as foraging and roosting grounds or include important surveillance sites but also areas where vultures gain kinetic energy for locomotion, whereas movement corridors were represented by moderate-use segments, located between core areas, through which vultures moved quickly (presumably glide). Low-use areas

reflected the uncertainty across the entire range and did not appear to be associated with stopovers or movement corridors.

Corridors used by >33% of the sampled population (2 idividuals) were considered to have the highest conservation priority and were mapped against the population-level flight movement corridor (Figures 3a, 3b). By applying this criterion it came out that the low used areas (10%-25%) as well as the moderate-low use (25%-50%), the moderate-high use (50%-75%) and the high use areas (75%-100%) had to be kept free of wind farms (Figure 3a, 3b).

The area estimated to be used by the entire population reaches the 7500 km^2 (Table 2, Figure 3a). The very low use areas (<10%) covered a surface of 4448 km^2. At least 474 wind turbines with a capacity exceeding 500 MW are planned to be constructed within these last areas. The capacity of wind farms in the respective Bulgarian territory is not known. These numbers correspond to 27% of the investor demand for wind turbine installation and more than 52% of the planned capacity by the Greek state (930 MW in WPA 1). The low-use areas (10%-25%) covered a surface of 1272 km^2, where there is a demand for the construction of at least 506 wind turbines with a capacity exceeding 634 MW. The capacity of wind farms in the respective area in Bulgarian territory is also not known. These numbers correspond to 29% of the investor demand for wind turbine installation and more than 68% of the planned capacity by the Greek state. The moderate-low use movement area (25%-50%) covered a surface of 865 km^2, concentrated the highest portion of wind turbine and thus the larger portion of the capacity demanded (34 % and 93%, respectively) (Table 2). 44% of the proposed wind turbine sites (771) overlapped with areas highly used as population-level flight movement corridors. 73% of the proposed wind turbine sites (1277) overlapped with the high conservation priority population-level flight movement corridors.

DISCUSSION

The survival of the endangered Eurasian black vulture population in the Dadia NP depends on the management of the areas outside the national park and on an international scale. Its viability in the area remains uncertain, as mortality factors such as poison baits continue to negatively affect the population (Skartsi et al. 2008) and new potential threats have appeared in the vicinity of the nesting area and inside the foraging area of the population. The application of a continuous-time stochastic movement model (Brownian bridge movement model, BBMM) was successful at identifying population-level flight movement corridors for this endangered vulture species and this paper might be useful for conservation planning and the decision making process. UDs showing areas in which species of conservation concern spend different proportions of their time can contribute to their management, allowing decision makers and managers to conserve vital resources for them. Such maps can be valuable for the spatial planning not only of protected areas (Wilson et al. 2009) but also of conflicting activities like wind farm development and conservation of large raptorial birds prone to collision.

The maximum harnessing of wind for energy production is more than crucial to the country and the planet. However, the cumulative effects from erecting multiple wind farms in a region densely used by endangered resident birds prone to collision, is a serious threat (Barrios & Rodríguez 2004, de Lucas et al. 2008). Although low collision rates have been recorded at many wind farms (e.g. Erickson et al. 2001,

Percival 2005, Drewitt & Langston 2006), some poorly-sited wind farms show high collision mortality (Barrios & Rodríguez 2004, Smallwood & Thelander 2008).

Vasilakis and Akriotis (2009), aiming to apply black vulture's UDs for the better spatial planning, of refuted activities in its foraging areas, used data from satellite transmitters to investigate the flying height. The black vulture in this area flies rather low (median flight height was 68 m) and may use more the orographic currents than the thermals. Vultures spend increased amount of their flying time (68%) in the rotor risk zone (between 30 and 110 m) and probably high collision mortality has to be expected if sensitive siting of the wind farms is not achieved. The black vulture's population-level flight movement corridors can be considered as a valuable tool for the management of the species in Thrace. However, certain aspects of their flying behaviour like species-specific avoidance rate (Band et al. 2007), activity pattern, flying height over ridges and ridge fidelity need to be further investigated. Nevertheless, it can be argued that managers and decision makers have to be conservative and that based on prevention and on the precautionary principle should dencourage investors to locate their investments within low used areas (10%-25%) but certainly should advise investors avoid highly used areas like moderate-low use (25%-50%), the moderate-high use (50%-75%) and the high use areas (75%-100%) (Figure 3a, 3b). Although the 33% criterion was arbitrarily selected, the vulture flocking foraging behavior was taken in consideration. It is well known that the Eurasian black vulture forage in small groups of 3-5 individuals. The 33% proportional level of use criterion that was applied in this paper is not the most conservative in favor of the species conservation as it is three times higher than what is used by other researchers when applying a similar approach (Sawyer et al. 2009). Nonetheless, when large-scale development poses a threat to movement flight corridors of an endangered species, managers must make difficult decisions, often with imperfect data. Conserving movement flight corridors used by a large proportion of the population might minimize the number of vultures that are potentially impacted by such disturbances.

The objective set by the Greek state to succeed installation of 480 typical WTs (930 MWe) Wind Priority Area (WPA 1) might be achieved by sensitive siting of wind farms in only the very low use areas (<10%). In these last areas at least 474 wind turbines with a capacity exceeding 500 MW are planned to be constructed. These numbers correspond to 27% of the investor demand for wind turbine installation and more than 52% of the planned by the state capacity.

Our Eurasian black vulture flight movement corridors might be of equal importance for other vulture species, like the Eurasian griffon vulture *Gyps fulvus*, that roams over the same area in larger numbers and has quite similar foraging behavior.

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RESEARCH HISTORY & AUTHOR CONTRIBUTIONS

The research was conceived, designed, conducted from 2007 to 2009. The data where partly analyzed in 2009. Data analysis, compilation and paper writing was done in 2010. Conceived and designed the experiments: Dimitris Vasilakis. Performed the experiments: Dimitris Vasilakis. Analyzed the data: Dimitris Vasilakis. Contributed reagents /materials/analysis tools: Dimitris Vasilakis and Maria Noidou. Wrote the paper: Maria Noidou.

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