

# NJE Namibian Journal of Environment

**Environmental Information Service, Namibia for the Ministry of Environment and Tourism, the Namibian Chamber of Environment and the Namibia University of Science and Technology.**

The *Namibian Journal of Environment* (NJE) covers broad environmental areas of ecology, agriculture, forestry, agro-forestry, social science, economics, water and energy, climate change, planning, land use, pollution, strategic and environmental assessments and related fields. The journal addresses the sustainable development agenda of the country in its broadest context. It publishes two categories of articles. **SECTION A: Peer-reviewed papers** includes primary research findings, syntheses and reviews, testing of hypotheses, in basic, applied and theoretical research. **SECTION B: Open articles** will be editor-reviewed. These include research conference abstracts, field observations, preliminary results, new ideas and exchange of opinions, book reviews.

NJE aims to create a platform for scientists, planners, developers, managers and everyone involved in promoting Namibia's sustainable development. An Editorial Committee ensures that a high standard is maintained.

ISSN: 2026-8327 (online). Articles in this journal are licensed under a Creative Commons Attribution-Non Commercial-NoDerivatives 4.0 License.

Editor: J IRISH



## SECTION A: PEER-REVIEWED PAPERS

Recommended citation format:

Hauptfleisch M, Knox NM, Heita P, Aschenborn O & ML Mackenzie (2020) An analysis of the risk of collisions between aircraft and vultures in Namibia. *Namibian Journal of Environment* 4 A: 41-49.

Cover image: LANDSAT 5 TM / Acquisition date: 09.05.2009 / False Natural Color Composite (RGB: 5,4,3) / Source: USGS Earth Explorer

## An analysis of the risk of collisions between aircraft and vultures in Namibia

M Hauptfleisch<sup>1,3,\*</sup>, NM Knox<sup>1</sup>, P Heita<sup>1,2</sup>, O Aschenborn<sup>3</sup>, ML Mackenzie<sup>1,4</sup>

URL: <http://www.nje.org.na/index.php/nje/article/view/volume4-hauptfleisch>

Published online: 28<sup>th</sup> May 2020

<sup>1</sup> Biodiversity Research Centre, Namibia University of Science and Technology, Windhoek, Namibia

<sup>2</sup> Surveyor General's Office, Ministry of Lands and Resettlement, Windhoek, Namibia

<sup>3</sup> Veterinary Medicine, University of Namibia, Windhoek, Namibia

<sup>4</sup> Centre for Research into Ecological and Environmental Modelling (CREEM), University of St Andrews, Scotland

\* mhauptfleisch@nust.na

Date received: 6<sup>th</sup> February 2020; Date accepted: 13<sup>th</sup> May 2020.

### ABSTRACT

Collisions between aircraft and birds and other animals occur frequently and are known in the aviation industry as wildlife strikes. They are considered to be one of the most serious safety and financial risks to the global aviation industry. The International Civil Aviation Organisation, a United Nations specialised Agency, requires that the appropriate authority shall take action to eliminate or to prevent the establishment of any source which may attract wildlife to the aerodrome, or its vicinity, unless an appropriate wildlife assessment indicates that they are unlikely to create conditions conducive to a wildlife hazard problem. Namibian airports reduce the wildlife strike risk by managing the airport habitat and actively chasing birds and other hazardous animals away. The bird strike risk in airspace between airports is not managed or assessed in Namibia. Following one White-Backed Vulture strike and several reports of near-misses with vultures by pilots of small aircraft, this study investigated possible collision hotspot areas considering small commercial aircraft flight paths and vulture movement areas. The study used spatial proximity analysis and temporal overlap to compare telemetry and nesting location data for the three most commonly encountered vulture species to flight paths and times of small commercial aircraft. Collision risk hotspots were identified over three national parks: Etosha, Waterberg and the Pro-Namib portion of the Namib-Naukluft. Ascending from, or approaching, Hosea Kutako International Airport from the east was identified as a particular risk for White-backed Vulture conflict, while risk of Lappet-faced vulture strikes was high to the east of Walvis Bay airport. Flight times of vultures and aircraft corresponded greatly, increasing the collision risk. The recommendations of this work are that pilots of small commercial aircraft should be made aware of particular risk areas, and that landing at Hosea Kutako from the east, or taking off in an easterly direction should be minimised when wind conditions allow, to reduce vulture collision risk.

**Keywords:** aircraft; Cape Vulture; Lappet-faced Vulture; Namibia; White-backed Vulture; wildlife strike

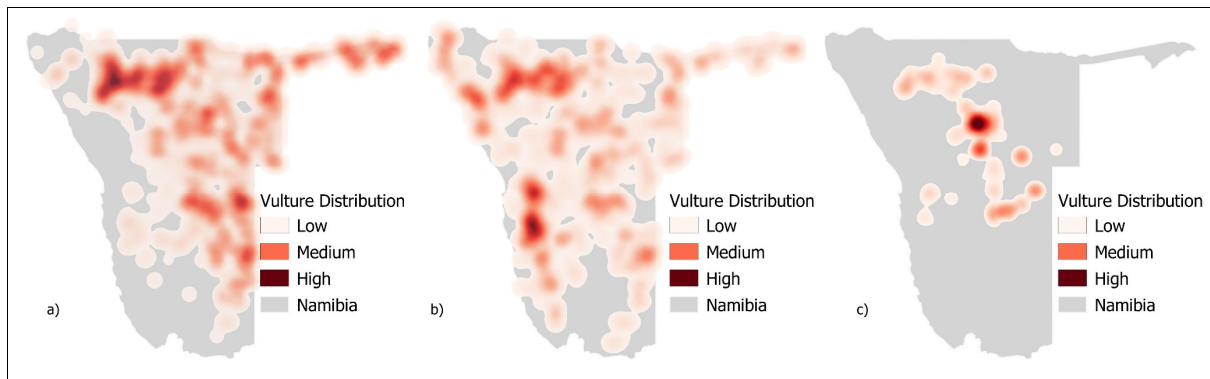
### INTRODUCTION

Collisions between aircraft and birds and other animals, known as wildlife strikes, are a safety and financial hazard to the global aviation industry. The International Civil Aviation Organisation, a United Nations specialised Agency, requires that the appropriate authority shall take action to eliminate or to prevent the establishment of any source which may attract wildlife to the aerodrome, or its vicinity, unless an appropriate wildlife assessment indicates that they are unlikely to create conditions conducive to a wildlife hazard problem (ICAO Airport Services Manual 2012).

In Namibia, the requirement of registered airports to manage the wildlife strike risk is reflected in the Namibian Civil Aviation Act (6) of 2016. Research into the causes of wildlife strikes has been conducted at Hosea Kutako International and Eros airports. Since the majority of wildlife strikes occur at airports and in their direct vicinity (Hauptfleisch 2014, Hauptfleisch & Avenant 2015, Hauptfleisch & D'Alton 2015), none of this research has focused on

the airspace between airports. Following one White-Backed Vulture strike and several reports of near-misses with vultures by pilots of small aircraft, the need arose to acquire more knowledge about the flight altitude, time and behaviour of vultures to be able to compare these parameters with aircraft flying in Namibia.

Of the five species of vulture (Family Accipitridae) occurring in Namibia, the movement and nesting of three: White-backed (*Gyps africanus*) (WBV), Lappet-faced (*Torgos tracheliotos*) (LFV) and Cape (*Gyps coprotheres*)(CV) (Figure 1), have been thoroughly studied in Namibia and other parts of southern Africa (Anderson 2004, Bamford *et al.* 2007, Mendelsohn & Diekmann 2008, Hancock 2017, Kolberg 2017). Breeding observations of these three species within Namibia have also been recorded (Diekmann *et al.* 2004, Mendelsohn & Diekmann 2008, Kolberg 2017). While Figure 1(c) shows a limited range of CV in Namibia, subsequent work of Mendelsohn & Diekmann (2008) found CV to forage far more widespread across Namibia. All the above mentioned studies have shown that the movement



**Figure 1:** Distribution of (a) White-backed, (b) Lappet-faced and (c) Cape Vulture within Namibia (Data Source: EIS – adapted from SABAP (“Southern African Bird Atlas Project 2”)).

ranges of vultures within Namibia and the surrounding countries is vast. Single vultures tracked in Namibia have been recorded to visit as far afield as Angola, Zambia, Botswana, South Africa and Zimbabwe (Mendelsohn & Diekmann 2008, Hancock 2017).

Vulture behaviour in terms of movement patterns, soaring height and range extent makes them potentially vulnerable to interactions with aircraft (DeVault *et al.* 2005, Avery *et al.* 2011). Additionally, the studies of vulture movements in Namibia to date have not investigated their movement with respect to interactions with aircraft flight paths. Spatial analysis and statistics provide a means to demonstrate such interactions. In ecology, most spatial studies focus on the behaviour of a single species, however with increasing environmental impact legislation being implemented for the approval of infrastructural developments (Government of the Republic of Namibia 2007), the focus is shifting toward a better understanding of human-wildlife conflicts. On the topic of how vultures interact with infrastructural development, there have been a number of studies which involve potential interactions with wind farms (Garvin *et al.* 2011). In particular, it has been shown that without appropriate consideration, wind farms will negatively impact vulture populations. Walter *et al.* (2012) used spatial analysis to provide recommendations to reduce collision risks between a marine corps air station and both Black and Turkey Vultures (family Cathartidae, not Namibian). Similar to these studies, Namibian research conducted by the Wildlife and Aircraft Research Namibia Project (WARN) (Hauptfleisch & Avenant 2015, Hauptfleisch & Dalton 2015) focused on the airport surveillance radius and not on the larger airspace.

Unlike regional and international commercial flights, tourist/scenic flights are flown in smaller planes at lower cruising altitudes (approximately 600 m above sea level) (Scenic Air, pers. comm.). These flights occur frequently over sites located in natural areas

where vultures are known to breed and/or search for food (Fly-In Safaris Scenic Flights 2019). Thus, we propose that within Namibia there are potential risks specifically between tourist/scenic flights and vultures.

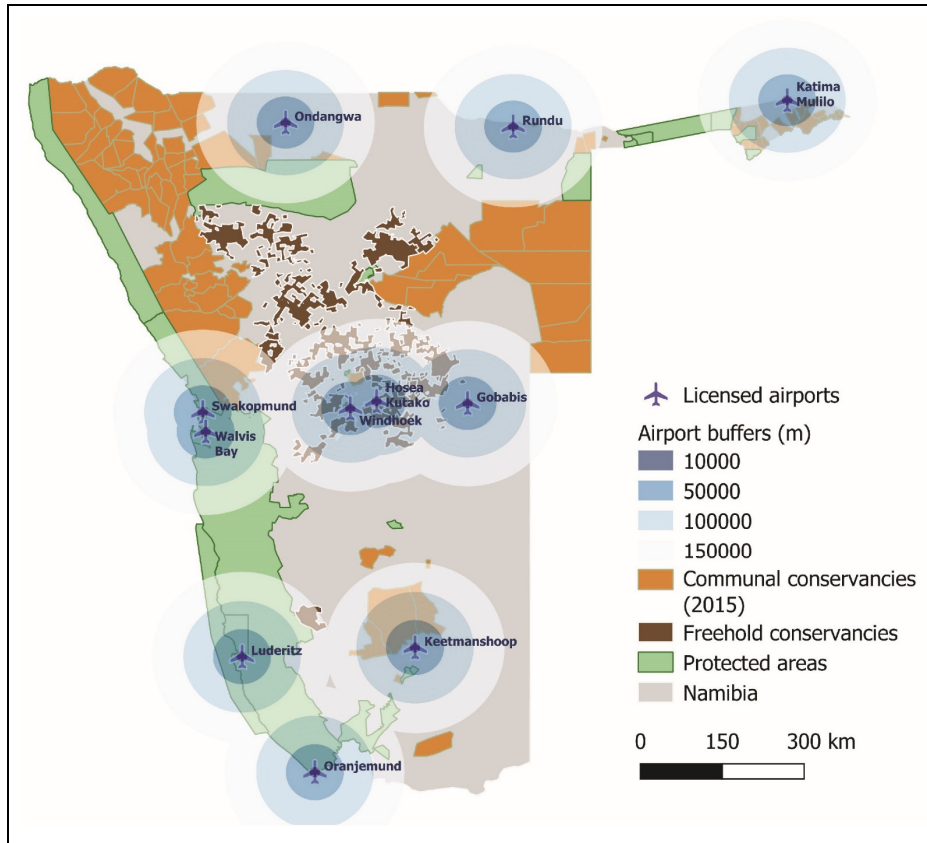
In this research we used spatial proximity analysis to investigate hotspots for potential interactions between vultures and tourist aircraft, both within the airport surveillance radius and across Namibia. We analysed historical and current telemetry and nesting data for the WBV, LFV and CV. These data were combined with data from aviation flight paths, enabling us to determine their interaction potential. Based on our findings, recommendations are made regarding aviation flight planning parameters such flight paths and flight times in order to reduce the collision risk.

## METHODOLOGY

### Study Area

Namibia is an arid to semi-arid country covering approximately 854,000 km<sup>2</sup>. With 43.6 % of the country under wildlife related land-uses, including national parks and conservancies (NACSO 2017) (Figure 2), its diversity and density of wildlife, including avian species, is high and even increasing. With extensive livestock farming dominating much of the remaining rural areas and human population density being low, scavengers such as vultures are widespread (SABAP 2016) (Figure 1) and relatively abundant compared to other parts of southern Africa (Simmons *et al.* 2015).

There are 11 airports in Namibia that are licensed by the Namibia Civil Aviation Authority (NCAA) (Figure 2), and over 200 private airstrips. In this study we focus on licensed airports, as these are expected to comply with civil aviation legislation regarding the monitoring of wildlife strikes and carry the largest number of flights.



**Figure 2:** The location and airport zone buffers of the licensed airports considered in this study in conjunction with the various types of managed conservation areas (communal, commercial and protected areas) within Namibia. (Source: GIS data sourced NAC 2020 and Mendelsohn 2010).

**Data source**

Spatial data used for this study comprise multiple datasets collected between January 2004 and October 2018 (Table 1). The vulture data include a combination of vulture telemetry data obtained from GPS collars and field observations of nesting sites acquired from multiple studies as listed in Table 1. Since nests are often used over multiple years, the individual bird identification tags or rings were used

to remove nest records collected multiple times over successive years. Aircraft flight data were acquired from a Namibian tourist flight operator (Scenic Air) which uses onboard GPS trackers in its aircraft. A month’s worth of flight tracking data is stored online in a running file and the company only downloads these files when required. The study acquired nine months of flight tracking data comprising 18,290 location points representing 3048 flying hours.

**Table 1:** Description of acquired data used for the spatial analysis in this study. Information includes: data description, source, period of data collection, the number of records and the time interval between recordings of the GPS tracked data. Note that the data description captures the combined datasets from individual sources. The time frame for individual collars differed, based on the operational time frame of the GPS collar.

Spatial data	Source	Number of records	Time interval	Date range
Cape Vulture (9 individuals)	Mendelsohn & Diekmann 2008	86,504	1 hour	01/2004-05/2010
Lappet-Faced Vulture (10 individuals)	Hancock 2017	28,897	2 hours	11/2012-01/2017
White-backed Vulture (full dataset – 13 individuals)	Faustino 2020	408,941	10 minutes	03/2017-10/2018
White-backed Vulture (subset – 8 individuals)	Faustino 2020	256,992	10 minutes	02/2017-03/2017; 07/2017-01/2018
Nesting sites (2 species) <sup>a</sup>	Kolberg 2017	3,040	Annual nest records – multiple use of nests removed	03/1991-10/2016
Aircraft flight data (recordings from 18 pilots)	Scenic Air GPS on-board instruments	18,290	10 minute intervals, 3048 flying hours	02/2017-03/2017; 07/2017-01/2018
Licensed airport locations	NAC 2020	11 airports		2006

<sup>a</sup> Nesting sites of only Lappet-faced and White-backed Vulture species were used in the nesting site analysis.

### Data preparation and analysis

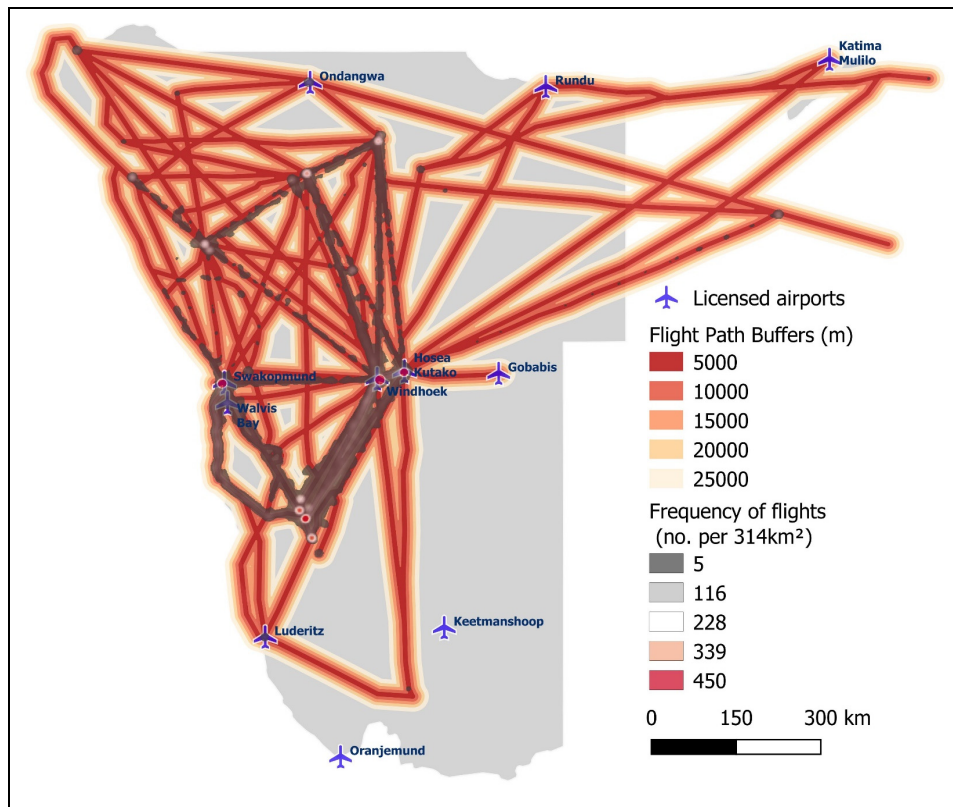
To analyse potential spatial overlap or spatial interaction between vultures and aircraft within Namibian airspace, proximity analysis was conducted between these datasets (Milne *et al.* 1989). The analysis was subdivided into two components. The first analysed potential interaction within the airport surveillance zones (ASZ) and the second component considered potential interaction during flight.

The ASZ includes the 13 km radius within which the international regulations recommend to manage the wildlife strike risk (ICAO 2012). For this study, the ASZ was extended to buffer zones with distances 10, 50, 100 and 150 km surrounding each airport (Figure 2). The furthest was selected as commercial airlines ascend to cruise altitude at this distance (pers. comm. M. Botger; X. Schoeman) whereas other aircraft types use various shorter distances (Figure 2).

The second component considered potential interactions during flight. Flight data for aircraft were obtained as individual points. Using the “Points to Path” plugin in QGIS, the individual flight paths for the different routes were generated. Multiple flight lines followed similar paths between the different destinations. To simplify the analysis a central flight path was manually defined for each route. As a result of the deviations flown for each route, it is not practical to look at interactions directly along a single flight line. Thus, around each flight line multiple

buffer rings were defined at 5, 10, 15, 20 and 25 km from the central flight lines for each flight route (e.g. Eros Airport to Rundu Airport). Interactions with the vultures were then analysed within these buffered flight areas (Figure 3). It must be noted that the flight paths do not all connect between the licensed parastatal airports. As indicated previously these flight paths are derived from the tourist aircraft that often use private airports, which are often based at tourist lodges within Namibia.

For the vulture data (Table 1), all data points available to this study within CV, LFV and nesting sites (NS) datasets were used in the analysis. Since vultures used the same nests on multiple occasions, density of nest sites was not considered in analyses, only nest locations. For some of the collared WBV data, there were readings at a higher frequency than 10 minute (the frequency of the aircraft flight data), therefore to expedite data processing time and enable comparison between the WBV and flight data, all WBV data were subset down to 10 minute intervals. This resulted in a total of just under 409,000 data points for WBV. Of the four vulture datasets, only some of the WBV data overlapped with the time frame of the aircraft flight data for which a subset was created (Table 1). This dataset was firstly used to determine if the spatial range of the data differed substantially from the full WBV dataset, and secondly to enable a direct comparison on potential flight interaction risks. It should be noted that analysis was also conducted on the CV dataset, however CV are thought to no longer breed within



**Figure 3:** The derived flight path areas and the frequency of flights within these flight path areas. Frequency was calculated as the number of flight location points that occurred within a 10 km radius. For ease of interpretation all areas with fewer than five points within a 10 km radius are not displayed.

Namibia (Simmons *et al.* 2015), and the CV dataset is rather outdated. No current study is being conducted on breeding of the species in Namibia, therefore it cannot be verified whether the species is in fact extinct as a breeding species in Namibia or not.

All spatial analyses were conducted in QGIS 3.4.2 (Madeira). Two forms of spatial analysis were conducted to evaluate the potential risks between vultures and aircraft within Namibia. The first of these was a visual spatial analysis, and the second a numeric analysis of potential interactions both in-flight and when approaching landing at any of the licensed airports.

In the visual analysis, heat maps of the frequency of either nesting data or telemetry recordings (GPS collar data) were derived for the 4 different vulture datasets (Table 1). The heat maps were calculated as the number of points recorded within a 10 km radius of the centre of each 1 km<sup>2</sup> pixel. For all the visualisations, pixels with fewer than 5 points per 314 km<sup>2</sup> were masked out to focus on the areas with higher potential risk of interaction. These visualisations were illustrated in combination with the flight paths of aircraft and airport buffer zones and used to identify the highest potential conflict areas - a useful visual result for airline and airport operators.

For the flight interaction risk analysis all vulture points (sightings or recordings) that fell within aircraft flight paths or airport ASZ areas were summed and the percentage of the total number of recordings were calculated for each buffer area. This enabled an incident probability analysis to determine the likelihood of potential interaction between aircraft and vultures.

To verify the potential time clashes between vultures and aircraft, the time of day that the vulture data points occurred within the interaction areas (flight paths and ASZ) was also considered. This provided insights about times of day the probability of interaction was highest. The time of day for the vulture locations were categorised and summed into

four categories: “morning” (05h00-10h00), “midday” (10h00-14h00), “afternoon” (14h00-18h00) and “evening” (18h00-05h00). Vulture roosting, feeding, thermal airflow use, climbing and prey detection behaviour (Hockey *et al.* 2005) informed the determination of time categories.

**RESULTS AND DISCUSSION**

The movement of the collared birds for all three vulture species obtained for this study (Figure 4) aligns well with the distribution of the three vulture species as per distributions maps adapted from the South African Bird Atlas project (“Southern African Bird Atlas Project 2”) (Figure 1). This comparison represents a consensus regarding point densities for the WBV and to an extent CV. The densities for both these species show a concentration over Etosha National Park and for CV also over the Waterberg National Park. WBV movement data show three additional hotspots which appear to be linked to commercial rangelands not associated with any of the conservation areas marked in Figure 4. The LFV observations exhibit the highest densities in the central-south west of Namibia in the Bird Atlas project, but in our study the collared birds spent significantly more of their time in the central-south east of the country. This may be due to the birds having been collared in western Botswana and may not represent the Namibian population completely. More recent studies (Hirschauer *et al.* 2017, Phipps *et al.* 2017) show the distribution of CV to include areas west and south of Windhoek in addition to the hotspots identified in our assessment.

With respect to potential interactions with tourist aircraft, it is seen that over 45 % of the observed GPS points for WBV (and the subset data) and CV occur within 10 km of the central flight lines taken by the tourist aircraft (Table 2) and over 65 % of recorded nests of WBV Vultures occur within 5 km of the centre of flight lines between most-used airports (Table 2). Combining the visual (Figure 4) and numeric assessments (Table 2), it would appear that greatest tourist flight risk interactions are likely to occur in the vicinity of the Etosha National Park and

**Table 2:** The cumulative percentage of vulture observations (either visually observed vulture nests, or from GPS collared vultures) that fell within and the remainder that fell outside of the flight paths of the aircraft.

Distance (km)	Nesting			Vulture GPS Recordings			
	All Nests (%)	WBV (%)	LFV (%)	WBV (%)	WBV subset <sup>a</sup> (%)	LFV (%)	CV (%)
5	31.72	66.90	9.49	23.63	24.84	0	30.27
10	38.63	72.00	17.54	47.01	49.34	0	49.28
15	67.37	76.75	61.44	60.82	64.36	0	56.21
20	87.92	87.15	88.41	73.19	76.87	0	60.13
25	93.66	91.66	94.92	80.40	80.82	0	62.02
Beyond	6.34	8.34	5.08	19.60	19.18	100	37.98
<b>Total Observations</b>	<b>5,265</b>	<b>2,039</b>	<b>3,226</b>	<b>408,941</b>	<b>256,992</b>	<b>28,896</b>	<b>86,503</b>

<sup>a</sup> subset of WBV GPS recordings that coincide with the flight data from the tourist airplanes.

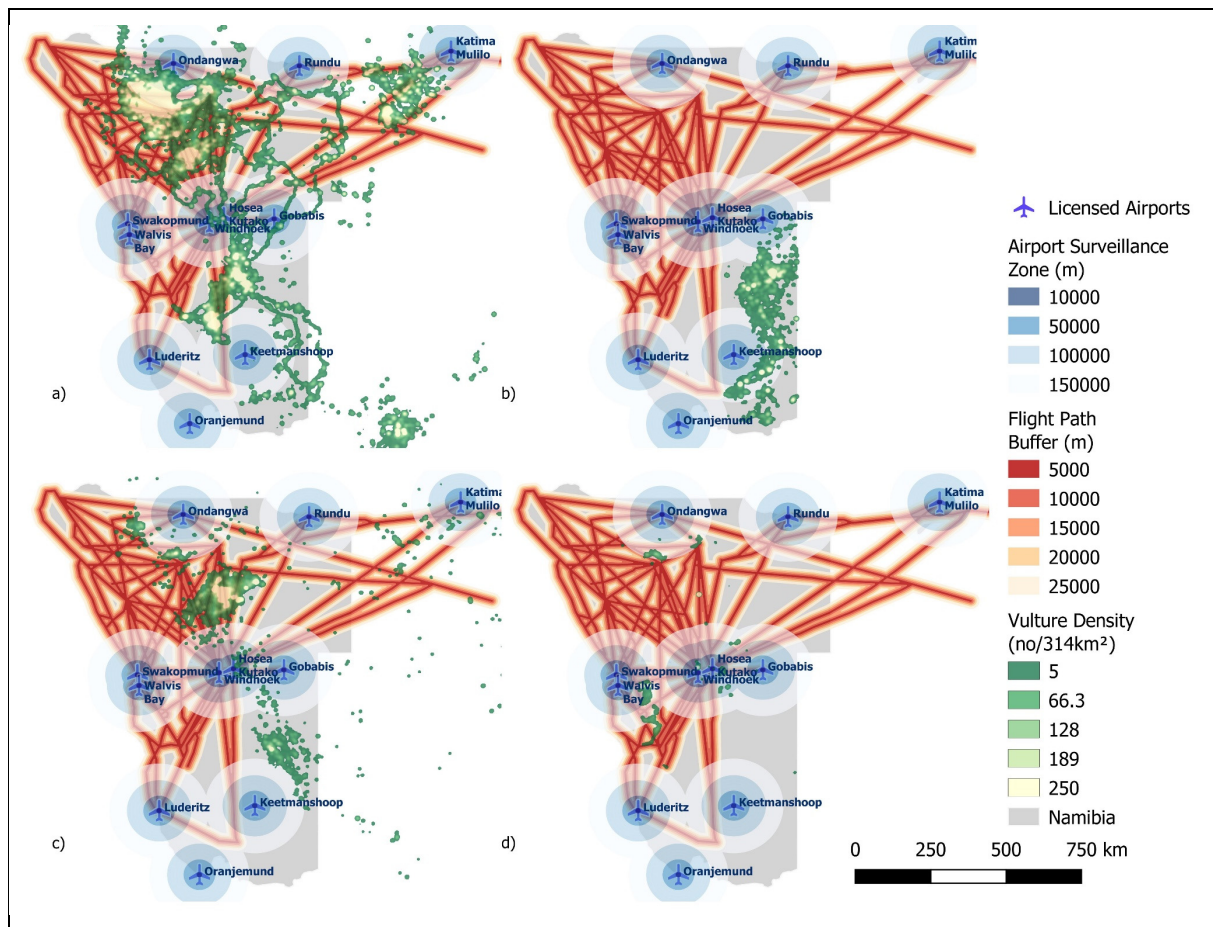
the Waterberg Plateau Park. The high prevalence of vultures in the vicinity of the Waterberg Plateau Park is likely as a result of the vulture restaurant which was at the time situated at Rare and Endangered Species Trust (REST) at Waterberg. The feeding site was abandoned when REST moved to the Otjiwarongo area in 2016.

None of the collared LFV used in this study interacted within a 25 km distance of the identified tourist flight paths (Table 2), thus we conclude that there is a low risk of potential interactions. The telemetry data however contradicts the nest locations of the LFV where just under 10 % of the nests are found to occur within 5 km from the flight path, and 50 % of all LFV nests were observed within 15 km of flight paths (Table 2). Based on this and noting the already mentioned discrepancy between the distribution of the location data and the distribution maps produced by the Bird Atlas Project, we believe our results based on the LFV GPS recordings should be treated with caution.

For the two most prevalent nesting species in Namibia, WBV have most plotted nests in the vicinity of the Etosha National Park and on

commercial farmlands east of Hosea Kutako International airport (Figure 1). LFV similarly have many recorded nests in Etosha NP, but most of the recorded nests occur along the eastern boundary of the Namib-Naukluft National Park. For all nests, there appears to be a high potential risk of in-flight interaction; more than 60 % of the nest sites occur within 15 km of the central flight line (Table 2). The Namib-Naukluft LFV nesting sites also pose potential risks around Walvis Bay Airport with flights travelling to Sossusvlei exhibiting the highest potential risk. This risk is intensified during egg-incubating and chick-rearing activities, with peak egg laying season between May and July with an incubation period of approximately 2 months and chicks fledging after approximately 125 days (Hockey *et al.* 2005). Risk for aircraft collisions are likely to be high throughout this period as breeding pairs will increase foraging flights to feed their chicks. Fledging birds (likely between September and October) would also add to this risk, in the absence of the necessary flight experience to avoid collisions.

In contrast to the high numbers (39-49 %) of potential vulture-aircraft interactions that could occur within



**Figure 4:** Density of a) White-backed, b) Lappet-faced, c) Cape Vulture and d) Nesting vultures in relation to flight paths of tourist airlines and within the airport surveillance zones of Namibia's licensed airports.

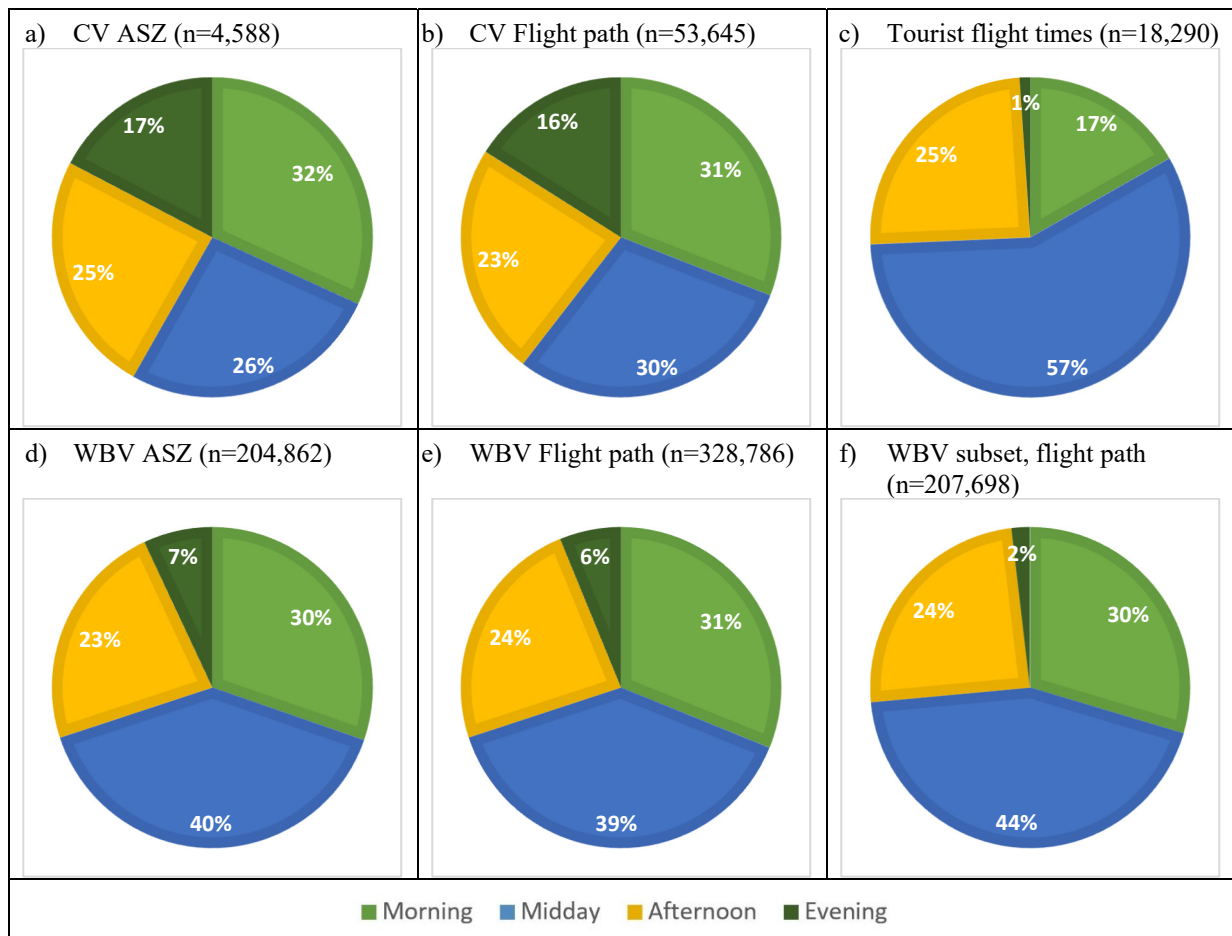
**Table 3:** The cumulative percentage of vulture observations (either visually observed vulture nests, or from GPS collared vultures) that fell within, and the remainder that fell outside, the airport surveillance zones.

Distance buffer from airport (km)	Nesting			Vulture GPS Recordings			
	All Nests (%)	WBV Nests (%)	LFV Nests (%)	WBV (%)	WBV subset <sup>a</sup> (%)	LFV (%)	CV (%)
10	0.13	0.29	0.03	0.10	0.18	0.00	0.01
50	9.12	21.38	1.36	0.70	0.91	0.02	0.59
100	55.16	29.08	71.64	6.00	4.17	10.26	1.63
150	73.96	53.46	86.92	41.00	52.19	32.51	5.30
Beyond	26.04	46.54	13.08	59.00	47.81	67.49	94.70
<b>Total Observations</b>	<b>5,265</b>	<b>2,039</b>	<b>3,226</b>	<b>408,941</b>	<b>256,992</b>	<b>28,896</b>	<b>86,503</b>

<sup>a</sup> subset of WBV GPS recordings that coincide with the flight data from the tourist airplanes.

10 km of flight lines (Table 2), the number of potential interactions within 10 km of the airport surveillance zone (ASZ) for both nesting and GPS collared vultures, were below 1 % (Table 3). A specific risk emerges with LFV, where 70 % of nests were found within 100 km of the airports, mostly within the range of Walvis Bay airport. Up to 10 % of the GPS collared LFV found to be overlapping with the ASZ at distances of up to 100 km, were also found to overlap with the two licensed airports of Gobabis and Keetmanshoop.

For both WBV and LFV, many birds have been observed to nest within the approach distance for commercial aircraft to the Hosea Kutako International airport (WARN 2014). Most of these nesting sites are to the east of the Hosea Kutako airport in the Seeis riverbed, one of the primary approach directions (into Runway 08) taken by commercial aircraft. In the study by DeVault *et al.* (2005) in which they found potential flight interaction risks with military aircraft, the authors proposed revising aircraft flight schedules and landing directions. Whether such a recommendation



**Figure 5:** Percentage of the total number of GPS observations (in parenthesis) of the Cape Vultures (CV) and White-backed Vultures (WBV) that fell within the airport surveillance zones (ASZ) and flight paths, broken down into the time of day that tourist aircraft were recorded to be flying.



for focusing on a west to east landing at Hosea Kutako would be practical requires further investigation.

The majority of daily vulture activity was recorded during the morning (05h00-10h00) and up to midday (10h00-14h00) (Figure 5a,b,d-f), which is consistent with the literature (Anderson 2004, Hockey *et al.* 2005, Murn & Anderson 2008). Similarly, most tourist flights took place during the midday time period (Figure 5c), increasing the temporal collision risk between smaller aircraft and vultures. From our dataset, CV appear to have been substantially more active than WBV throughout the late afternoon to evening (beyond 18h00) (Figure 5 a,b vs. d-f).

## CONCLUSION

Our study found a low risk of interaction between aircraft and vultures within the direct ASZ which is monitored by licensed airports, however, we found that up to 10 % of nesting vultures are a risk to both commercial and tourist aircraft on approach and climb phases within 50 km of the airports. Hosea Kutako International and Walvis Bay airports (Namibia's most important international airports), have the highest potential risk of vulture interactions during approach and climb.

The risk of in-flight interactions between tourist aircraft and vultures seems most likely in the vicinity of Etosha and Waterberg Plateau National Parks, and this is further exacerbated by the fact that both vultures and tourist aircraft are simultaneously most active at similar altitudes during morning and midday hours.

To strengthen the spatial analysis conducted in this study, it would be valuable to obtain data from both flights and vultures which are coincident in time. Additionally, this work would benefit from obtaining in-flight altitude values for the aircraft, to compare with altitude data collected by vultures, since aircraft altitude data were unavailable for this study. This additional data at coincident times, would enable a three-dimensional analysis based on observed interaction risks between aircraft and vultures to be carried out.

## ACKNOWLEDGEMENTS

We thank Scenic Air for providing flight-log data, as well as their pilots for providing context. Scenic Air pilot Michael Botger, and Bushskies pilot Xander Schoeman are specifically thanked. We thank the Vultures Namibia group and in particular the Ministry of Environment, Forestry and Tourism and Holger Kolberg for providing nesting location data. Reviewers Drs J. Mendelsohn and A. de Hoon, both anonymous at the time, are thanked for valuable comments on the manuscript.

## REFERENCES

- Anderson MD (2004) African white-backed vulture *Gyps africanus*. *The vultures of southern Africa—quo vadis*: 15–27.
- Avery ML, Humphrey JS, Daughtery TS, Fischer JW, Milleson MP, Tillman EA, Bruce WE, Walter WD (2011) Vulture flight behavior and implications for aircraft safety. *Journal of Wildlife Management* 75: 1581–1587.
- Bamford AJ, Diekmann M, Monadjem A, Mendelsohn J (2007) Ranging behaviour of Cape Vultures *Gyps coprotheres* from an endangered population in Namibia. *Bird Conservation International* 17: 331–339.
- DeVault TL, Reinhart BD, Brisbin Jr IL, Rhodes Jr OE (2005) Flight behavior of black and turkey vultures: implications for reducing bird–aircraft collisions. *Journal of wildlife management* 69: 601–608.
- Diekmann M, Scott A, Scott M, Diekmann J (2004) Capture and fitting of satellite-and radio-telemetry equipment onto Cape Griffon vulture, *Gyps coprotheres*, African white-backed vulture *Gyps africanus* and Lappet-faced vulture *Torgos tracheliotos* in the Waterberg area, Namibia in 2004. *Vulture News* 51: 34–45.
- Faustino C (2020) *Movement ecology and conservation - the case of African vultures*. PhD Thesis. University of St. Andrews, United Kingdom
- Garvin JC, Jennelle CS, Drake D, Grodsky SM (2011) Response of raptors to a windfarm. *Journal of Applied Ecology* 48: 199–209.
- Government of the Republic of Namibia (2007) *Environmental Management Act* 7 of 2007.
- Hancock P (2017) *What were the Lappet-faced Vultures doing on the other side of the country?* First Symposium of the Namibian Chamber of Environment. Otjikoto Nature Reserve, Namibia.
- Hauptfleisch ML (2014) *The use of ecosystem parameters in predicting the risk of aircraft-wildlife collisions at Namibian airports*. PhD thesis. University of the Free State, South Africa.
- Hauptfleisch ML, Avenant NL (2016) Actual and perceived collision risk for bird strikes at Namibian airports. *Ostrich* 87: 161–171.
- Hauptfleisch M, D'Alton C (2015) Arthropod phototaxis and its possible effect on bird strike risk at two Namibian airports. *Applied Ecology and Environmental Research* 13: 957–965.
- Hirschauer MT, Wolter K, Green RE, Galligan TH (2017) Immature Cape Vulture *Gyps coprotheres* breaks species range record. *Biodiversity Observations* 8: 16–1.
- Hockey PAR, Dean WRJ, Ryan PG (2005) *Roberts Birds of Southern Africa*, 7th edn. Trustees of the John Voelcker Bird Book Fund, Cape Town, South Africa.
- International Civil Aviation Authority (ICAO) Airport Services Manual (2012).
- Kolberg H (2017) Unpublished Namibian vulture nesting data.
- Mendelsohn J (2010) *Atlas of Namibia—A Portrait of the Land and its People*, 3rd ed. Sunbird Publishers, Cape Town, South Africa.
- Mendelsohn J, Diekmann M (2008) *Some findings from tracking Cape Vultures in Namibia*. Report. Environmental Information Service. Windhoek, Namibia. URL: <http://the-eis.com/elibrary/search/8635>. Accessed 1 July 2019.

- Milne BT, Johnston KM, Forman RT (1989) Scale-dependent proximity of wildlife habitat in a spatially-neutral Bayesian model. *Landscape Ecology* 2: 101–110.
- Murn C, Anderson MD (2008) Activity patterns of African White-backed Vultures *Gyps africanus* in relation to different land-use practices and food availability. *Ostrich-Journal of African Ornithology* 79: 191–198.
- NACSO (2017) Latest statistics on Conservation areas in Namibia. URL: <http://www.nacso.org.na/nacso-updates>. Accessed 14 June 2020.
- Namibia Airports Company Website (2019) URL: <https://www.airports.com.na/about-us/namibia-airports-company-management/63/>. Accessed 19 November 2019.
- Phipps WL, Diekmann M, MacTavish LM, Mendelsohn JM, Naidoo V, Wolter K, Yarnell RW (2017) Due South: A first assessment of the potential impacts of climate change on Cape vulture occurrence. *Biological Conservation* 210: 16–25.
- Scenic Air (2019) Website. URL: <http://scenic-air.com/flights/>. Accessed 20 February 2020
- Simmons RE, Brown CJ, Kemper J (2015) *Birds to watch in Namibia: red, rare and endemic species*. Ministry of Environment and Tourism. Windhoek, Namibia.
- Southern African Bird Atlas Project (SABAP) (2016). Website. URL: <http://sabap2.birdmap.africa/>. Accessed 6 July 2019.
- Walter WD, Fischer JW, Humphrey JS, Daughtery TS, Milleson MP (2012) Using three-dimensional flight patterns at airfields to identify hotspots for avian-aircraft collisions. *Applied Geography* 35: 53–59.
- WARN (2014) Wildlife and Aircraft Research Namibia Project. Website. URL: <http://warn.nust.na>. Accessed 9 November 2019.