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Flight Altitudes of Raptors in Southern Africa Highlight Vulnerability of Threatened Species to Wind Turbines

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Energy infrastructure, particularly for wind power, is rapidly expanding in Africa, creating the potential for conflict with at-risk wildlife populations. Raptor populations are especially susceptible to negative impacts of fatalities from wind energy because individuals tend to be long-lived and reproduce slowly. A major determinant of risk of collision between flying birds and wind turbines is the altitude above ground at which a bird flies. We examine 18,710 observations of flying raptors recorded in southern Africa and we evaluate, for 49 species, the frequency with which they were observed to fly at the general height of a wind turbine rotor-swept zone (50–150 m). Threatened species, especially vultures, were more likely to be observed at turbine height than were other species, suggesting that these raptors are most likely to be affected by wind power development across southern Africa. Our results highlight that threatened raptor species, particularly vultures, might be especially impacted by expanded wind energy infrastructure across southern Africa.

Keywords: Africa, bird of prey, flight behavior, raptor, wind turbine, wind power

INTRODUCTION

Globally, wind energy has expanded substantially in past decades (Wiser et al., 2011; Energy Information Agency, 2020; Global Wind Energy Council, 2020). Particularly in Africa, the quantity of energy generated from wind power has increased, with potential for expansion across the continent (Mentis et al., 2015; Mas'ud et al., 2017; Kazimierczuk, 2019). The Global Wind Energy Council (2020) predicted that wind energy production in Africa will more than double over the period from 2018 to 2023.

There are considerable ecological challenges to the expansion of wind energy (Katzner et al., 2019). Among the most prominent of these is wildlife fatality from collisions with turbines (Arnett et al., 2008; Smallwood and Thelander, 2008; Loss et al., 2013). Even if animals can avoid collision by adjusting their use of space, such avoidance of turbines results in a functional loss of habitat (Larsen and Guillemette, 2007; Diehl, 2013; Marques et al., 2020).

Raptors (Iriarte et al., 2019; McClure et al., 2019) are of particular conservation concern because they are more threatened and declining than other groups of birds (McClure and Rolek, 2020). Unfortunately, compared to other bird taxa, raptors are especially susceptible to negative impacts of wind energy because they are often victims of fatal collisions (Thaxter et al., 2017). These birds

tend to be long-lived and reproduce slowly (Newton, 1998; Madders and Whitfield, 2006; Smith and Dwyer, 2016; Watson et al., 2018), thus survival rates tend to drive population trajectories (Newton, 1979; Sæther and Bakke, 2000). Indeed, collision at wind turbines creates population-level risk for species as diverse as Egyptian Vultures (Carrete et al., 2009) and Red Kites (Schaub, 2012).

Africa is a hotspot of threatened and declining raptors (McClure et al., 2018b). Accipitrid vultures are among the most threatened groups of birds on the planet (Buechley and Şekercioğlu, 2016; Ogada et al., 2016; McClure and Rolek, 2020), but there are also a suite of other declining species throughout Africa (McClure et al., 2018b). Within South Africa, diurnal raptors in the families Accipitriformes and Falconiformes are the group of birds most often killed by wind turbines (Perold et al., 2020).

Whether a given turbine affects a flying animal depends on that animal's use of three dimensional space. Indeed, flight altitude is an important determinant of collision risk (Band et al., 2007; Furness et al., 2013; Khosravifard et al., 2020). For example, Poessel et al. (2018) demonstrated that Critically Endangered California Condors (*Gymnogyps californianus*) more frequently flew at altitudes of wind turbine blades at specific times of the day and the year. Thus their flight behavior modulates their risk of collision with wind turbines (Poessel et al., 2018). Examining flight altitude is frequently used to lend inference into risk of collision with wind turbines (Katzner et al., 2012; Johnston A. et al., 2014; Ainley et al., 2015; Péron et al., 2017; Tikkanen et al., 2018).

Perhaps the most accurate method of determining flight altitude is via high-resolution global positioning system (GPS; Schaub et al., 2020) or barometric altimeters (Cleasby et al., 2015; but see Péron et al., 2020). However, a more commonly used method to determine flight altitude, especially in relation to turbine height, is visual estimation by human observers (Osborn et al., 1998; Larsen and Guillemette, 2007; Rothery et al., 2009; Smallwood et al., 2009; Dahl et al., 2013; Johnston A. et al., 2014; Johnston N. et al., 2014; Ainley et al., 2015). In fact, a recent review demonstrated that; of methods to discern bird flight altitude, visual methods were by far the most often used (Largey et al., 2021).

Here, we analyze thousands of observations of raptors flying in southern Africa. We calculate the proportion of observations in which each species was seen at the height of a typical wind turbine and evaluate which taxa are more often observed at turbine height. We also test whether threatened species are more often observed at turbine height than non-threatened species, and if scavenging vultures were more often observed at turbine height than were other raptors.

MATERIALS AND METHODS

We evaluated flight altitudes from observation records stored in the Global Raptor Impact Network (GRIN) database (sourced 2 September, 2020). GRIN is a collaborative information platform designed to support raptor ecology and conservation by collecting, storing, analyzing, and distributing information about raptors (McClure et al., 2021a).[1] The majority of the data within the GRIN database were collected using one of two smartphone applications [hereafter, apps; either the GRIN mobile app (2020–present), or its deprecated predecessor the African Raptor Observations app (2012–2020)]. These apps allow users to record georeferenced observations of raptors including the species, whether the bird is flying, and at what estimated altitude. Most of the users of these apps are raptor biologists.

Altitude above ground was recorded by users of the GRIN and African Raptor Observations apps into categories of 0, 1– 20, 20–50, 50–150, 150–500, and >500 m. Users were given references for each altitude category as ground level, low tree, tall tree, turbine risk, low altitude, and high altitude, respectively. We assumed that using such categories lessens some of the error associated with estimating altitude.
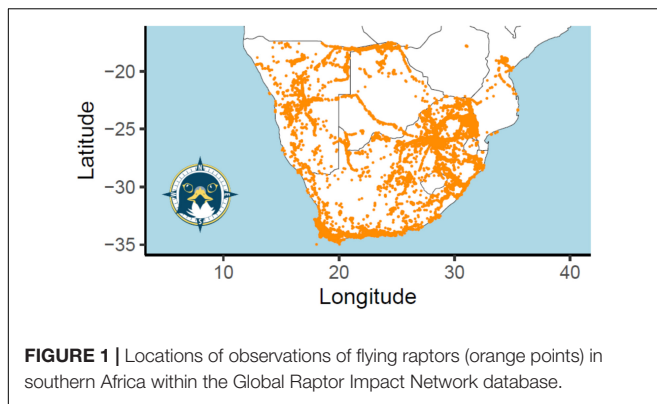
Users can log their confidence in each species identification on a scale of 0–100%; for this analysis, we only analyzed observations with 100% confidence in identification. We also only considered observations of raptors flying. We considered data from all seasons for each species for which there were ≥25 flight observations within southern (≤−17.5° latitude) Africa. For each of those species, we calculated the category in which they were most often observed (i.e., the mode) and the proportion of observations at turbine height (50–150 m).

We used logistic regression to test whether the proportion of observations approximately at the height of the rotor-swept zone of modern turbines (50–150 m) was greater for species designated as threatened with extinction on the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species (BirdLife International, 2021). We categorized species as threatened when listed by IUCN as Vulnerable, Endangered, or Critically Endangered (IUCN Standards and Petitions Subcommittee, 2019). The response variable for this regression included two vectors, one containing the number of observations at turbine height and the other containing the number of observations outside of turbine height. The explanatory variable was binary with 1 indicating a threatened species and 0 indicating a non-threatened species. To analyze whether vultures were observed more at turbine height than other raptors, we performed another similar logistic regression where we coded the explanatory variable as 1 when the species was a vulture and a 0 otherwise. We performed analysis using the glm() function in R (R Core Team, 2019) with a binomial distribution.

RESULTS

Within our study area, there were 111,024 observations of raptors; 62,911 observations were collected using the apps; and 19,061 were of flying raptors. Of these, we analyzed the 18,710 observations that had 100% confidence in identification and were of the 49 species with ≥25 observations (**Figures 1,2**). These were collected by 73 users, although one (author AB) collected

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[1] www.globalraptors.org

FIGURE 1 | Locations of observations of flying raptors (orange points) in southern Africa within the Global Raptor Impact Network database.

a plurality of the data (39%). Proportions of observations at turbine height ranged from 0.49 for the Lappet-faced Vulture (*Torgos tracheliotos*) to 0.02 for the Barn Owl (*Tyto alba*; **Figure 2** and **Supplementary Tables 1,2**). Nine (18%) species, including five vulture and three eagle species, had the mode of their observations at turbine height, and one species had a mode above turbine height (**Figure 2** and **Supplementary Tables 1,2**).

Of the 49 species, 11 met our criteria for 'threatened'; five of these were vultures. The nine species with the highest proportions of observations at turbine height also had modes at turbine height and six of these species were threatened (**Figure 2** and **Supplementary Tables 1,2**). Threatened species ($\beta = 0.97$, $SE = 0.03$, $p < 0.01$) and vultures ($\beta = 1.08$, $SE = 0.03$, $p < 0.01$) were observed proportionally more at turbine height than non-threatened species and non-vultures, respectively.

DISCUSSION

Our results provide initial insight into the set of raptor species that may be affected by wind power development within southern Africa. However, if the two-dimensional distribution of birds and turbines do not overlap, then collision risk is essentially zero. Some studies have identified areas of potential conflict and for potential prioritization for conservation by examining the spatial overlap of potential wind power development with two-dimensional species ranges (Santangeli et al., 2018, 2019). That said, within a species distribution, collisions with wind turbines occur in three-dimensions such that a bird must be within both the horizontal and vertical planes of a rotor-swept zone. We therefore interpret our results under the assumption that species seen more often at rotor-swept zone height are at increased risk of collision. Our results thus add perspective to two-dimensional distributional studies by highlighting which species behavior might influence their demographic risk from wind power development within their southern African range.

Populations of vultures are declining drastically across Africa (Ogada et al., 2016), and these species were among those for which the greatest proportion of observations were at turbine height. When African vultures are evaluated for conservation purposes, wind energy is only rarely considered a threat (BirdLife International, 2021). In fact, of the 11 threatened species we
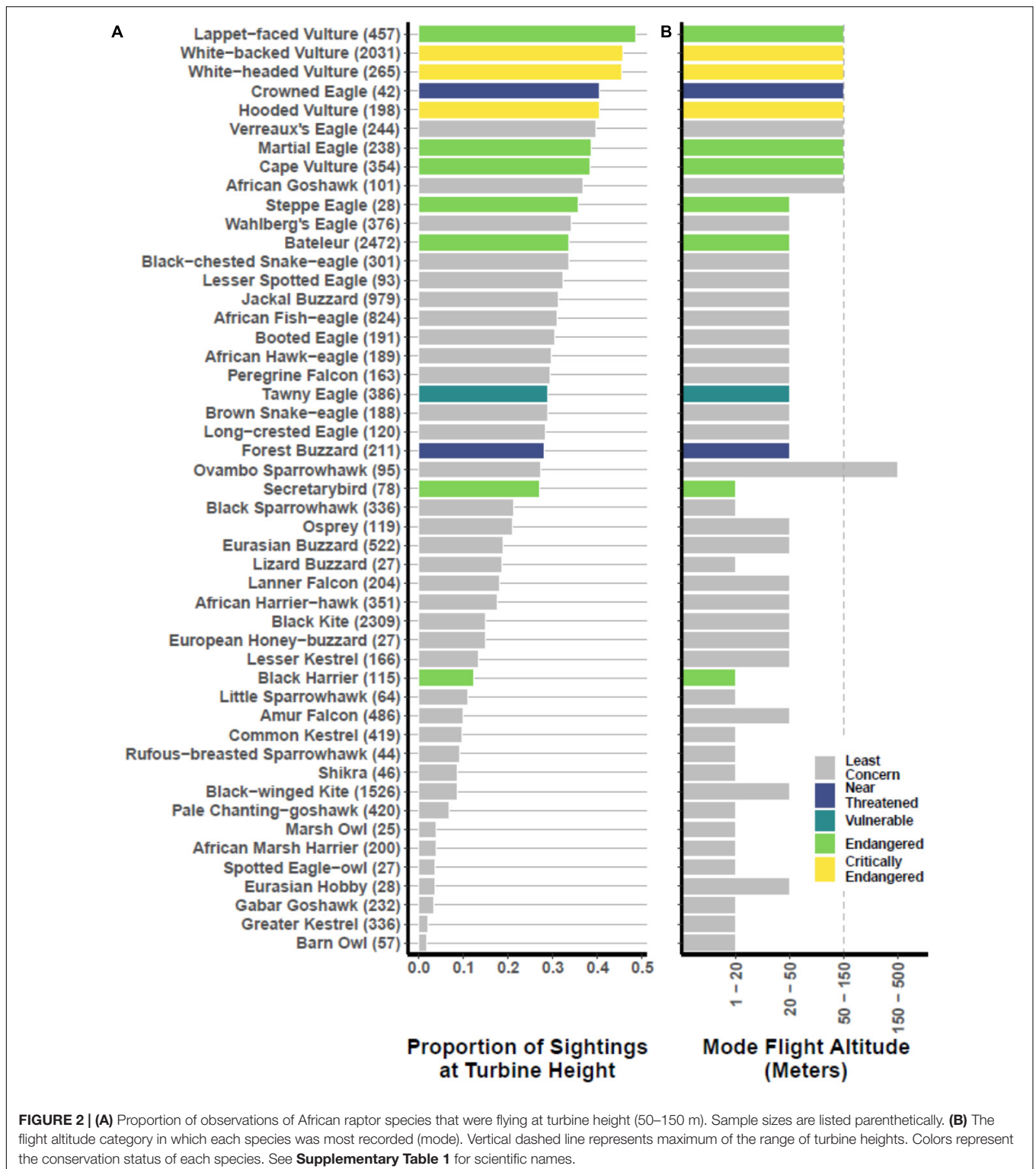
considered, the IUCN Red List (BirdLife International, 2021) identifies renewable energy as a threat for only one vulture and two eagles (Cape Vulture *Gyps coprotheres*, Steppe Eagle *Aquila nipalensis*, and Crowned Eagle *Stephanoaetus coronatus*). However, the Multi-species Action Plan to Conserve African-Eurasian Vultures (Botha et al., 2017), prominently lists collisions with wind turbines as a threat to vultures. It is possible that the Red List underestimates the threat wind power poses to raptors in Africa (Santangeli et al., 2018), or it is possible that wind energy is such a novel threat that it has not yet been incorporated into these assessments.

The number of existing wind power facilities across Africa is unlikely to be large enough to be threatening most raptor populations at a large scale. That said, despite the lack of a current threat from existing wind turbines, our approach is useful because it identifies species that might be at risk if such infrastructure expands into their habitat. Horizon scanning—i.e., systematically searching for potential threats and opportunities—is important (Sutherland and Woodroof, 2009) and our evaluation of flight altitude adds to prior work on this subject (Santangeli et al., 2018, 2019). The fact that threatened species were observed more often at turbine height suggests that expansion of wind power across southern Africa might expose more of these African raptor species to increased mortality.

Many factors determine the flight altitude of a bird at any given moment. Such factors include topography, vegetation, weather, wind conditions, and time of day or year (Lanzone et al., 2012; Poessel et al., 2018; Tikkanen et al., 2018; Duerr et al., 2019). Despite its utility as a first analysis of risk, our analyses ignore many of these factors. Future research, therefore, could discern other patterns in our dataset that would provide further inference into raptor flight behavior.

Site-specific factors also influence a bird's risk of collision within a wind power facility (de Lucas et al., 2008). Indeed, certain turbines present more collision risk than others (McClure et al., 2021b), even under low bird densities (de Lucas et al., 2012). Weak relationships between pre-construction abundance and post-construction mortality at wind power facilities make it difficult to predict where collision risk will be greatest (Ferrer et al., 2012). The flight paths of Griffon Vultures through a wind power facility in Spain matched predominant wind flows (de Lucas et al., 2012). Thus, flight altitude is but one factor of the many that determine the collision risk of birds with wind turbines (Marques et al., 2014).

Any study is subject to some error, especially when using human observers. Our methodology minimized errors by relying to a large part on data collection by raptor biologists and by classifying observations into broad altitudinal ranges. Human ability to identify raptors declines with distance (McClure et al., 2018a), but we avoid this problem to some extent by only including data in which the user was 100% confident in identification. Detection probability also decreases with distance (Berthiaume et al., 2009; Nolte et al., 2016; McClure et al., 2018a), meaning that many species probably spend more time at greater altitudes than our results suggest. Importantly, large birds are easier to detect than smaller ones at greater distances (Nolte et al., 2016). Because threatened species were

FIGURE 2 | (A) Proportion of observations of African raptor species that were flying at turbine height (50–150 m). Sample sizes are listed parenthetically. **(B)** The flight altitude category in which each species was most recorded (mode). Vertical dashed line represents maximum of the range of turbine heights. Colors represent the conservation status of each species. See **Supplementary Table 1** for scientific names.

mostly vultures and eagles, which are relatively large, it is possible that they are observed more often at turbine height than other species because they are more detectable at that altitude. Because of these constraints, we interpret our results in the context of these limitations and for bird flight within the range of human sight. Our work says little about high altitude bird flight that is difficult for humans to observe from the ground.

Despite these potential sources of error, our results match what one would expect *a priori* based on the biology of many focal

species. For example, kestrels and harriers are known to fly or hover close to the ground, whereas vultures and eagles are soaring birds that fly at greater altitude (Ferguson-Lees and Christie, 2001). Barn Owls (*Tyto alba*) were observed the least at turbine height and were most often observed flying at low altitude (1–20 m). It is possible this is partly due to the inability of observers to see far at night when owls are active. However, Barn Owls most often forage by quartering low (1.5–4.5 m; Marti et al., 2020) over open areas (König and Weick, 2008; Marti et al., 2020). This species is also a frequent victim of vehicle collision (Gomes et al., 2009; Boves and Belthoff, 2012; Arnold et al., 2019), reflecting their low-flying behavior. We were surprised that the Ovambo Sparrowhawk (*Accipiter ovampensis*), a relatively small woodland-dwelling accipiter (Ferguson-Lees and Christie, 2001), had the highest mode flight altitude. However, this species sometimes forages by stooping from high over the canopy (Kemp and Kemp, 1975; Kemp and Kirwan, 2020). Ferguson-Lees and Christie (2001, p. 576), state that this species "stoops at prey from up to 150 m." Thus, past observations of these species support our results.

There is a paucity of quantitative work examining the flight altitudes of our focal species. Indeed, we are aware of a single study that we can use to quantitatively check our results. In South Africa, Murgatroyd et al. (2021) used GPS tracking to demonstrate that Verreaux's Eagles (*Aquila verreauxii*) fly at turbine height (defined as ≤200 m) 68 ± 4% of the time. This is consistent with the data from GRIN, in which Verreaux's Eagles were seen flying at or below turbine height 73% of the time. Thus, although error estimation by human observers is imprecise, the data for this species are consistent with existing GPS data. Given the prevalence of studies using visual estimation of flight altitude (Largey et al., 2021), a fruitful avenue for future work would therefore be to compare our observations with results from GPS telemetry.

This is the first study to examine the flight altitudes of so many species across such a large region. As the number of users of the GRIN app rises, future work will expand the current analysis to a global scale. Although Africa is certainly a hotspot of raptor diversity and conservation need, other areas including South America and South and Southeast Asia are also priorities (McClure et al., 2018b). Study of flight altitude of raptors in those understudied regions, whether via the GRIN app or otherwise, would contribute to understanding of the potential risk these birds may face from wind energy development. This may be especially important given the height of wind turbines is projected to grow with time, and already

some turbines have blades that extend above the 150 m we considered here. Works such as this are an important component of efforts to encourage compatibility of energy development with conservation of biodiversity.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because we did not handle any animals.

AUTHOR CONTRIBUTIONS

CM devised the study, performed analysis, and wrote the first draft. LD managed the data. All authors provided substantial input in interpretation of results and edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2021.667384/full#supplementary-material

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