A contribution to the

Biodiversity Management Plan for Jeffreys Bay

Black Harrier Population Size and Critical Habitat at the Jeffreys Bay Wind Farm

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Black Harriers *Circus maurus* are an *Endangered* species, endemic to South Africa and Namibia, and among the rarest raptors on the African continent. They are now known to be susceptible to wind farms in South Africa. This document seeks to put in perspective the population size and sensitivity of the South African Black Harrier population, and at the Jeffreys Bay Wind Farm (JBWF) in particular. Our aim is to provide essential background on the species to allow us to assess how vulnerable it is to a changing environment, and specifically to determine the levels of mortality that may be pivotal to the global population of Black Harriers, using a population modelling approach. This modelling work was carried out by Francisco Cervantes Peralta and forms part of this report. We use this to argue that even low levels of mortality at wind farms will reduce the global population and, thus, mitigations are essential at wind farms. This is a contribution to the Biodiversity Management Plan for Jeffreys Bay Wind Farm by Birds & Bats Unlimited.

Summary

Black Harriers are an Endangered *raptor with a very small world population, centred in South Africa. Increased unnatural mortality of this species was recently found during a 4-year study of Black Harriers at Jeffreys Bay Wind Farm (JBWF) where six Black Harriers have been killed in four years (five by turbine blades and one dependent young lost). Two active nests are known – in the north-east and the south-west portions of the wind farm – but have never successfully fledged young. Three independent methods reveal that between 5 and 10 nests are likely in the Greater Kromme area and between 1% and 3.5% of the global population occurs at two nearby roosts. These exceed the criteria for the area to be classified as Critical Habitat (sensu IFC performance Standards). Black Harrier fatalities are related to their increase in flight height behaviour, within the blade swept area, during the breeding season. Fatalities of all collision-prone raptors on the JBWF site were also significantly related to the passage rate – the more flights, the more risk of being struck and killed. To determine the effects of this high rate of mortality at JBWF we modelled South Africa's small global Black Harrier population with inputs of survival, reproductive success and fatalities per year. For any level of mortality beyond 0.5 birds per year at just five wind farms (i.e. one harrier killed every second year) or for JBWF alone (at 1.25 adults and 0.25 killed per year) we forecast a long-term decline in the global population of Black Harriers over 120 years. Thus, at an average 3-fold higher than that (1.5 harriers killed at JBWF per year) the global population of the Black Harrier could collapse in 120 years in a cumulative sense. Given that the only large roost of these endemic birds is found 7-km north-east at Zuurbron farm and holds significant numbers of the world population, then birds are always present either breeding or wintering and would always be under threat. Independent modelling of the species likelihood of occurrence in the Great Kromme area (R Colyn unpubl data) indicates that it is prime habitat for globally* Endangered *Black Harriers. Given that the area holds five operational wind farms – including the longest running farm at JBWF– Globeleq must lead the way with its biodiversity plan to help prevent the long-term extinction of this endemic raptor.*

Background

The Black Harrier *Circus maurus* is a highly threatened species that occurs regularly at Jeffreys Bay Wind Farm (JBWF) and surrounding areas. It was upgraded to the IUCN *Endangered* category in 2018 http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T22695379A118433168.en following the publication of the South African (Taylor et al. 2015) and Namibian (Simmons et al. 2015) Red Data books, both of which re-classified the Black Harrier as *Endangered* in their regional populations. Together these countries hold the world population of this rare species.

The global population is small, for a continental harrier species (Simmons and Simmons 2000) and is estimated at 1,000 mature individuals (Siegfried 1992, Taylor et al. 2015). It is declining due to severe habitat loss and degradation in the Overberg (Curtis et al. 2014) and suffers from high pesticide burdens in some areas in the Western Cape (Garcia-Heras et al. 2018) and a low genetic diversity throughout its global population (Fuchs et al. 2014). The concern over the impact of wind farms has precipitated specific guidelines to protect the species (Simmons et al. 2020). The extent of its global population is well researched (Simmons 1997) and updates from the second Southern African Bird Atlas project http://sabap2.adu.org.za/species/169#pgcontent) are shown (Figure 2).

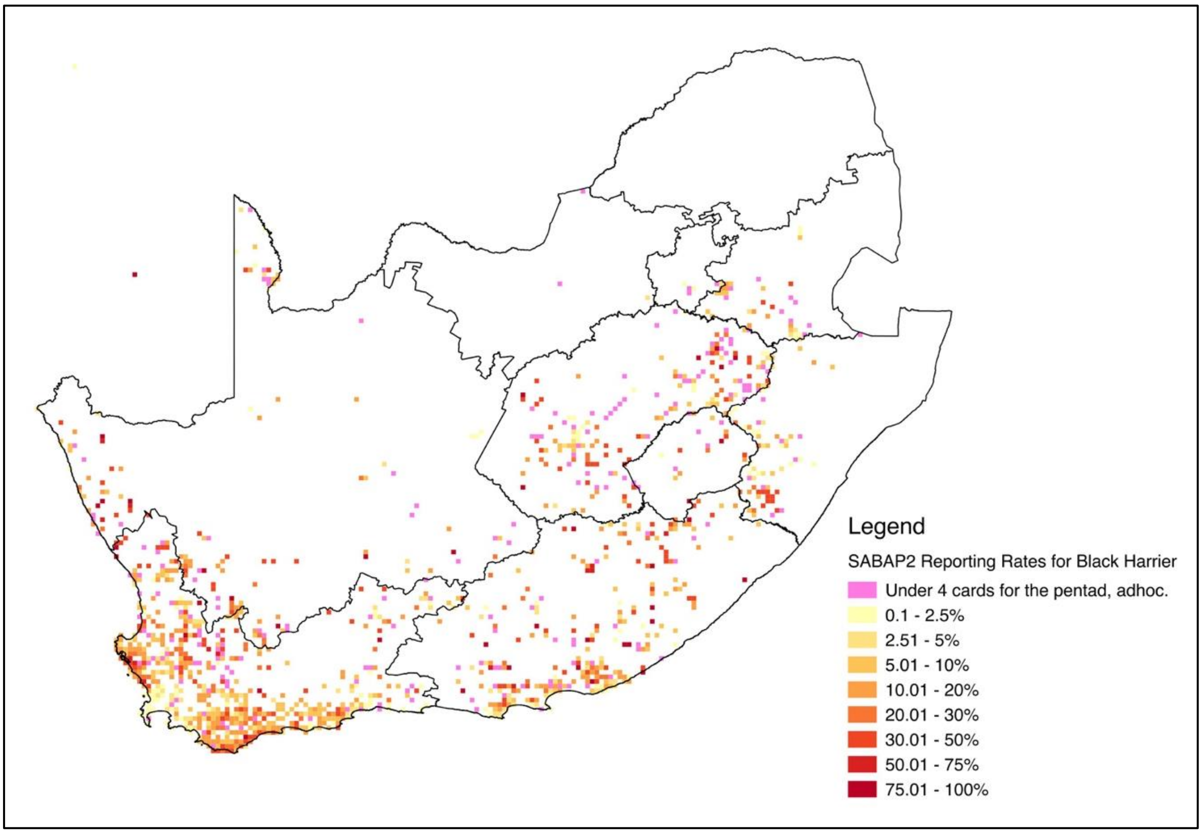

Figure 1.The global distribution of the Black Harrier, as determined by the Southern African Bird Atlas Project 2. This species is concentrated in south-western South Africa during breeding with less frequent breeding in the Eastern and Northern Cape. Most of the population then moves eastwards to the Eastern Cape, Free State, Lesotho and KZN in summer (Garcia-Heras et al. 2019). The percentages refer to the reporting rates (the number of times a bird is recorded relative to the number of atlas cards submitted). This is a measure of the likelihood that the harrier occurs in that pentad.

Is the Breeding habitat Critical Habitat ?

The Greater Kromme region was chosen as the area of assessment, because it includes Jeffreys Bay Wind Farm. Within its 1800 km² area it is the subject of a long-term conservation stewardship programme by Conservation Outcomes https://www.gksinitiative.co.za/ and the JBWF is part of this initiative. It is being conserved because of its high biodiversity and unspoiled habitats – both of which attract breeding harriers (Jenkins et al. 2013). It is also home to five operational wind farms, and several more in the pipeline.

The question is: Is the area Critical Habitat for the Black Harrier? Under IFC performance standards the area identified can be classed as Critical Habitat if it holds > 0.5% of the global population and > 5 breeding units.

We answered this using several independent methods : (i) Black Harrier habitat suitability models (ii) Black Harrier nesting numbers and (iii) Roost numbers.

Recent unpublished modelling of habitat suitability for Black Harriers was undertaken by Robin Colyn, of Birdlife South Africa, (in prep). This was based on the results of the satellite-tagging programme started in 2008 by RES (Garcia et al. 2019). Thirteen adult Harriers were followed with Argos tags and GPS/GSM tags all over South Africa and Namibia for an average of 365 $\pm$ 168 days. This research reveals that the habitat suitability score of the areas in and around the Jeffreys Bay Wind Farm falls within the highest range 40–99%; meaning it is among the most suitable harrier habitat in South Africa (Figure 2). While 40% may not appear to be highly suitable, one must appreciate that Black Harriers migrate in an out of areas (see Migration section below) and highly suitable breeding habitat may be used only once every second (or more) years as the birds sample all across southern South Africa for areas with good rainfall and high prey populations to breed (Garcia et al. 2019). This is why the 40% - 99% occupancy is regarded as the highest category (R Colyn unpubl. data) Large sections of the Greater Kromme (GK) trust fall into this category amounting to approximately 20% of the 1801 km^2 area.

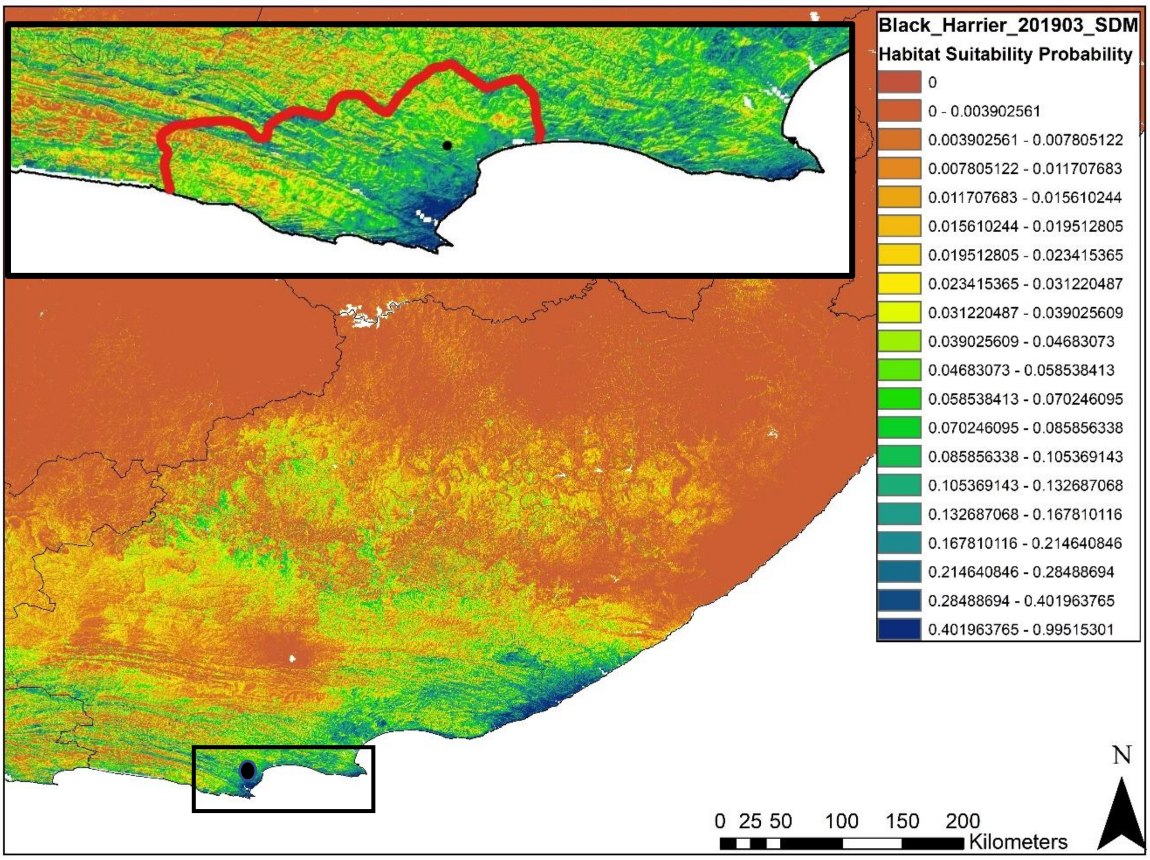

Figure 2: Output of breeding habitat suitability model for Black Harriers in the Eastern Cape; cool colours indicate highly suitable habitat for breeding and warm colours a low probability of suitable habitat (Colyn et al. in prep). The black circle shows

the position of the JBWF within the Greater Kromme stewardship area. Inset is the area enlarged indicating the Greater Kromme area (red polygon line). Five operational wind farms occur within this area as shown in Figure 3..

We can use this to estimate the number of harrier nests in the GK. Based on the average number of active harrier nests (8) in the West Coast National Park (WCNP - an area of ~300 km^2) each year over the last 18 years (RES unpubl data) gives a nesting density of 2.7 nest/100 km^2. Unsurprisingly, this core breeding area was also modelled as falling within the highest suitability category of 40 – 99% by Colyn et al. (in prep). We can use these figures to guesstimate the approximate number of nests likely within the Greater Kromme area as follows:

- Area of highest harrier suitability within GK is ~20% of 1800 km^2 = 360 km^2
- Harrier nesting density in these highly suitable areas (from WCNP) = 2.7 nest/100 km^2
- Number of Black Harrier nests in the 360 km^2 area is 2.7 x 3.6 = 9.7 nests.

These estimates suggest a minimum of **10 active Black Harrier nests** in the Greater Kromme area.

How do these estimated 10 nests compare with the number of Black Harrier nests actually found in the area?

While no systematic harrier nest searching was undertaken outside JBWF, the presence and breeding of Black Harriers in the Jeffreys Bay area has been researched since 2015 (Smallie 2015) and on the Jeffreys Bay Wind Farm (JBWF) in detail since 2016 (Simmons and Martins 2017, 2018, 2019). These reports are lodged with Globeleq and sent annually to Manager, Mr P Oosthuisen and Environmental Control Office, Ms M van Rooy. This research shows:

- Two nests are known within the JBWF as seen in Figure 3 These were active in 2015 and 2016 but have never been successful.
- A third and fourth harrier nest were recorded outside the wind farm, but within the Greater Kromme area. They were also within the 16 km foraging radius found for satellite tagged harriers foraging away from their nests (Garcia-Heras et al. 2019). One of these nests was reported by J Walton from the Zuurbron farm, near the harrier roost sites (Figure 3). This is 6.5-km north-east of the JBWF and was active for several years (J Walton pers. comm.). Another pre-breeding female was recorded by us in the Kabeljous River estuary in October 2017, 6.0-km east of the wind farm, and this area will likely be used in future years.
- A fifth nest was known but never found based on numerous observations of a male Black Harrier foraging within JBWF and heading out of the farm with prey in a north-west direction. Prey-carrying males are the single best indication of an active nest and are the main method for finding harrier nests (Simmons and Mendelsohn (2009).
- Thus, a **minimum of 5 nests** is known within about 6-7 km of JBWF and more are likely outside that but within the Greater Kromme area.

A third independent way of assessing the number of harriers found in and around the JBWF is from counts at two harrier roosts located 6.5 km north-east of JBWF. These are South Africa's only known large roosts and they can be active throughout the year but generally are most active from December (end of breeding) until August (the start of the breeding season: Walton 2013). Tracking studies indicate that non-breeding birds range 18.1 ± 14.4 km (max-min: 5.5–41.7 km) from their roosts (Garcia-Heras et al. 2019) thus JBWF is well within their foraging range. This allows us a direct gauge, rather than an indirect assessment, of the number of birds in the area. These two

Figure 3 The Greater Kromme area (red line) showing the JBWF (white circle) and all known Black Harrier nests (= blue pins) and roosts (= yellow pins) in relation to all proposed wind farms in the area. Four Black Harrier nest sites are known and the roosts hold an average of 9.96 birds throughout the year.

harrier roosts vary in numbers through the year **with an average number of 9.96 birds per night** from May 2014 to September 2015. This varied from no harriers once in 15 sample months (in October) to a peak average of 22.7 birds in December 2014 (J Walton unpublished data). The highest individual count was 35 birds in one night in March.

Thus, the three independent measures of Black Harrier populations in the Greater Kromme area are as follows:

(i) **10 active nests** from extrapolations from occupancy and nesting density;
(ii) A minimum of **5 active nests** within 6-7 km of JBWF from harrier surveys;
(iii) An average of **10 birds per night** at the only known harrier roosts 6.5 km east;

Since the global population is estimated at 1000 birds (Taylor et al. 2015) then these estimates of 5-10 active nests (20 birds) and a roost average of 10 birds (and maximum of 35) puts the proportion of the world population within the Greater Kromme area between 2% and 3.5%. This is well above the 0.5% of the population and equal to more than 5 breeding units required for the *Critical Habitat sensu* IFC guidelines – https://www.ifc.org/wps/wcm/connect/5e0f3c0c-0aa4-4290-a0f8-4490b61de245/GN6_English_June-27-2019.pdf?MOD=AJPERES&CVID=mRQjZva

While this is important for the IFC guidelines and the required mitigations, we show below in the population modelling that the population numbers alone are irrelevant if the numbers being killed are reducing the global population in a steady fashion. We appreciate however, that both are important in convincing management that mitigations are essential for the long-term conservation of the Black Harrier population.

Migration and breeding

An unusual feature of this endemic species is that it undertakes regular East-West migrations within southern Africa as first suggested by Van der Merwe (1981). The cycle follows the rains (and, thus, flushes in primary productivity) in that birds occur in the Western Cape from May until December/January coincident with winter rainfall. There they breed over a 3-month period with egg-laying peaks in August-September, rear young over a month and half in September-October and fledge young from November through December (Garcia-Heras et al. 2016). Adults then fly rapidly, in the summer and autumn, across the Karoo http://blackharrierspace.blogspot.com/2014/04/black-harrier-migration-confirmed.html to spend the non-breeding period in the Eastern Cape, Lesotho and the Free State. Birds arrive in Lesotho coincident with the emergence of Ice Rats and their young, before heading back west, sampling possible breeding areas as they go (Garcia-Heras et al. 2019). In one case a tagged bird flew 5000-km – sampling all the way back to its previous breeding ground in the Langebaan lagoon – over six months before flying back to Aberdeen in the Karoo to breed in the Camdeboo mountains 500-km from its previous nest (http://blackharrierspace.blogspot.com/2011/11/from-langebaan-to-lesotho-and-back.html Taylor 2015). Since harriers use the Zuurbron roost throughout the year (J Walton unpubl data) and regularly breed in the Eastern Cape (17 of 170 nests known occur here: RES unpubl data) then clearly some of these birds are resident and others pass through the Eastern Cape, and this is confirmed below.

The migration strategies and speeds of Black Harriers have recently been summarised by Garcia et al. (2019). In addition to the tracks recorded by GPS trackers, we included re-sightings of colour-ringed birds. One such record was of a female hatched in the West National Park, photographed 18 months later, 635-km east in the Zuurbron roost in the Greater Kromme area, Jeffreys Bay (http://blackharrierspace.blogspot.com/2016/04/ringed-youngster-found-at-harrier-roost.html. This shows that birds are attracted to this highly suitable habitat from far and wide, and the Greater Kromme area does not constitute a small closed population for the Eastern Cape. This is important for the modelling presented below.

What factors influence the fatalities of Black Harriers on wind farms?

Harriers are rarely victims of wind farms and tend to avoid turbines elsewhere (Schaub et al. 2019). From four years' research at JBWF, three factors emerged that influence the number of Black Harriers and other raptors killed by wind turbines at Jeffreys Bay

(i) **flight frequency**; (ii) **breeding season**; and (iii) **location on wind farm.**

(i) **Flight frequency**: As the number of flights per hour (Passage rates) recorded for all raptors increased, so the number of fatalities increased (for all species summed). The relationship was significant (Figure 4).

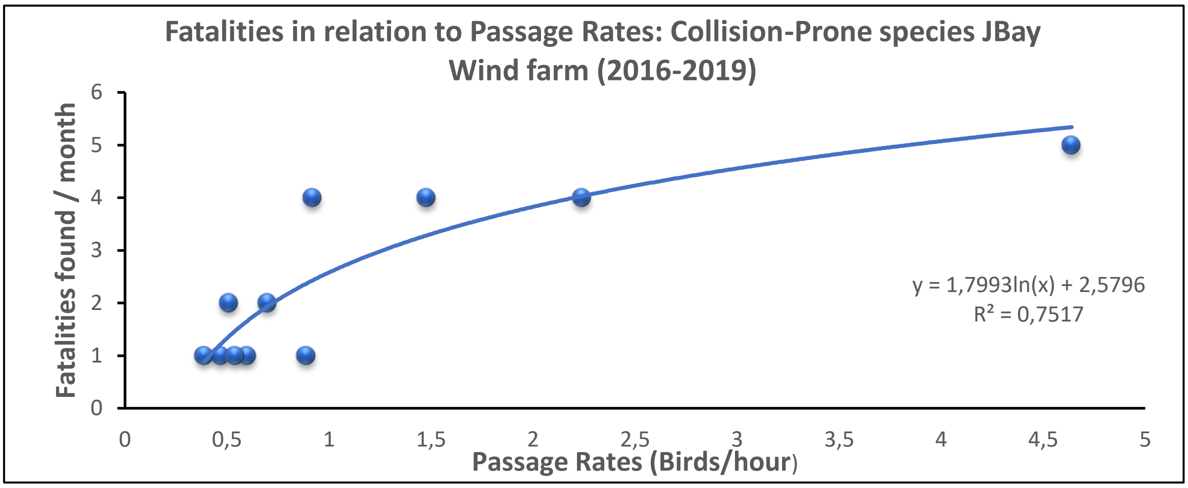

Figure 4: The significant relationship between Passage Rates of collision-prone birds on JBWF and fatalities of those birds. Passage Rates and fatalities were assessed every two months for 8 months. The other months are not included as no Passage Rate data were simultaneously collected (despite fatalities occurring in those months). The graph indicates that as more collision-prone birds occur in flight the more fatalities are likely. The same relationship held when the (3) stork fatalities were removed.

(ii) From a **seasonal aspect**, Black Harriers on site are more prone to impacts with turbine blades when they are breeding than at any other time of the year.

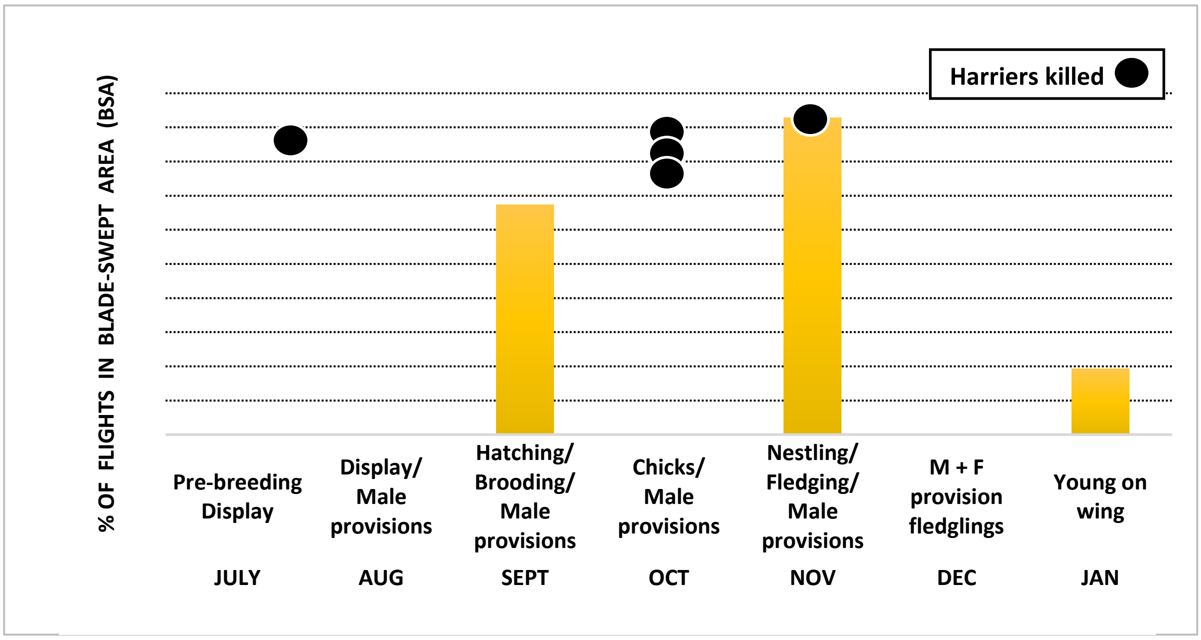

Figure 5. The seasonal increase in risky flights (those within the blade-swept area) by Black Harriers in relation to recorded fatalities of harriers at JBWF. Note that flights were only recorded in the months shown (no site visits in Aug, October and December) and no harrier fatalities were recorded outside these months.

This trend for more fatalities in October and November coincided with an increase in the number of risky flights (Figure 5) – that is, the number of flights recorded for Black Harriers within the blade swept area of 30-130m. This explains why the Black Harrier, with its typical low-level flights (1-3m above the vegetation) suddenly becomes vulnerable to impacts with turbine blades.

Their flight behaviour may change because breeding males, in particular, are the main food providers and forage on average 16.4 ± 6.8-km and range from 7.1-33.4-km from the nest (Garcia-Heras et al. 2019). We noted that, to carry prey back to their nests, birds soared and then planed across country to the next thermal. This takes them into the danger-zone of the turbines – the blade-swept zone.

The seasonal distribution of fatalities differed for **migrants vs residents**. Residents were killed throughout the year, except for those breeding on site, whose deaths were concentrated in the summer months for reasons explored above.

The migrants, which appear from November onwards include European (White) Storks *Ciconia ciconia,* Amur Falcons *Falco amurensis* that fly in from China and eastern Russia, as well as species such as Ospreys *Pandion haliaetus.* All these species are among the total 15 species killed at the wind farm. The seasonal occurrence of these fatalities occurs from November, peaks in January and declines into May, when migrants return to their northern breeding areas (Figure 6).

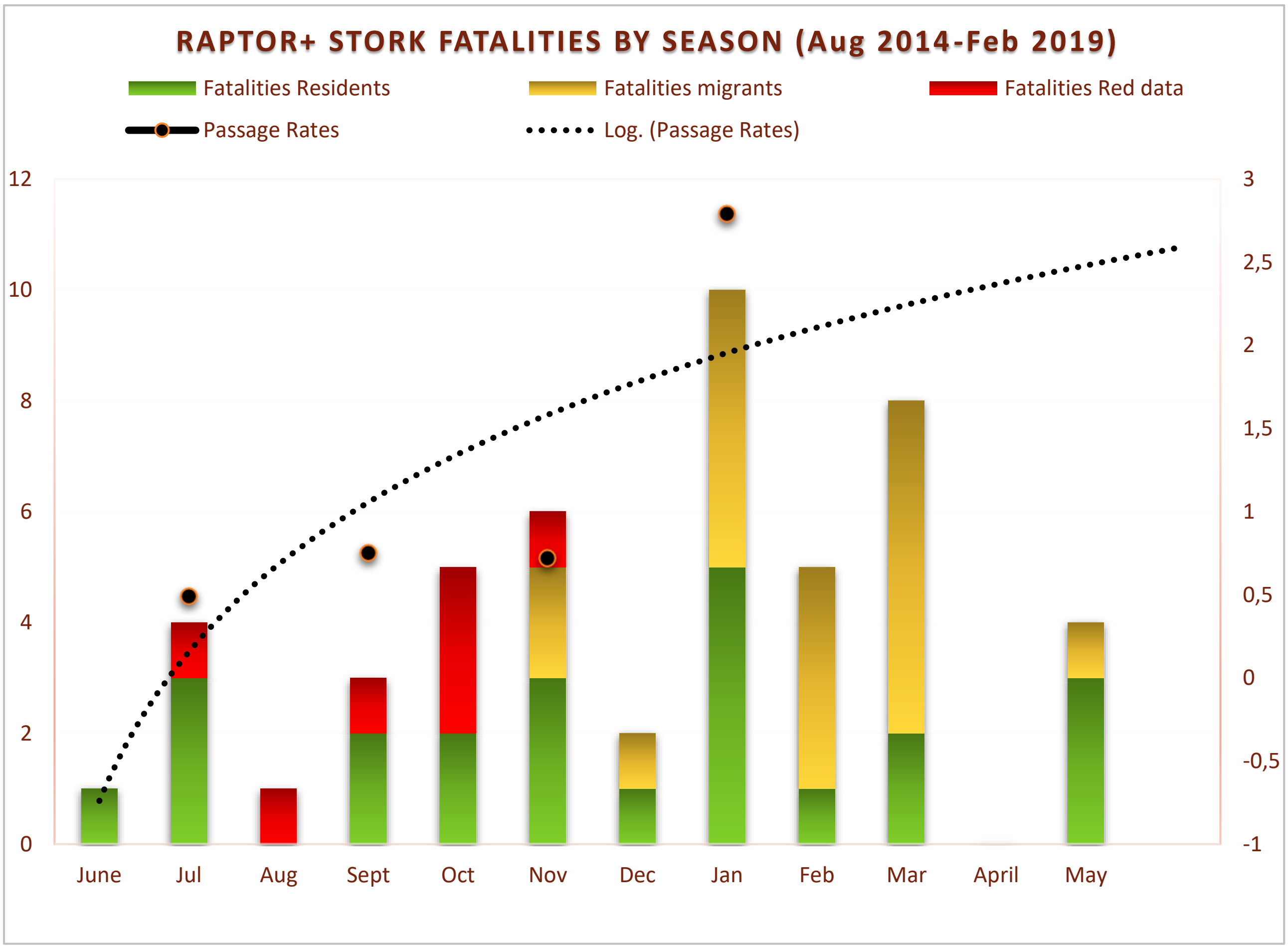

Figure 6: The seasonal incidence of fatalities for Red Data raptors and migrant species killed from August 2014 to January 2019 (months shown on the horizontal axis). The number of fatalities on the vertical axis is based on 49 fatalities, and all Red Data deaths occurred in the breeding season. Migrant deaths peaked between January and March. The increase in fatalities coincided with the increasing Passage Rates for the season (black dots and trend line – see Fig 4 for details). In other words, the more flying raptors that occur, the more fatalities there are. Note that no Passage Rates were collected after January until June as this was not part of our study.

(iii) **Location:** the number of fatalities differed for different areas of the wind farm

On dividing up the study area into quadrants, it became apparent that there was a predominance of fatalities (45% of 49 raptor deaths) in the south-west quadrant of the JBWF (Figure 7). This could not be attributed to more carcass searching effort as the Inkululeko carcass-searching team systematically covered all of the wind farm over the course of two weeks throughout the year.

The predominant wind direction and strength as depicted by the wind roses for JBWF at hub height (supplied by P Oosthuisen) mirrored the dispersion of fatalities across the site (Figure 7). This suggests that raptors spend more time hovering or flying in the south-west quadrant than anywhere else. Why? Because the prevailing south-westerly wind allows more slope soaring on south- and west-facing hills, and the presence of more birds in the air for longer is known to lead to a greater risk of being struck by a turbine blade (Figure 7).

The possibility exists that the habitat is more suitable in the south-west quadrant than elsewhere, bringing in more birds to this quadrant. We do not have any independent data to verify this, but our sense is that most of the JBWF area is still natural fynbos with the central valleys housing indigenous coastal woodland.

Photo 1: A migrant Amur Falcon from eastern Asia hovers within the blade swept area of a turbine at Jeffreys Bay. These were the most frequently killed migrants in the wind farm.

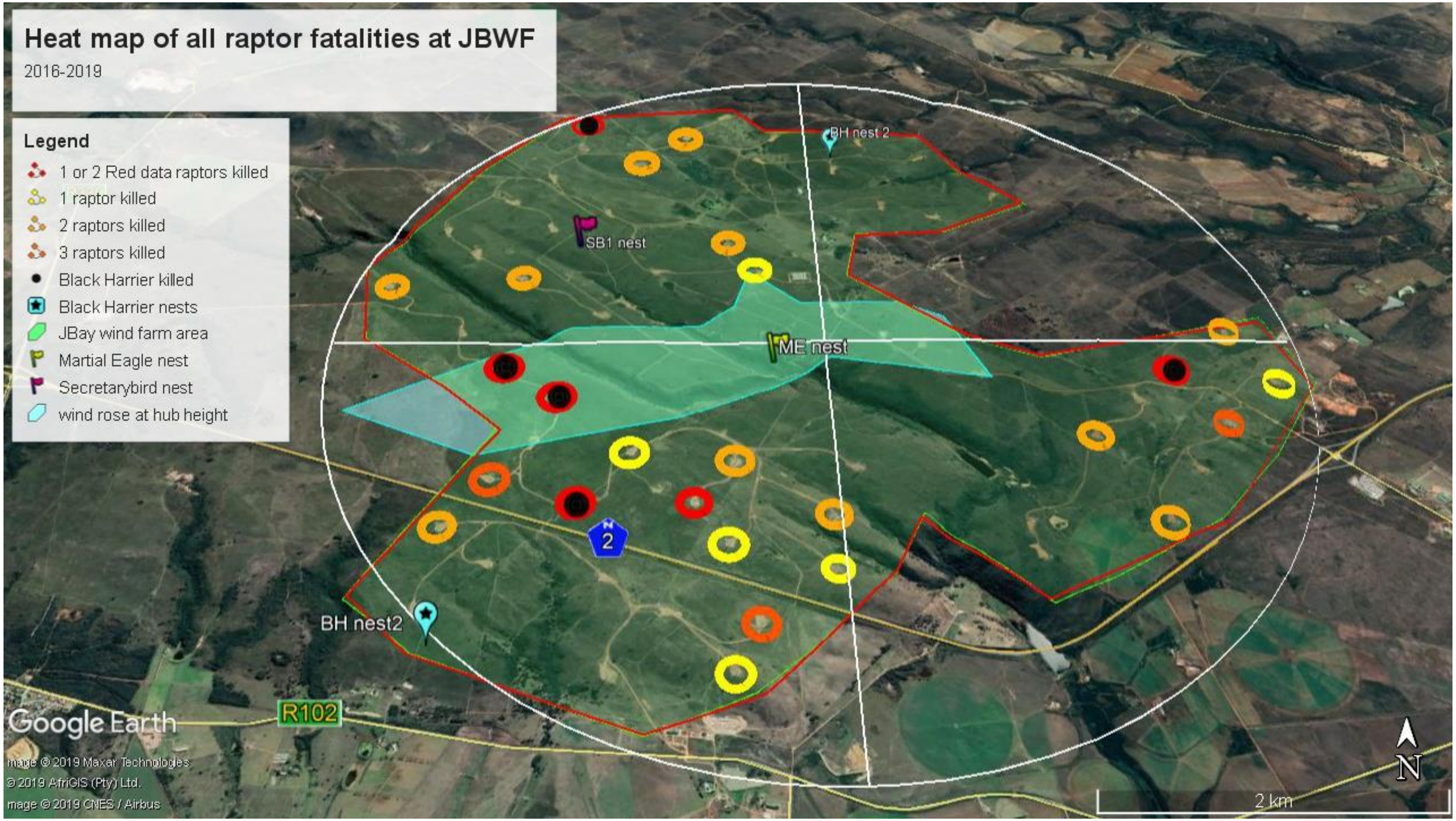

Figure 7: Heat map of all raptor fatalities at turbines across the JBWF from 2016-2019. Red circles indicate turbines at which one or more Red Data species were killed, and black centres those where Black Harriers were killed. Other colours as shown on the legend. Note: the predominance of fatalities in the south-west quadrant of the farm (45% of 49 raptor deaths occurred here), is consistent with the prevailing wind direction as depicted by the pale blue wind rose polygon.

Other Red Data raptors breeding on JBWF and their nest success

Other than the *Endangered* **Black Harriers** found breeding in JBWF there were two other red data species found nesting. It is important to note that for the Black Harriers found in 2015 and 2016 (Figure 7) both nests were unsuccessful, at the egg and the nestling stage. The latter failure arose following the turbine-death of the provisioning male in October 2016 at the BHnest2. The first nest "BHnest1" (in the north-west corner) was 278m from turbine 8, and "BHnest2" (in the south-west corner) was 245m from the turbine 45. Harrier fatalities at the time of these breeding events occurred at T37 (1.4 km) and T55 (5.8 km) from the active BHnest2.

Endangered **Martial Eagles** *Polemaetus bellicosus* were also present, and breeding, in the centre of the wind farm (Figure 8). The nest was active in 2015 and again in 2016. Two eagles were killed at turbine 38, 1.6 km south-west of the nest, in July and September 2016. The first bird was a subadult, photographed as it was struck by the blades https://www.birds-and-bats-unlimited.com/specialist-studies. A second adult bird was found decomposed at the same turbine in October 2016 after which the breeding event failed (chick on nest died). The adult bird found dead was probably the breeding male, leading to the demise of the nest. To date (2019) there has been no further activity at this nest, and we conclude that the pair was displaced by JBWF.

Vulnerable **Secretarybirds** *Sagittarius serpentarius* also bred in 2016 in the north-west quadrant of the wind farm (Figure 8) and appeared to be successful with at least one young Secretarybird recorded foraging at JBWF. No breeding was apparent in 2017 or subsequently. The nest – situated in a large 3-4m high bush – was 330m (T18) and 400m (T19) from the closest turbines. No Secretarybirds have been recorded as collision victims within the JBWF.

Figure 8: Red Data raptor nests inside and within 7 km of the Jeffreys Bay Wind Farm. Four Black Harrier nests (= blue pins) occurred – two nests inside JBWF, and two outside at Zuurbron (6.5-km north-east) and one in the Kabeljous River estuary (6-km east). One active Martial nest (= yellow flag), and an active Secretarybird nest (= purple flag) completed the four Red Data nests in the JBWF boundaries. More nests may be present outside the wind farm as exhaustive searches were not undertaken.

Population model to assess the impact of the observed mortality, at JBWF, on the Black Harrier population.

The level of mortality of the *Endangered* Black Harriers at Jeffreys Bay Wind farm is high at 1.5 birds killed per year over a 4-year period (Simmons and Martins 2019). We have used 6 Black Harrier fatalities which includes 5 direct impacts and the indirect loss of a dependent nestling at the BHnest 2 in 2016. We have included this bird because it can be directly ascribed to the killing of the adult male because males are the main food provider in harriers and most other birds of prey (Newton 1979, Simmons and Simmons 2000). With the male gone, females are forced to leave the young to forage and we noted (and photographed) the adult female chasing off possible predators including Yellow-billed Kites *Milvus parasitus* and Booted Eagles *Hieraaetus pennatus* over the nest. These hidden costs must be accounted for in any assessment of wind farm fatalities as they are unlikely to occur in the absence of a wind farm.

Note that we have used this unadjusted rate because raptors and other large birds tend to be found more often (over-looked less often) by carcass searchers than smaller birds, and scavenged less often than other species (Moleon et al. 2017). This means biases for raptors are likely to be minimal. The critical question is: what effect does this level of mortality have on the global population?

This specialised statistical modelling work was undertaken by PhD candidate Francisco Cervantes Peralta at the department of Statistical Sciences at University of Cape Town. He has employed a Population Viability Approach to determine the effect of different levels of mortality on global and regional population levels of the Black Harrier.

Inputs to the model such as breeding success are based on over-400 breeding events recorded from 2000-2016, measured during the Black Harrier survey period by RES and his students. Breeding output was measured in two ways: nesting success (nests rearing at least one young, known for n = 263 breeding attempts) and if so, how productive were they (n = 261 nests, Garcia et al. 2016).

Dr Cervantes Peralta's analysis is as follows: Appendix 1 gives details of the population model.

Modelling population-level effect of wind farms on the Black Harrier

Our objective is to model Black Harrier population dynamics to understand the population-level effects of wind energy production on this species. Wildlife population are complex systems in which many elements interact with each other at various levels. In addition to the inherent complexity of the population dynamics, there are many sources of uncertainty that arise from our limited understanding of the systems. Here, we aim at building a population model that incorporates the minimum degree of complexity necessary to make realistic inference, and that at the same time, is simple enough to be meaningful with our incomplete knowledge about Black Harrier population parameters.

The model structure is based on Newman *et al.*, (2014) and the parameter values for harriers were extracted from the scientific literature, when possible (Simmons and Simmons 2000; Curtis et al. 2004; Simmons 2005; García-Heras *et al.* 2016). We also consulted well-known experts on the ecology and population dynamics of this and other harrier species (Drs Beatriz Arroyo, Francois Mougeot and Marie-Sophie Garcia-Heras from Spain). The formulation of the model can be found in appendix A[1]. There are still some unknown population parameters for the Black Harrier, and it was unavoidable to make some assumptions. However, we incorporate uncertainty and inter-annual variation in population parameters by considering them to be random variables with some associated probabilistic distribution.

The likely trajectory of the global Black harrier population, given a set of parameters, is investigated using Monte Carlo simulation. Using a time step of one year, we sequentially sample population parameters from their probabilistic distributions, update current population according to the sampled parameters, then sample parameters for the next year, and so on. Creating multiple such population trajectories we investigate the properties of the long-term behaviour of the population, while accounting for all sources of uncertainty.

As a first step, we strive to get a model that mimics a population size and trend that is consistent with what is known about Black Harriers. The global population may be declining slowly based on habitat loss in research over the last 18 years (e.g. see sequence index in SABAP2 data for the species[2]). Red data books (Taylor et al. 2015) estimate a higher rate of decline (20% reduction in two generations i.e. 15 years) correctly based on the very high historical decline in core areas like the Overberg's renosterveld habitat which has been decimated (Curtis et al. 2004). We believe this rate of decline has slowed partly because there is little habitat left to destroy there. We have defined a slow decline of the populations as a starting point for our models, although we acknowledge we might have been optimistic, and the real decline could be faster.

Some parameters are better known than others, and we tried to anchor our models in those parameters that are best known. Other less-known parameters were tuned to match the current state of the population. Once we achieve a model that describes well our present understanding of Black Harrier populations, we can include additional mortality produced by wind farms. We model the effects of wind farms on the global population of Black Harriers because the local population in the Eastern Cape is open to the global South African population and, therefore, we would expect a steady influx of birds rather than a local extinction, should Eastern Cape harrier numbers decline.

The models consider harrier mortality due to wind farms being independent of harrier density. Although this assumption might not hold, the form of this relationship is unknown at present and we preferred to model the effect of having a constant fatality regardless of harrier density.

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[1] An interactive document to explore and simulate from the model can be found at: https://fcervantes.shinyapps.io/bharrier_dynamics_age/

[2] http://sabap2.adu.org.za/species/169#pgcontent

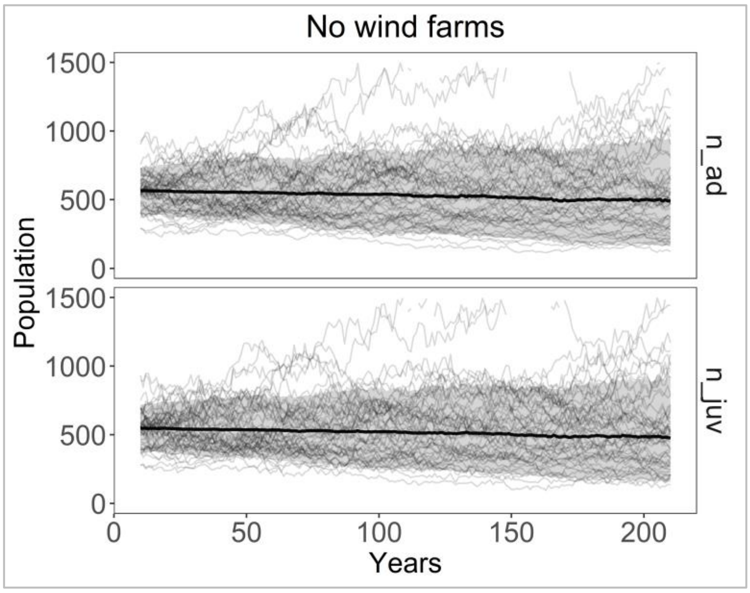

Figure 9a: Results of 500 Monte Carlo simulations of the evolution of Black Harrier populations **with no wind farms.** The black line corresponds to the average population level trend and the grey band captures an 80% prediction interval. Each panel also shows a sample of 50 iterations of the population dynamics model, for adults (top) and juveniles (bottom). With no wind farms Black Harrier populations are relatively stable, with a 1% decrease in 30 years (2% in 50).

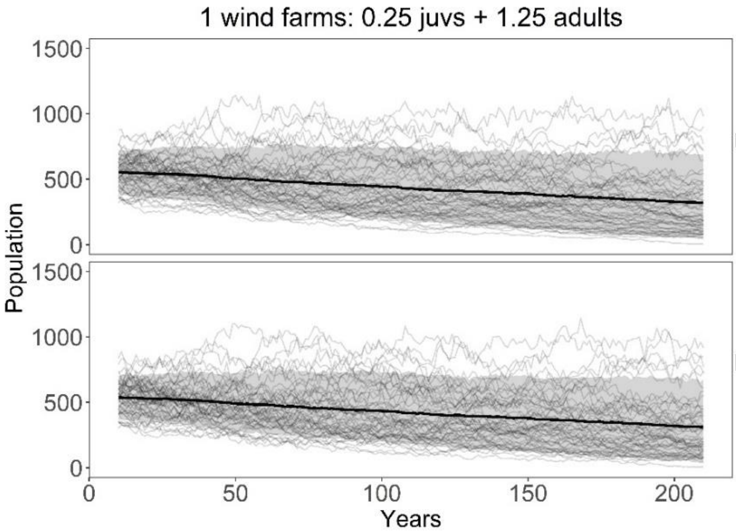

Figure 9b: If just one wind farm **(JBWF alone)** were to kill 5 adults and 1 juvenile in 4 years (**1.25 adults + 0.25 juvenile harriers every year),** the global Black Harrier population will decline. The model predicts an average decline of 5% in 30 years and 10% in 50 years.

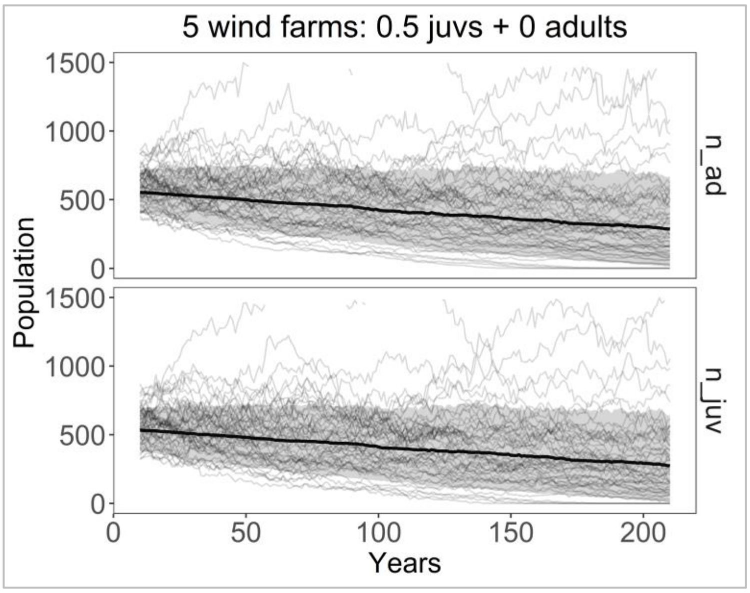

Figure 9c: If five wind farms were to each kill **one juvenile harrier every two years,** the global Black Harrier population will decline. The model predicts an average decline of 8% in 30 years (14% in 50 years).

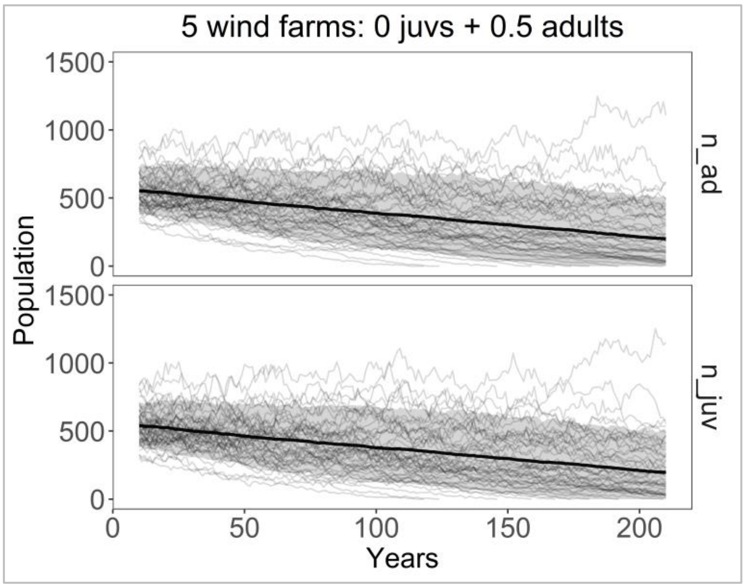

Figure 9d: If five wind farms were to each kill **one adult harrier every two years,** the Black Harrier population will decline more rapidly. The model predicts an average decline of 11% in 30 years (19% in 50 years).

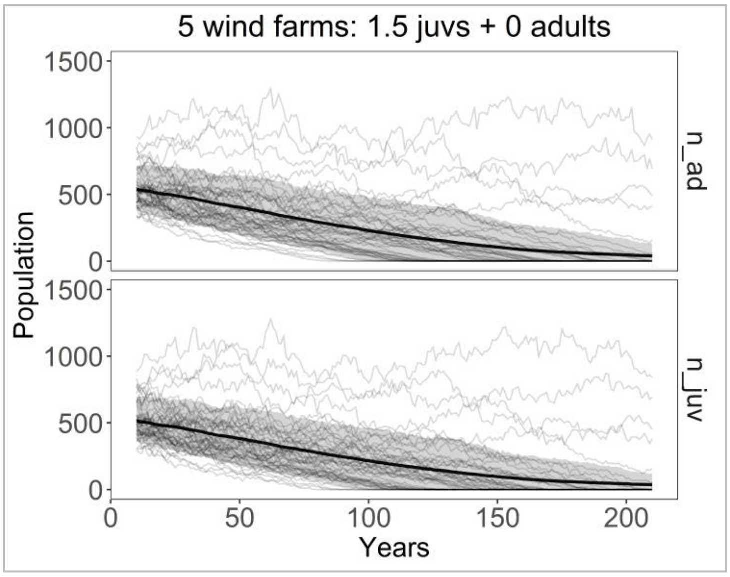

Figure 9e: If five wind farms were to each kill **three juvenile harriers every two years,** the Black Harrier population may collapse in just over 200 years. The model predicts an average decline of 21% in 30 years (36% in 50 years).

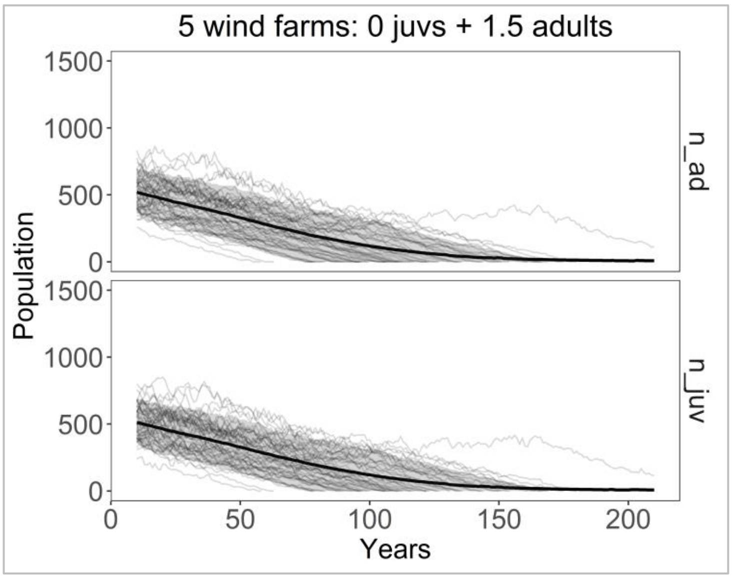

Figure 9f: If five wind farms were to each kill **three adult harriers every two years,** the Black Harrier population may collapse in about 125 years. The model predicts an average decline of 30% in 30 years (50% in 50 years).

The models above indicate that if JBWF were the only wind farm to be killing Black Harriers at the rate empirically measured over 4 years (5 adults, 1 juvenile) then the population would decline 10% in 50 years.

Since there are five operational wind farms in the Greater Kromme area then we modelled the trend at a lower average fatality rate (one juvenile or one adult fatality every second year per wind farm) for five farms. The Black Harrier population then declines relatively fast (Figures 9c and 9d). It is, therefore, troubling that the average fatality rate is 1.5 birds per year over four years at JBWF.

The observed (unadjusted) rate at JBWF is three-fold higher than the modelled rates above (0.5 x 3 = 1.5) giving a disturbing picture of the forecast rate of decline for the Black Harrier (Figures 9e and 9f). So severe is this modelled effect on the population that we predict that the Black Harrier population will collapse in about 120 years if just five farms anywhere in South Africa maintain such a rate. Since there are five operational farms in the Greater Kromme area alone, this is a real possibility as about 20% of the area is modelled as falling within the highest suitable areas for breeding harriers (Colyn et al. in prep.). We do not have any data on fatality rates for these other farms but note that there are about 27 operational wind farms in South Africa, and this can be seen as a reflection of the possible cumulative impacts across South Africa.

What effect would this population trend have on the global population? A record of a ringed 18-month-old bird that migrated from the West Coast National Park to the Jeffreys Bay Zuurbron roost 630-km west, suggests that any harriers killed at wind farms in the Eastern Cape can come from core breeding areas in the west. Thus, birds killed at JBWF can negatively impact the global population dynamics of this rare species. Thus, the area may act as a sink.

These results demand that mitigation measures are enacted, at JBWF, and indeed every other wind farm that kills Black Harriers in South Africa or Namibia. Without mitigations the already *Endangered* Black Harrier population is certain to decline more rapidly than it already is.

Mitigation strategies were laid out in Simmons and Martins (2019) but briefly we repeat the following options. These still apply:

- The most cost-effective option is **black-blade mitigation** to make blades more visible. This has been tested in Norway where two thirds of a single blade on each turbine was **painted black**. The results over six years indicates that the fatality rate of White-tailed Eagles *Haliaeetus albicilla* was reduced by 100% over unpainted controls. This contrasts with an average of 6 eagles killed per year at the un-painted white blades (B. Iuell pers comm.). A video of the turning blades is found at [www.birds-and-bats-unlimited.com/specialist-studies.](www.birds-and-bats-unlimited.com/specialist-studies) The latest research indicates that there is a highly significant difference in eagle fatality rates between the painted and un-painted blades (R May in litt.).
- **increasing grazing pressure** in certain camps in the wind farm that are favoured by hunting harriers (reducing cover, food and burrowing habitat for mice);
- **cutting or harvesting the vegetation** (e.g. flowers and Leucadendrons) in the high-use foraging areas to reduce their attractiveness to prey populations (birds and small mammals); mowing already occurs on the Lucca Game Ranch and the Black harriers that foraged through there indeed showed less interest in the short-cut vegetation. This will have little influence on the conservation status of the plants here as the vegetation type is classified as *Least Concern* (Mucin and Rutherford 2016).

- **increasing the frequency of fire** through the habitat to decrease cover and, thus, small mammal populations. This needs to be done with careful consideration, and at a specific time of year, to protect ground-breeding birds such as Black Harriers whose chicks will succumb to the fire; and
- **Strategically shutting down certain turbines** at certain times of year to avoid collision. In Altamont Pass, California, for example, it has been reported that 13% of the hundreds of turbines are responsible for killing most of the birds, and since then, these turbines have been de-commissioned. It is important to note that a study of the financial implications of selective stopping of turbines at 10 wind farms in Spain was undertaken by De Lucas et al. (2012). They found that mortality of migratory Griffon vultures was reduced by 50% and energy production was reduced by only 0.07%. At JBWF since 27% of the 60 turbines are responsible for 75% of 47 fatalities (Simmons and Martins 2019) any new mitigation measure (e.g. black blade or shut down) can be focussed on these problem turbines.
- **Employing a system of automatic detection and shut down** – similar to, or identical to, the "DT bird" detection system developed by the Spanish to reduce direct impacts by birds at wind farms and other facilities. A new improved Multi-sensor system is now out marketed by Bioseco.

Each mitigation has its costs and benefits. However, because 27% of the 60 turbines are responsible for 75% of the 47 fatalities (Simmons and Martins 2019) any new mitigation measure (e.g. painting of blades) can be focussed on these problem turbines.We believe that black (or coloured) blade mitigation is the best of these since (i) it has been field tested and shown to be 100% successful in reducing fatalities and (ii) and there are no further costs once in operation.

Some potential offset or net gain projects that could be included in the BMP

Biodiversity Offsets: The demise of *Endangered* Black Harriers at Jeffreys Bay Wind Farm, despite mitigation strategies suggested since 2017 (Simmons and Martins 2017, 2018, 2019), or that arise from this BMP, could be offset by improving harrier habitat elsewhere. This is one such approach recommended by IFC Performance Standard 6 where all available strategies for avoidance and mitigation have been tried but still result in unavoidable fatalities of endangered species. Since none of the mitigation strategies suggested over the last 4 years have been implemented this should be a last resort.

The areas surrounding Jeffreys Bay are ideal for this approach as they are all classified as highly suitable habitat for the Black Harrier, and conservation programmes exist around the site in the form of stewardship work by the *Greater Kromme Trust* (Maggie Langlands) and *Conservation Outcomes* (Wentzel Coetzer pers comm.). The Greater Kromme area cover 1800 km^2 (Figure 3) and includes four Black Harrier nests, and two harrier roost sites. It was chosen because it includes all five operational wind farms and is already chosen as an of outstanding biodiversity, with an active conservation plan https://www.gksinitiative.co.za/

They both promote the conservation of threatened bird species and work closely with farming communities and other local wind farm managers to reduce impacts on endangered species such as the Black Harrier. Our BMP approach should include them as partners to facilitate the offsets planned. The largest known Black Harrier roosts in South Africa (Walton 2013) occurs 7-km north west of the JBWF and, with an average of 10 birds and a maximum of 35 Black Harriers frequenting the site, it represents well over 0.5% of the known global population. It is, currently, an unprotected site. This site would therefore benefit the Black Harrier population in any offset programme pursued in the BMP.

Thus, there is considerable scope to improve harrier habitat in this area through a biodiversity offset programme around Jeffreys Bay Wind Farm.

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Appendix 1: Details of the population model for Black Harriers

In this document we explore basic population parameters of the Black Harrier and how they affect population dynamics of the species. This basic model structure is used as a starting point for developing more complex and realistic models. First, the parameters that modulate population dynamics are explained one by one; then, the way they interact with each other within the model structure; and finally, we use Monte Carlo simulation to show how parameter configurations affect the evolution of a virtual population.

In short, the model contemplates a population with two age classes: juveniles and adults. The basic difference between the ages is that juveniles don't breed, and adults do. The user may define different population parameters for the two age classes for the Monte Carlo simulations (e.g. lower survival rate for juveniles).

<u>Initial population (N0)</u>

The first parameter we need to define is the initial population of Black Harriers. This will be the starting point of our simulations. The total Black Harrier population is denoted as N0 and because it is an unknown number, we have represented it as a normal random variable. The mean of the normal distribution μ represents our best estimate of the population and the standard deviation σ our uncertainty around our best estimate.

Fecundity (B)

The next parameter we consider is the expected number of fledglings for a Black Harrier **adult pair** in one year (as opposed to per nest). This parameter is denoted by B (for births) and it is represented by a negative binomial random variable. We use a random variable to account for the fact that not all years and not all nest will produce the same number of fledglings. We have chosen a negative binomial random variable because it supports positive integers only and it allows specifying a dispersion parameter that control "excess" zeros. An alternative formulation would have been a Poisson random variable; however, the Poisson is controlled by a single parameter and the number of zeros in a sample is completely controlled by the same parameter that controls the mean of the distribution. It is therefore less flexible. We could have also used something like a multinomial distribution instead. It is more flexible than the negative binomial, because it allows to assign any probability we like to any number of fledglings. It is a bit more arbitrary though, in the sense that we need to guess each particular probability, therefore defining four parameters instead of two.

We favoured the compromise of flexibility and number of parameters of the negative binomial. García-Heras et al. 2016 showed that approx. 35% of Black Harrier **nests** failed to produce any offspring and the mean number of fledglings was 1.6 per nest. Note that some breeding pairs may not even attempt breeding (Simmons unpublished data) and therefore, if we consider productivity per breeding pair instead of per nest, we should expect more than 35% zeros and a lower mean production than that observed by García-Heras et al. 2016. Because the maximum number of nestlings ever recorded for a Black Harrier is 4, we truncated the negative binomial to this quantity.

Annual survival rate (φ)

The annual survival rate is expressed as the proportion of the population that survives the current year. Birds during the first winter have a particularly low survival rate and from then onwards there is little difference in survival rates between ages (Beatriz Arroyo personal communication). We therefore set one survival parameter for the year and another one for birds of age one year or older.

There is no evidence that survival in this species is dependent on population density and experts advised against including density dependent parameters in the models. Therefore, survival is considered to be only dependent on the age of the harriers.

To account for variability between years and for the uncertainty around the true value of survival parameters, these are sampled from a beta distribution. The beta distribution is constrained to values between 0 and 1 and is therefore appropriate to model proportions.

Wind farm mortality (F)

Mortality produced by wind farms is included in the model through the term F. This term produces a systematic random reduction in the population of harriers each year. It is proportional to the number of wind farms built on Black Harrier habitat. The number of harriers killed by each wind farm j in any given year is sampled from a Poisson random variable F_j. These random variables are always positive integers and the mean number of harrier fatalities is given by λ_F.

Population dynamics model

We are now ready to combine the parameters into a model structure. The model considers two age classes: juveniles and adults. However, juveniles do not achieve adult status until they are two years old (when they can start reproducing). Therefore, there are three possible states in the population: year 1, year 2 and adults.

In any given year t the population is represented by a column vector of three values, corresponding to the three age states:

$$N_t = [n_1, n_2, n_3],$$

being the sum of n_1 and n_2 the population of juveniles and n_3 the population of adults.

The model follows a sequential update based on step matrices. First, we update the current population according to the survival rates.

$$N_t^{(s)} = N_{t-1}\Phi.$$

The parameter matrix Φ captures the survival rates of all age classes. As mentioned earlier, harriers are particularly vulnerable in their first winter, and therefore, their survival rates are lower than for other years. We set two different survival rates: one for first year ϕ_1 and another one of year 2 and adults ϕ_2.

$$\Phi = \begin{bmatrix} \phi_1 & 0 & 0 \\ 0 & \phi_2 & 0 \\ 0 & 0 & \phi_2 \end{bmatrix}$$

where

$$\phi_i \sim \text{beta}(\alpha_i, \beta_i).$$

Once the population has survived the previous year, we can account for changes in ages. So, year one individuals in the previous year become year 2 in this year, year 2 in previous year become adults. Adults stay adults forever, until they die. The age evolution matrix is

$$A = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 1 \end{bmatrix}$$

and the current population becomes

$$N_t^{(a)} = N_t^{(s)} A.$$

The adult birds in the population are now ready to breed. B is a column vector of births that updates the population column vector $N_t^{(a)}$. The first element of B is given by the sum of all births α_i of all breeding pairs $i = 1,2, \dots, n_{4/2}$ and the rest of the elements in B are 0, because births only produce birds of year 1. The number of breeding pairs has been set to half of the adult population. Therefore, all adults are potential breeders and we consider the same number of males and females in the population. Note that some pairs may not produce any fledglings, either because they nest and lose the clutch or because they take a sabbatical year (Simmons unpublished data?). These two sources of "zeros" are incorporated by the dispersion parameter k of the negative binomial distribution. The number of fledglings each breeding pair produces is given by a realization of the fecundity negative binomial distribution with parameters μ and k.

$$B = \left[\sum_{i=1}^{n_{3t}/2} \alpha_i \,, 0{,}0 \right]; \quad \alpha_i \sim \mathrm{NegBin}(\mu, k)$$

Now, we can update the population of year 1 harriers, by adding the matrices $N_t^{(a)}$ and the column vector B.

$$N_t^{(b)} = N_t^{(a)} + B.$$

Finally, to the "natural" mortality we need to add the mortality produced by the J wind farms in harrier habitat, F. We have considered bird under one year of age to be particularly prone to collision and therefore there are two mortality rate parameters: λ_{F1} for juveniles under one year of age and λ_{F2} for other ages. We believe it is more informative to consider what happens when a wind farm systematically kills the same number of birds on average every year. For this reason, we have set wind farm mortality to be independent of harrier population density. Therefore, F is given by a column vector

$$F = \sum_{j=1}^{J} \left[f_{j,1}, f_{j,2}, f_{j,3} \right].$$

Each entry of F represents the sum of birds of age $i = 1, 2, 3$ killed by wind farm j.

$$f_{j,1} \sim \mathrm{Pois}(\lambda_{F,1})$$

$$f_{j,2,3} \sim \mathrm{Pois}(\lambda_{F,2}/2)$$

The final resulting population is calculated as:

$$N_t = N_t^{(b)} + F.$$

The parameters used for the simulations were:

Parameter	Adult	Juvenile
μ_{N0} – estimated population	700	300
σ_{N0} - uncertainty population	150	100
μ_B - uncorrected fecundity	1.65	NA
$disp_B$ - fecundity dispersion	1.8	NA
α_ϕ - survival parameter 1	80	100
β_ϕ - survival parameter 2	25.9	100

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An 18-month old female Black Harrier from the West Coast NP photographed at the Zuubron rooast in the Greater Kromme area 7 km east of JBWF (J Walton).