From the Field

Identifying Birds' Collision Risk with Wind Turbines Using a Multidimensional Utilization Distribution Method

SAM KHOSRAVIFARD,[1] *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

ANDREW K. SKIDMORE, *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

BABAK NAIMI, *Department of Geosciences and Geography, University of Helsinki, 00014, P.O. Box 64, Helsinki, Finland; and Faculty of Science, Institution for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Postbus 94240, 1090 GE Amsterdam, The Netherlands*

VALENTIJN VENUS, *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

ANTONIO R. MUÑOZ, *Biogeography, Diversity and Conservation Research Team, Department of Animal Biology, Faculty of Sciences Universidad de Málaga, E-29071, Malaga, Spain*

ALBERTUS G. TOXOPEUS, *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

ABSTRACT Renewable energy plays a key role in reducing greenhouse gas emissions. However, the expansion of wind farms has raised concerns about risks for bird collisions. We tested different methods used to understand whether birds' flight occurs over wind turbines and found kernel density estimators outperform other methods. Previous studies using kernel utilization distribution (KUD) have considered only the 2 horizontal dimensions (2D). However, if altitude is ignored, an unrealistic depiction of the situation may result because birds move in 3 dimensions (3D). We quantified the 3D space use of the Griffon vulture (*Gyps fulvus*) in El Estrecho natural park in Tarifa (southern Spain, on the northern shore of the Strait of Gibraltar) during 2012–2013, and, for the first time, their risk of collision with wind turbines in an area in the south of Spain. The 2D KUD showed a substantial overlap of the birds' flight paths with the wind turbines in the study area, whereas the 3D kernel estimate did not show such overlap. Our aim was to develop a new approach using 3D kernel estimation to understand the space use of soaring birds; these are killed by collision with wind turbines more often than any other bird types in southern Spain. We determined the probability of bird collision with an obstacle within its range. Other potential application areas include airfields, plane flight paths, and tall buildings. © 2020 The Authors. *Wildlife Society Bulletin* published by Wiley Periodicals, Inc. on behalf of The Wildlife Society.

Wind farms have received public and government support as a clean source of renewable energy because they do not cause air pollution as does the burning of fossil fuels (Stigka et al. 2014, Yuan et al. 2015). The use of wind energy is therefore expanding rapidly worldwide. The Global Wind Energy Council reported that 2015 was another record-breaking year for the

wind energy industry (Global Wind Energy Council 2016). However, wind farms may be causing a large number of fatalities to flying animals, affecting a large area of potential soaring-habitat around them (De Lucas et al. 2012, Zimmerling and Francis 2016, Marques et al. 2020). Therefore, the expansion of wind farms has raised concerns about their potential negative effects on wildlife populations and associated habitat quality.

Relatively high collision fatality rates have been recorded at several large wind farms in locations indicating that turbines pose a risk, especially to large raptors and other soaring birds (Marques et al. 2014). The Griffon vulture (*Gyps fulvus*) is one of the raptor species frequently killed by collision with wind turbines in southern Spain (Barrios and Rodríguez 2004; De Lucas et al. 2008, 2012; Olea and

Mateo-Tomás 2014). For instance, Carrete et al. (2012) found 342 dead Griffon vultures during a 10-year period (Jan 1998–Mar 2008) in an area of 34 wind farms with 799 turbines in the province of Cádiz, southern Spain.

To develop efficient conservation practices, it is necessary to know where and when a threat of collision may occur (Wilcove 2010). The 2 most common approaches, namely home range and utilization distribution, have been used to depict and portray animal movements and their space use (Rutz and Hays 2009, Kie et al. 2010, Tomkiewicz et al.

2010, Monsarrat et al. 2013). The home range is the area "traversed by an individual [animal] in its normal activities of food gathering, mating and caring for young" (Burt 1943:351), whereas the utilization distribution reflects the animal's spatial use probability density (Van Winkle 1975, Signer et al. 2017). Recently, the home range has been viewed as one attribute of the animal's utilization distribution. Animal space use or home range has been quantified using different methods such as minimum convex polygon (Mohr 1947), bivariate normal method (Jennrich
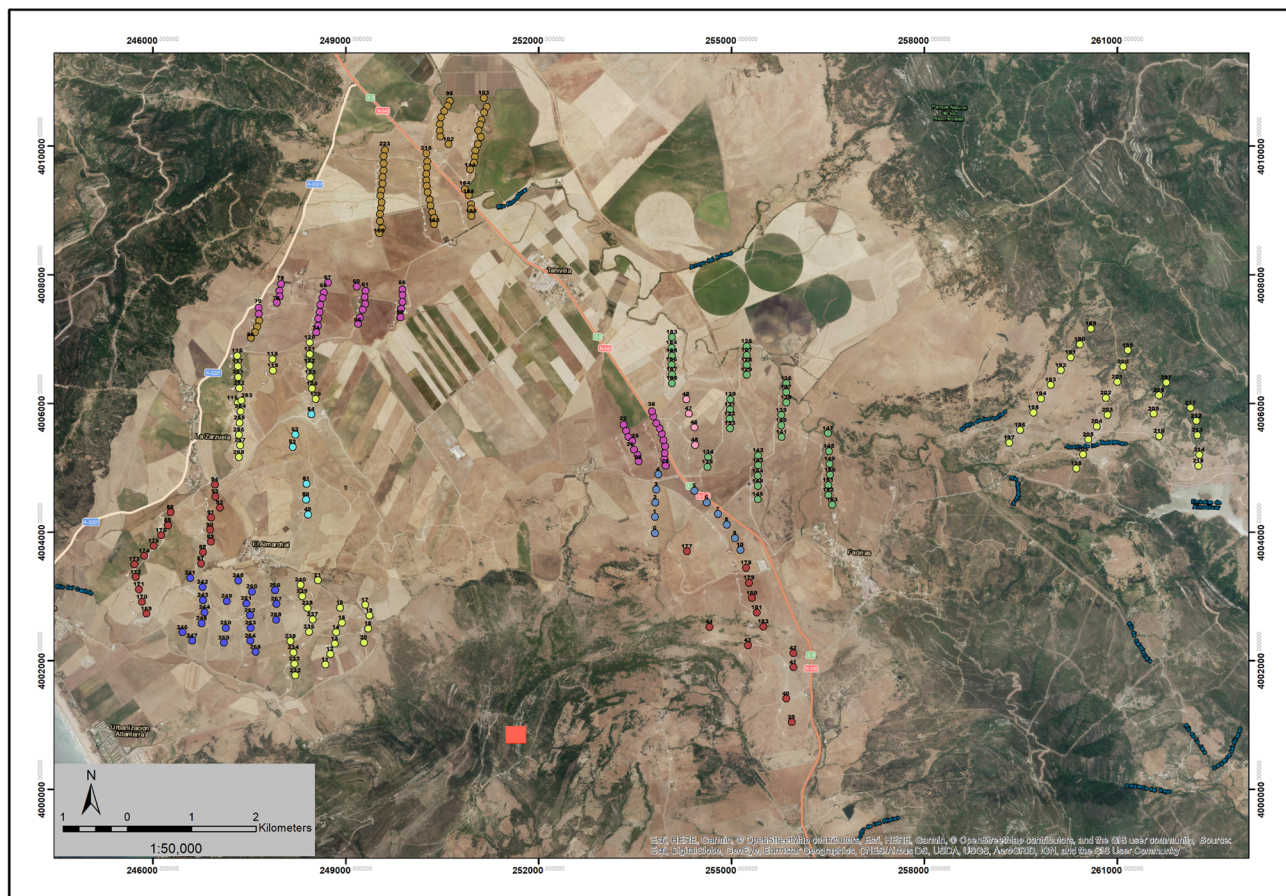
Figure 1. The study area during 2012–2013 was part of the El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar. The Griffon vulture colony (red square) was located at an escarpment close to wind turbines (colored circles with numbers, each color represents a group of identical turbines).

and Turner 1969), grid square method (Siniff and Tester 1965, Macdonald et al. 1980), population utilization distribution (Ford and Krumme 1979), and kernel density (Worton 1995). Several methods have recently been developed for the time-explicit estimation of animal space use, such as the dynamic Brownian bridge movement model and bivariate Gaussian bridges (Kranstauber et al. 2012, 2014). The kernel density estimator method has low bias, and greater flexibility in handling complex location patterns and in assuming location independence (Worton 1989, 1995; Seaman and Powell 1996; Fieberg 2007; Benhamou and Cornélis 2010).

So far, most studies estimating animal home ranges or utilization distributions have only considered the 2 horizontal dimensions (Katajisto and Moilanen 2006, Cagnacci et al. 2010, Powell and Mitchell 2012, Fleming et al. 2015). If altitude—the third dimension—is neglected, an unrealistic depiction of reality may be attained for species moving in 3-dimensional (3D) space, such as birds, bats, fish, or climbing species (Belant et al. 2012, Monterroso et al. 2013). However, few studies have quantified space use patterns in 3D. For instance, Koeppl et al. (1977) presented a model based on an ellipsoid of a particular size, shape, and orientation in space. It was one of the first models used to compute home range in 3D. Hindell et al. (2011) quantified the 3D space use of 5 different species (2 mammals and 3 bird species). They highlighted that the greatest concentrations of locations of southern elephant seals (*Mirounga leonina*) occurred within the 1,000-m bathymetric contour.

Simpfendorfer et al. (2012) calculated the utilization distribution of European eels (*Anguilla anguilla*) using 2D and 3D kernel density. They emphasized that the 2D analysis overestimated the amount of movement overlap between individuals by 13–20%. Recently, Cooper et al. (2014) studied the 3D space use and overlap of American redstarts (*Setophaga ruticilla*) using a direct observation method for data collection and kernel density estimator. Their study was confined to observing focal territories throughout each sampling period, with birds located visually and the altitude estimated by observers. The number of locations for each observed bird was also limited. Nevertheless, their findings concurred with a former study on the overestimation by 2D analysis compared with the 3D method. They also found that American redstarts may avoid areas of overlap, presumably to limit interactions with neighbors.

We collected locations of an individual Griffon vulture with the use of a bio-logger, quantified the bird's 2D and 3D utilization distributions, and, for the first time, its collision risk with wind turbines using kernel utilization distribution (KUD). We demonstrate that volumetric analysis (3D) is more informative than planar analysis (2D) in utilization distributions. We show that neglecting the third dimension would provide incomplete depiction of the aerial species' space use, whereas 3D kernel estimators cannot only be used to improve our understanding of the bird's movements, but they also can be considered as a way to determine wildlife collision risk with an obstacle in the territory or home ranges in conservation plans.

Table 1. Wind turbine data: model name, number, hub height, blade length, and total height (in meters) in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar, where space-use activity by a Griffon vulture was studied during 2012–2013.

Model	Color on Fig. 1	No. of turbines	Hub height	Blade length	Total height
ECOTECNIA ECO-74		34	70	35.5	105.5
ENERCON E-70		20	84	33.5	117.5
GAMESA G-80		30	67	40.0	107.0
GAMESA G-87		11	78	42.3	120.3
MADE AE-56		43	60	27.3	87.3
MADE AE-59		55	60	28.8	88.8
VESTAS V-72		4	78	36.0	114.0
VESTAS V-80		6	78	40.0	118.0
VESTAS V-90		66	80	44.0	124.0

STUDY AREA

The study area was located in the natural park of El Estrecho, in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar (Fig. 1; 36°07′−36°06′N, 5°45′−5°46′W). This area was the most southern protected area in Europe. It was a maritime–terrestrial park along 54 km of coastline in Andalusia and an Important Bird Area (Guerra García et al. 2009, BirdLife International 2017). In this area, Ferrer et al. (2012) reported the greatest collision rates ever published for birds (1.33/turbine/yr) with the Griffon vulture being the most frequently killed species (0.41 deaths/turbine/yr). There were several Griffon vulture colonies in the area, consisting of approximately 320 breeding pairs in total. We focused on a colony at an escarpment running north–south, 4 km from the Strait of Gibraltar; with approximately 65 breeding pairs (Del Moral 2009). Our analysis was constrained to the space used by one tagged Griffon vulture; the space encompassed an area of 152 km^2 and included 20 wind farms with 269 operational turbines (Table 1).

METHODS

We captured a Griffon vulture using a foot-snare trap. We attached a bio-logger as a backpack using a harness made of Teflon (Chemours, Wilmington, DE, USA) ribbon with one strap fitted across each wing and another strap below the crop (Kenward 2000). The capture and release took place on 11 September 2010. We attached distinctive yellow patagial markers, with a unique combination of numbers and letters (i.e., 9FJ) to both wings. This method was shown to be harmless to the bird and led to no detectable changes from its normal behavior (Reading et al. 2014). Our Griffon vulture was a male, subadult, and with a body mass of approximately 7 kg.

We used the Bird Tracking System biologger developed at the University of Amsterdam (Bouten et al. 2013). The key features of this bio-logger are solar rechargeable batteries, light weight (45 g, <0.6% of body mass), 2-way data-communication, 4-megabyte flash memory (capable of

storing 60,000 Global Positioning System [GPS] fixes), and a GPS tag with high-resolution temporal intervals from 3 to 7,200 seconds. This bio-logger had a biometric pressure sensor and transferred the GPS data (with 3D coordinate positions) to a base station. It could be programmed remotely using the BirdTracking software (http://www.uva-bits.nl/). The positional and altitude mean errors were 1.13 m and 1.42 m as shown by a test of stationary bio-loggers GPS in open space (Bouten et al. 2013). We used the GPS fixes and their properties to quantify the Griffon vulture's 3D movement to determine the overlap of air space use between the bird and wind turbines. We retrieved the GPS fixes of our Griffon vulture for 18 months (Feb 2012–Jul 2013). These data comprised 169,778 locations at 5-minute intervals. The procedures of this research, including the bird trapping and bio-logger tagging were conducted with permission from the Consejería de Medio Ambiente of the Junta de Andalucía (Regional Council for the Environment).

Data Analysis

The Griffon vulture is a diurnal species; therefore, we considered only data points collected during daytime and filtered out stationary locations (speed <4 m/sec). We used the remaining 12,611 locations to quantify KUDs (50% and 95%) in 3D (Benhamou and Cornélis 2010). The multivariate kernel density estimate is defined by

$$\hat{f}_h(x) = n^{-1} \sum_{i=1}^{n} h^{-d} K\left(\frac{x_1 - X_{i1}}{h_1}, ..., \frac{x_d - X_{id}}{h_d} \right) \quad (1)$$

where $x = (x_1, x_2, ..., x_d)$ is an independent and identically distributed sample of a random variable X, h is the bandwidth, and K is the kernel function of dimensions d.

We used a plug-in bandwidth selector to estimate the smoothing factor matrix. This method provides adequate results in the utilization distribution estimation and
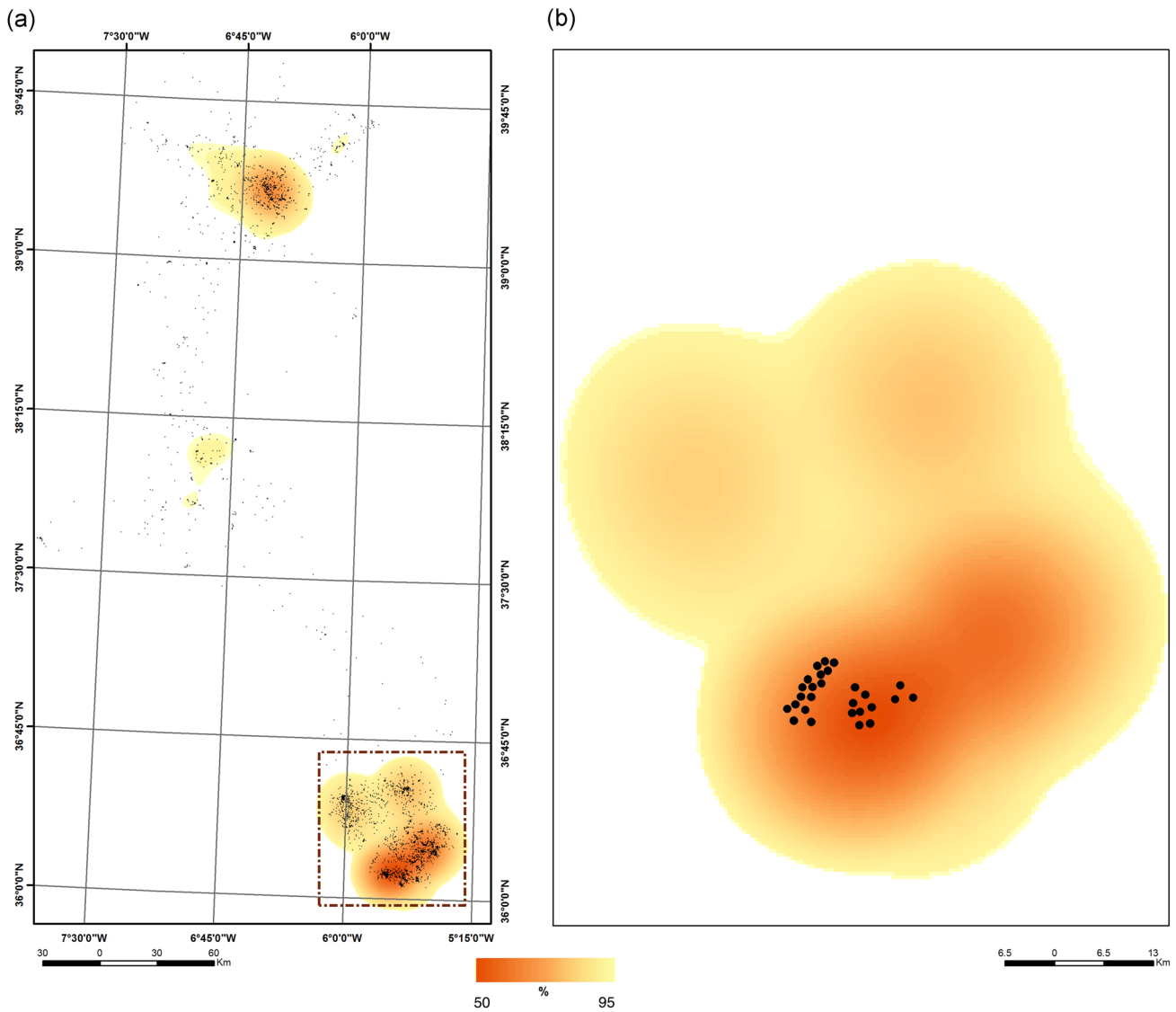
Figure 2. The activity space of a tagged Griffon vulture estimated by 2D kernel utilization distribution (KUD) for 17 months (Feb 2012 to Jul 2013) in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar. Panel (a) demonstrates the bird's entire activity space use, whereas panel (b) depicts the portion where wind turbines were located (black circles represent a portion of entire turbines).

requires less intensive computation compared with other methods, such as least-squares cross-validation or the reference method. We quantified monthly 2D and 3D KUDs (50% and 95%) for the Griffon vulture using the "ks" package (Duong 2007) in Program R Statistical environment (version 3.2.3, www.r-project.org, accessed 5 Sep 2016). At the location of each turbine, we extracted the value of probability density generated by the 2D kernel function. In a similar fashion, we extracted the density values generated by the 3D kernel, but this time the total height of a turbine (i.e., turbine height plus blade length) was considered. This is the sum of the turbine's height, the length of a blade, and the land elevation determined using a digital elevation model. In addition, we considered the value for the probability density in both 2D and 3D KUD as a proxy of the plausible collision risk. Then we used the Mann–Whitney–Wilcoxon test to examine any significant differences in the extracted values. In 2D and 3D KUD, values above the third quartile (i.e., the greatest 25% of the values) were selected as a proxy for plausible collision with

high risk. We calculated the frequency distribution of plausible risk pertaining to the turbines to determine which turbines might be relatively dangerous in the course of data gathering.

RESULTS

The 2D KUD of our tagged Griffon vulture showed that all the wind turbines were located in the core and extended home range, where the KUD values were relatively high (Fig. 2). Values extracted from the 2D KUD were greater than for the 3D model at the turbine locations (Mann–Whitney–Wilcoxon Test $W = 72,351$, $P < 0.001$). The 3D kernel estimation of the Griffon vulture's occurrence covered a large area of space use (Fig. 3): 50% and 95% KUD were estimated to be 476 km^3 and 11,120 km^3, respectively (more situations related to Fig. 3 are available in Supporting Information, available online). Values extracted from the 3D kernel estimation showed a high probability density in the winter and early spring of 2012 and 2013. The results showed that there was no sign of
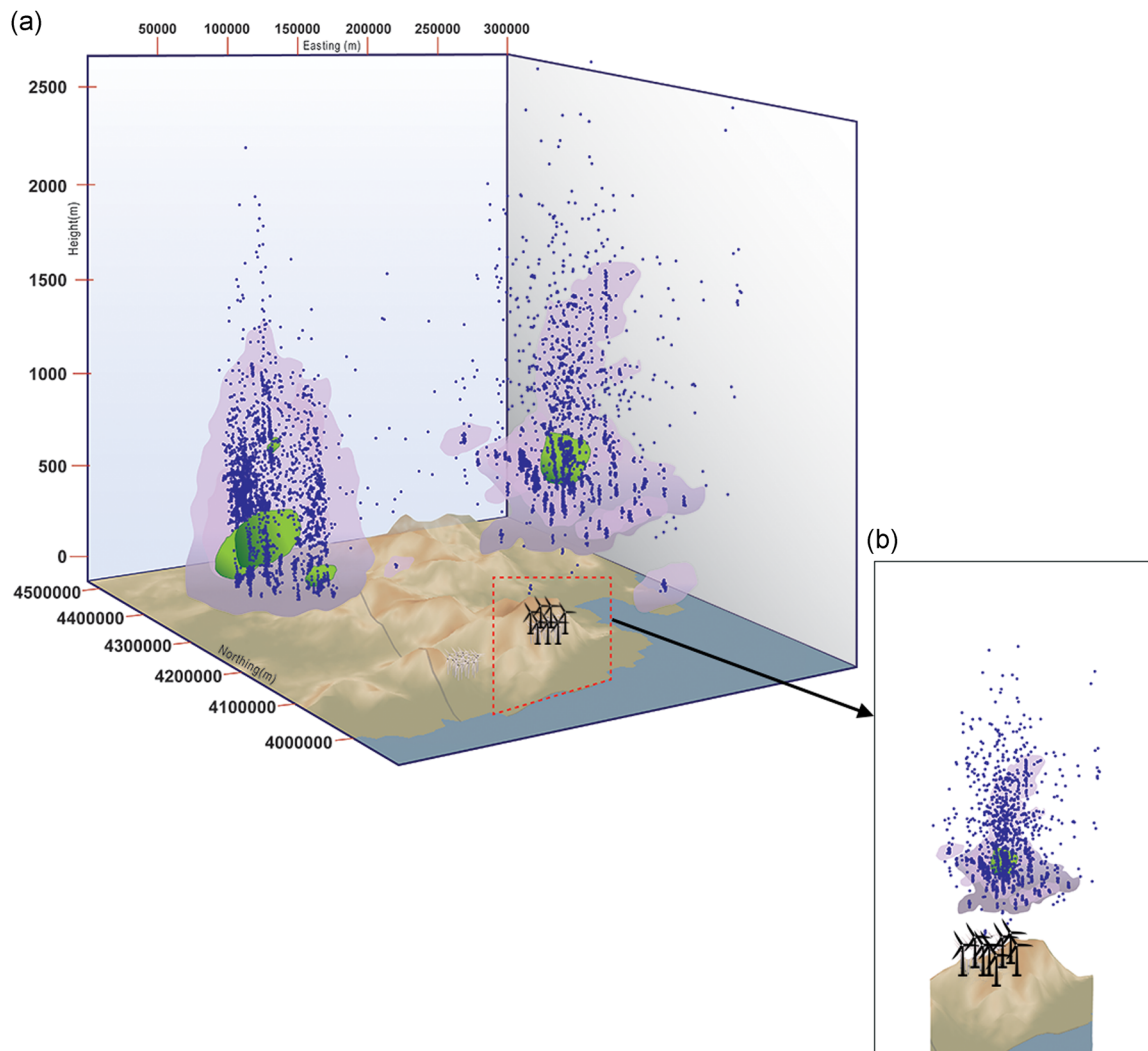
Figure 3. (a) Representation of 3D kernel utilization distribution (KUD) of a Griffon vulture for 17 months (Feb 2012 to Jul 2013) in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar. The green and purple shapes indicate 50% and 95% KUDs. The digital elevation model is presented. Panel (b) reveals that, in 3D space use, there is no overlap between the bird's space use and wind turbines.
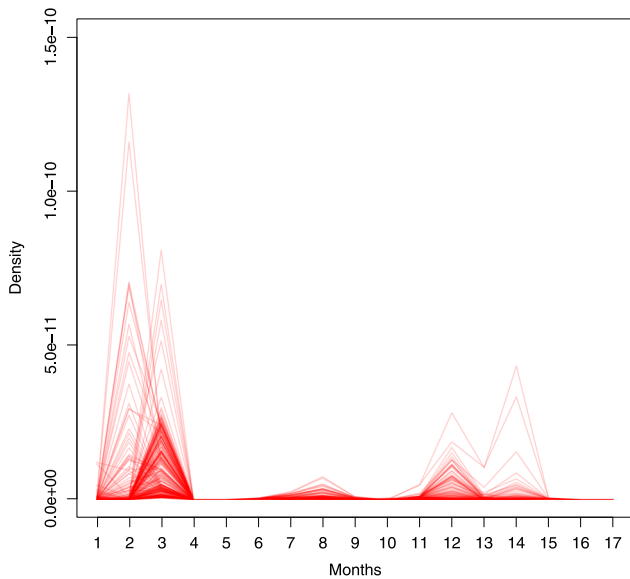
Figure 4. The value of probability density extracted from 3D kernel utilization distribution from month 1 (February 2012) to month 17 (July 2013) at the location of the wind turbines. It shows a relatively high space-use activity by a Griffon vulture in the winter and early spring of 2012 and 2013 in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar.

collision risk in May and June in both years because the Griffon vulture was not in the vicinity of the turbines. However, the concentration of collision risk increased in March and April of both years (Fig. 4).

In 3D space, just 3 turbines had a relatively high risk (i.e., above the third quartile) in 12 out of 17 months, whereas 7 turbines appeared to have such a risk in 2D space. The maximum number of turbines that had a relatively high risk in 3D and 2D space were 55 and 62, respectively (Fig. 5). To be specific, the high risk occurred in 2 months (Feb and Apr) for 3D and in 3 months (Feb, Apr, and Jun) for 2D space use. Turbines located in the southern part of the study area, in the vicinity of the Griffon vulture colony, had a
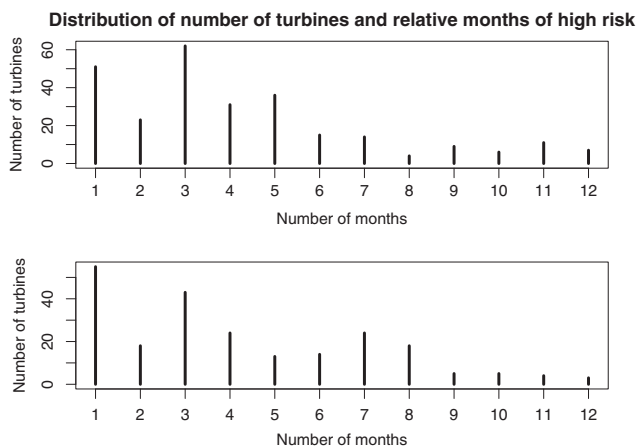
Figure 5. The total number of turbines with a relatively high risk of plausible collision in 12 months out of the entire study period by Griffon vulture in 2D (above) and 3D space (below) in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar during 2012–2013.

relatively high risk of collision in both the 3D and 2D analyses (Fig. 6).

DISCUSSION

We used kernel utilization distribution (KUD), for the first time, to understand the plausible collision risk between wind turbines and bird occurrence. Our results demonstrate the advantage of 3D KUD for modeling 3D space use by birds and, in particular, the comparative risk of a bird colliding with a turbine. Although 2D analyses are useful to summarize information on the location of individuals (Simpfendorfer et al. 2012), volumetric analyses (i.e., with altitude added as a third dimension) provide a more detailed depiction of species' occurrence. Using a 3D KUD, we show that the most dangerous times and greatest-risk turbines can be identified. This information can be used to reduce the mortality rate caused by bird collisions with turbines and offers wildlife managers insights on how to minimize the probability of such collisions (Belant et al. 2012).

To date, the probability of collision has been studied by analyzing a range of complex factors such as the species' flight behavior, topography, and weather (De Lucas et al. 2008). Those studies were conducted with the aim of reducing the avian mortality rate at wind farms, particularly of raptors (Barrios and Rodríguez 2004, DeVault et al. 2005, Drewitt and Langston 2008, Tellería 2009, Bellebaum et al. 2013). However, 3D space use was not considered and we show that including 3D space may influence results. A trial mitigation measure was instigated by Regional Council for the Environment in 2008–2009 that power companies selectively shut down some wind turbines when raptors were observed in their vicinity. This measure reduced the Griffon vulture fatality rate by 50% (De Lucas et al. 2012). The trial also demonstrated that the distribution of Griffon vulture mortality was not uniform, which is consistent with our results from the 3D KUD approach. Additionally, this approach can be considered in turbine selection if mechanisms are implemented to shut down the turbines when birds are in the vicinity.

In Europe, an environmental impact assessment (EIA) is required prior to the construction of new wind farms. The anticipated effects of development on the site's bird populations are included in the EIA (Environmental Impact Assessment Directive 97/11/EC). Ferrer et al. (2012) ascertained that risk assessment studies had erroneously assumed a linear relationship between the frequency of observed birds and fatalities. They concluded that the correlation between predicted and actual fatalities can be improved by changing the scale of studies and concentrating on the location of each proposed turbine. Our findings, with the focus on the location of the turbines, support this conclusion and offer a new tool for performing such calculations. Specifically, the proxy of plausible collision risk per turbine can be estimated by deriving the values generated by 3D KUD. This 3D model can assist wind farm developers to calculate the risk of installing a turbine at a specific location. Prior to calculating risk, preconstruction data are
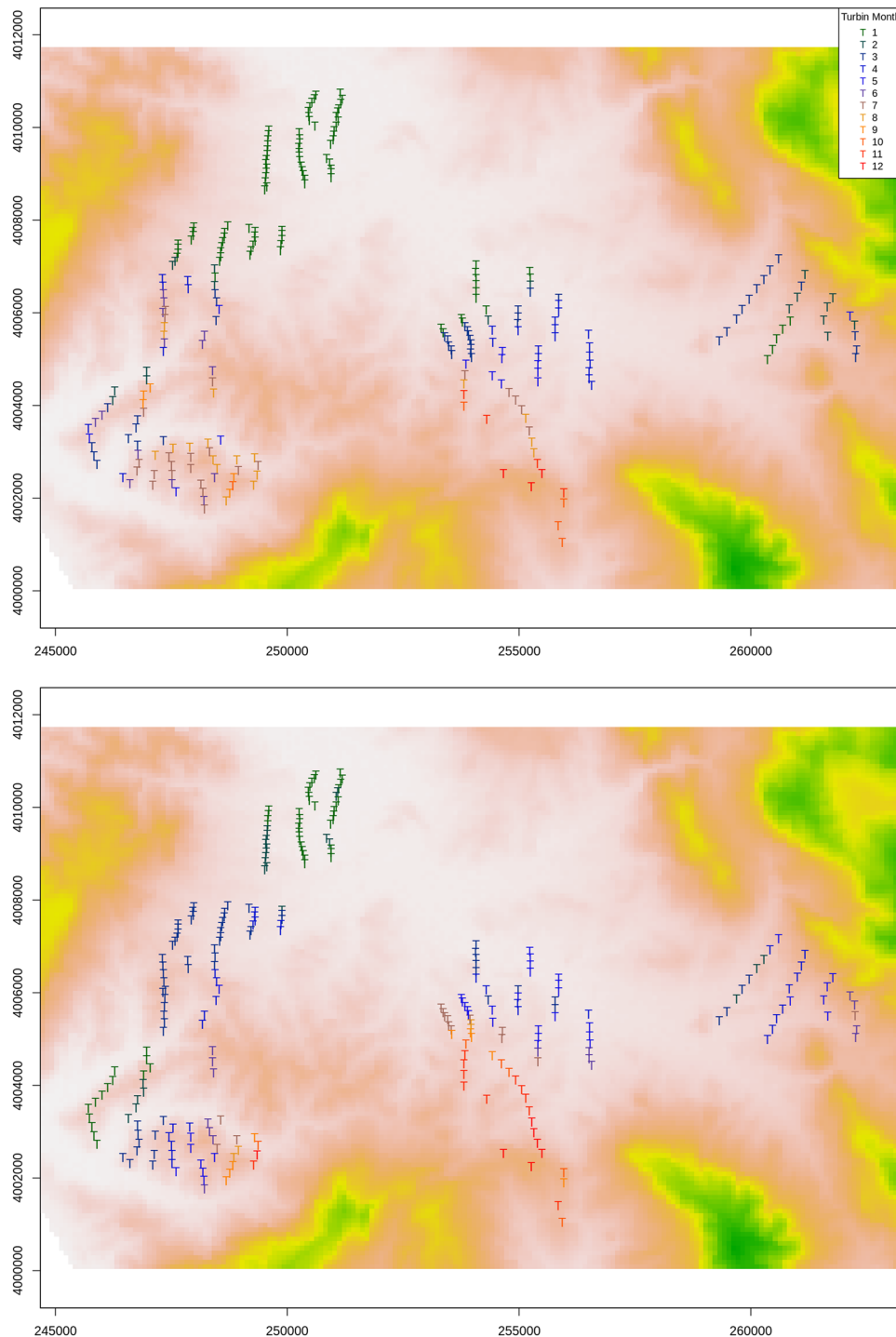
Figure 6. Spatial distribution of wind turbines with a relatively high collision risk in 12 out of 17 months (the entire study period) for a Griffon vulture in 2D (above) and 3D (below) space use in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar during 2012–2013.

needed for target species. Our 3D approach could also be used during the postconstruction and operational phases of wind farms, helping management to predict periods of high risk and reduce the number of bird collisions by selectively curtailing certain wind turbines.

We purposely used recorded movement data for a tagged Griffon vulture rather than simulated data to depict the real situation. Griffon vultures have similar flight and foraging behavior (Bosè and Sarrazin 2007, Xirouchakis and Andreou 2009, Mateo-Tomás and Olea 2011), so these results could be generalized to other individuals. Although this new application of 3D KUD can be used for identifying collision risk between obstacles and species in 3D space, some aspects of the method need to be investigated further. For example, more research into producing easily interpretable results with confidence measures is needed.

In addition, spatiotemporal autocorrelation in movement data is an important issue because this yields an underestimation of an individual's space use (Fleming et al. 2015). So far, in animal movement research, many studies have focused on autocorrelated data in 2D, whereas 3D data studies might well be required (Fieberg 2007, Fleming and Calabrese 2017). We expect this new application of 3D KUD to offer exciting opportunities for exploring the process of volumetric analysis in animal movement research, such as spatial autocorrelation in estimating risk and the need to develop methods for 3D kernel density estimators.

ACKNOWLEDGMENTS

LITERATURE CITED

Barrios, L., and A. Rodríguez. 2004. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. Journal of Applied Ecology 41:72–81.

Belant, J. L., J. J. Millspaugh, J. A. Martin, and R. A. Gitzen. 2012. Multi-dimensional space use: the final frontier. Frontiers in Ecology and the Environment 10:11–12.

Bellebaum, J., F. Korner-Nievergelt, T. Dürr, and U. Mammen. 2013. Wind turbine fatalities approach a level of concern in a raptor population. Journal for Nature Conservation 21:394–400.

Benhamou, S., and D. Cornélis. 2010. Incorporating movement behavior and barriers to improve kernel home range space use estimates. Journal of Wildlife Management 74:1353–1360.

BirdLife International. 2017. Important Bird Area factsheet: Country/Territory Spain. <http://datazone.birdlife.org/site/factsheet/estrecho-de-gibraltar-iba-spain>. Accessed 10 Mar 2017.

Bosè, M., and F. Sarrazin. 2007. Competitive behaviour and feeding rate in a reintroduced population of Griffon vultures Gyps fulvus. Ibis 149:490–501.

Bouten, W., E. W. Baaij, J. Shamoun-Baranes, and K. C. Camphuysen. 2013. A flexible GPS tracking system for studying bird behaviour at multiple scales. Journal of Ornithology 154:571–580.

Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy 24:346–352.

Cagnacci, F., L. Boitani, R. A. Powell, and M. S. Boyce. 2010. Animal ecology meets GPS-based radiotelemetry: a perfect storm of opportunities and challenges. Philosophical Transactions of the Royal Society B: Biological Sciences 1550:2157–2162.

Carrete, M., J. A. Sánchez-Zapata, J. R. Benítez, M. Lobón, F. Montoya, and J. A. Donázar. 2012. Mortality at wind-farms is positively related to large-scale distribution and aggregation in Griffon vultures. Biological Conservation 14:102–108.

Cooper, N. W., T. W. Sherry, and P. P. Marra. 2014. Modeling three-dimensional space use and overlap in birds. Auk 131:681–693.

De Lucas, M., M. Ferrer, M. J. Bechard, and A. R. Muñoz. 2012. Griffon vulture mortality at wind farms in southern Spain: distribution of fatalities and active mitigation measures. Biological Conservation 147:184–189.

De Lucas, M., G. F. E. Janss, D. P. Whitfield, and M. Ferrer. 2008. Collision fatality of raptors in wind farms does not depend on raptor abundance. Journal of Applied Ecology 45:1695–1703.

Del Moral, J. C., editor. 2009. El buitre leonado en España. Población reproductora en 2008 y método de censo. SEO/BirdLife, Madrid, Spain. https://www.seo.org/wp-content/uploads/2012/04/30_buitre_leonado.pdf. Accessed 18 Jul 2019. [In Spanish.]

DeVault, T. L., B. D. Reinhart, I. L. Brisbin, Jr., and O. E. Rhodes, Jr. 2005. Flight behavior of black and turkey vultures: implications for reducing bird–aircraft collisions. Journal of Wildlife Management 69:601–608.

Drewitt, A. L., and R. H. W. Langston. 2008. Collision effects of wind-power generators and other obstacles on birds. Annals of the New York Academy of Sciences 1134:233–266.

Duong, T. 2007. ks: kernel density estimation and kernel discriminant analysis for multivariate data in R. Journal of Statistical Software 21:1–16.

Ferrer, M., M. De Lucas, G. F. E. Janss, E. Casado, A. R. Muñoz, M. J. Bechard, and C. P. Calabuig. 2012. Weak relationship between risk assessment studies and recorded mortality in wind farms. Journal of Applied Ecology 49:38–46.

Fieberg, J. 2007. Kernel density estimators of home range: smoothing and the autocorrelation red herring. Ecology 88:1059–1066.

Fleming, C. H., and J. M. Calabrese. 2017. A new kernel density estimator for accurate home range and species-range area estimation. Methods in Ecology and Evolution 8:571–579.

Fleming, C. H., W. F. Fagan, T. Mueller, K. A. Olson, P. Leimgruber, and J. M. Calabrese. 2015. Rigorous home range estimation with movement data: a new autocorrelated kernel density estimator. Ecology 96:1182–1188.

Ford, R. G., and D. W. Krumme. 1979. The analysis of space use patterns. Journal of Theoretical Biology 76:125–155.

Global Wind Energy Council. 2016. Global wind energy outlook. Global Wind Energy Council. http://www.gwec.net/publications/global-wind-energy-outlook/global-wind-energy-outlook-2016. Accessed 12 Oct 2018.

Guerra García, J. M., E. Baeza-Rojano Pageo, M. D. P. Cabezas Rodríguez, I. Pacios, J. J. Díaz Pavón, and J. C. García Gómez. 2009. Spatial patterns and seasonal fluctuations of the intertidal Caprellidae (Crustacea: Amphipoda) from Tarifa Island, Southern Spain. Zoológica Baetica 20:59–72.

Hindell, M. A., M. A. Lea, C. A. Bost, J. B. Charrassin, N. Gales, S. Goldsworthy, B. Page, G. Robertson, B. Wienecke, M. O'Toole, and C. Gulnet. 2011. Foraging habitats of top predators, and areas of ecological significance, on the Kerguelen Plateau. The Kerguelen Plateau: Marine Ecosystem and Fisheries, Abbeville, France: Societe Francaise d'Ichtyologie 2011:203–215.

Jennrich, R. I., and F. B. Turner. 1969. Measurement of non-circular home range. Journal of Theoretical Biology 22:227–237.

Katajisto, J., and A. Moilanen. 2006. Kernel-based home range method for data with irregular sampling intervals. Ecological Modelling 194:405–413.

Kenward, R. E. 2000. A manual for wildlife radio tagging. Second edition. Academic Press, London, England, United Kingdom.

Kie, J. G., J. Matthiopoulos, J. Fieberg, R. A. Powell, F. Cagnacci, M. S. Mitchell, and P. R. Moorcroft. 2010. The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society of London B: Biological Sciences 1550:2221–2231.

Koeppl, J. W., N. A. Slade, K. S. Harris, and R. S. Hoffmann. 1977. A three-dimensional home range model. Journal of Mammalogy 58:213–220.

Kranstauber, B., R. Kays, S. D. LaPoint, M. Wikelski, and K. Safi. 2012. A dynamic Brownian bridge movement model to estimate utilization distributions for heterogeneous animal movement. Journal of Animal Ecology 81:738–746.

Kranstauber, B., K. Safi, and F. Bartumeus. 2014. Bivariate Gaussian bridges: directional factorization of diffusion in Brownian bridge models. Movement Ecology 2014:2–5.

Macdonald, D. W., F. G. Ball, and N. G Hough. 1980. The evaluation of home range size and configuration using radio tracking data. Pages 405–424 in C. J. Amlaner, Jr. and D. W. Macdonald, editors. A handbook on biotelemetry and radio tracking. Proceedings of an international conference on telemetry and radio tracking in biology and

medicine, Oxford 20–22 March 1979. Pergamon Press, Oxford, England; New York, New York, USA; Toronto, Ontario, Canada; Sydney, New South Wales, Australia; Paris, France; and Frankfurt, Germany. https://doi.org/10.1016/B978-0-08-024928-5.50052-X

Marques, A. T., H. Batalha, S. Rodrigues, H. Costa, M. J. R. Pereira, C. Fonseca, M. Mascarenhas, and J. Bernardino. 2014. Understanding bird collisions at wind farms: an updated review on the causes and possible mitigation strategies. Biological Conservation 17:40–52.

Marques, A. T., C. D. Santos, F. Hanssen, A. R. Muñoz, M. Wikelski, F. Moreira, J. M. Palmeirim, and J. P. Silva. 2020. Wind turbines cause functional habitat loss for migratory soaring birds. Journal of Animal Ecology 89:93–103.

Mateo-Tomás, P., and P. P. Olea. 2011. The importance of social information in breeding site selection increases with population size in the Eurasian Griffon vulture Gyps fulvus. Ibis 153:832–845.

Mohr, C. O. 1947. Table of equivalent populations of North American small mammals. American Midland Naturalist 37:223–249.

Monsarrat, S., S. Benhamou, F. Sarrazin, C. Bessa-Gomes, W. Bouten, and O. Duriez. 2013. How predictability of feeding patches affects home range and foraging habitat selection in avian social scavengers? PLoS ONE 8(1):e53077.

Monterroso, P., N. Sillero, L. M. Rosalino, F. Loureiro, and P. C. Alves. 2013. Estimating home-range size: when to include a third dimension? Ecology and Evolution 3:2285–2295.

Olea, P. P., and P. Mateo-Tomás. 2014. Living in risky landscapes: delineating management units in multithreat environments for effective species conservation. Journal of Applied Ecology 51:42–52.

Powell, R. A., and M. S. Mitchell. 2012. What is a home range? Journal of Mammalogy 93:948–958.

Reading, R. P., G. Maude, P. Hancock, D. Kenny, and R. Garbett. 2014. Comparing different types of patagial tags for use on vultures. Vulture News 67:33–42.

Rutz, C., and G. C. Hays. 2009. New frontiers in biologging science. Biology Letters 5:289–292.

Seaman, D. E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075–2085.

Signer, J., J. Fieberg, and T. Avgar. 2017. Estimating utilization distributions from fitted step-selection functions. Ecosphere 8(4):e01771.

Simpfendorfer, C. A., E. M. Olsen, M. R. Heupel, and E. Moland. 2012. Three-dimensional kernel utilization distributions improve estimates of space use in aquatic animals. Canadian Journal of Fisheries and Aquatic Sciences 6:565–572.

Siniff, D. B., and J. R. Tester. 1965. Computer analysis of animal-movement data obtained by telemetry. Bioscience 15:104–108.

Stigka, E. K., J. A. Paravantis, and G. K. Mihalakakou. 2014. Social acceptance of renewable energy sources: a review of contingent valuation applications. Renewable and Sustainable Energy Reviews 3:100–106.

Tellería, J. L. 2009. Overlap between wind power plants and Griffon vultures Gyps fulvus in Spain. Bird Study 56:268–271.

Tomkiewicz, S. M., M. R. Fuller, J. G. Kie, and K. K. Bates. 2010. Global positioning system and associated technologies in animal behaviour and ecological research. Philosophical Transactions of the Royal Society B: Biological Sciences 1550:2163–2176.

Van Winkle, W. 1975. Comparison of several probabilistic home-range models. Journal of Wildlife Management 39:118–123.

Wilcove, D. S. 2010. Endangered species management: the US experience. Pages 220–235 in N. S. Sodhi and P. R. Ehrlich, editors. Conservation biology for all. Oxford University Press, Oxford, England, United Kingdom.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Worton, B. J. 1995. Using Monte-Carlo simulation to evaluate kernel-based home-range estimators. Journal of Wildlife Management 59:794–800.

Xirouchakis, S. M., and G. Andreou. 2009. Foraging behaviour and flight characteristics of Eurasian Griffons Gyps fulvus in the island of Crete, Greece. Wildlife Biology 15:37–52.

Yuan, X., J. Zuo, and D. Huisingh. 2015. Social acceptance of wind power: a case study of Shandong Province, China. Journal of Cleaner Production 92:168–178.

Zimmerling, J. R., and C. M. Francis. 2016. Bat mortality due to wind turbines in Canada. Journal of Wildlife Management 80:1360–1369.

Associate Editor: Johnson.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article.

Figure S1. The different situations of space use of Griffon vulture in El Estrecho natural park in Tarifa (southern Spain) on the northern shore of the Strait of Gibraltar during 2012–2013. The space use displayed along (a) the X-, Y- and Z-axis, (b) X- and Z-axis, and (c) Y- and Z-axis, in 3 figures. The green and purple shapes indicate 50% and 95% kernel utilization distributions (KUDs).