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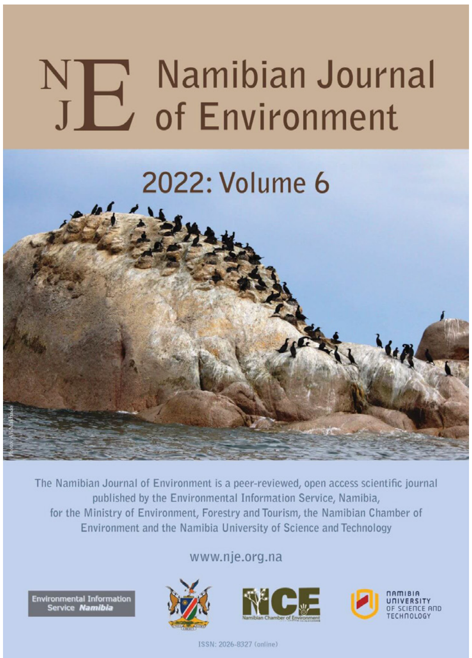
ISSN: 2026-8327 (online).



SECTION A: RESEARCH ARTICLES

Recommended citation format:

Pallett J, Simmons RE & Brown CJ (2022) Staggered towers on parallel transmission lines: a new mitigation measure to reduce collisions of birds, especially bustards. *Namibian Journal of Environment* 6 A: 14-21.

Cover photo: AB Makhado

Staggered towers on parallel transmission lines: a new mitigation measure to reduce collisions of birds, especially bustards

J Pallett[1], RE Simmons[2], CJ Brown[3]

URL: https://www.nje.org.na/index.php/nje/article/view/volume6-pallett
Published online: 9th February 2022

[1] FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, University of Cape Town. Present address Southern African Institute for Environmental Assessment, P O Box 6322, Ausspannplatz, Windhoek, Namibia. john.pallett@saiea.com
[2] FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, University of Cape Town, South Africa
[3] Namibian Chamber of Environment, P O Box 40723 Ausspannplatz, Windhoek, Namibia

Date received: 31st August 2021; Date accepted: 7th December 2021.

ABSTRACT
Significant numbers of birds are killed annually by flying into power lines across Africa, and numerous attempts have been made to mark lines to make them more conspicuous, to reduce these collisions. Results from surveys reported in this paper and many others indicate that bustards (family Otidae) are most susceptible. Bustard fatalities are not greatly reduced by adding bird diverters to earth wires. Here we propose a new mitigation measure that may reduce the number of mortalities by two-thirds where two power lines run in parallel: staggered towers. Power line surveys in Namibia and South Africa indicate that 87% of 134 bird collisions occurred in and near the middle sections of a span, while only 13% of collisions occurred near the towers themselves. Despite the skull morphology of bustards creating a blind spot immediately ahead of them, it appears that the towers are big enough to be seen (or heard) and avoided. Thus, by aligning power lines of similar size in parallel and as close as technically feasible and staggering the towers such that each tower is aligned with the mid-span of the neighbouring line, the lines may become more visible. This should allow collision-prone birds to gain altitude and fly over the lines. Theoretically, this method is expected to reduce power line fatalities by 67% for each new line. We call for experimental validation of this novel mitigation measure.

Keywords: bird mortalities; Namibia; power lines; span position; South Africa

INTRODUCTION

Power lines strung across the landscape inadvertently create problems for birds, through collisions, electrocutions and displacement from their preferred habitat (Bevanger 1998, Jenkins *et al.* 2010, Silva *et al.* 2010, Uddin *et al.* 2021). Collisions have been identified as particularly problematic for large birds, effectively making the power line grid a network of traps, running to tens of thousands of kilometres of lines in southern Africa alone. By 2007, South Africa's power utility Eskom had 27 770 km of high voltage transmission lines and 325 000 km of distribution lines (Eskom 2007), and in Namibia the current figure is 34 000 km of transmission and distribution lines (Wagner pers. com. 2021). The electricity network will continue to expand, increasing the level of concern for those large birds that are susceptible and known to be threatened by this infrastructure.

An estimated 47 000 Ludwig's Bustards (*Neotis ludwigii*) are killed annually in South Africa by power lines, at a rate of about one bustard per kilometre of line per year (Shaw *et al.* 2018), with the potential for population level effects. Other species of conservation concern killed in large numbers include flamingos, storks, other bustards, vultures, Secretarybirds (*Sagittarius serpentarius*) and cranes (Jenkins *et al.* 2010, Shaw *et al.* 2018), both in Namibia (Pallett in prep.) and South Africa (Shaw *et al.* 2021). Bustards are particularly prone to collisions, partly due to their skull and eye morphology which makes them blind in the direction of flight (Martin & Shaw 2010). In an evolutionary sense this was never a disadvantage because they are open-country birds with no need to navigate through a three-dimensional landscape that savanna or woodland species inhabit.

Globally reducing collision mortality has proven particularly intractable. When new power lines are to be constructed, careful routing may help to minimise the risks to susceptible birds (APLIC 2012). The most widespread method is marking the lines with static or dynamic bird flight diverters to make them more visible (Bernardino *et al.* 2018). Attempts to reduce the high rate of collision with power lines have shown good success for Blue Cranes (*Grus paradisea*) (92% reduction in fatalities) and other large birds (51% reduction) in South Africa (Shaw *et al.* 2021). This was achieved by affixing such bird diverters to the earth wire – the thin top-most conductor that protects the line from lightning strikes. While such methods have reduced fatalities by 40-94% in various experimental set-ups in high-strike areas (Janss 2000, Jenkins *et al.* 2010, Barrientos *et al.* 2011, Bernadino *et al.* 2019) the heavy-flying bustards show little decrease in collision rate compared to lines with no diverters, both here in Africa and elsewhere in the world (Jenkins *et al.* 2010, Shaw *et al*. 2015, Shaw *et al*. 2021). In Namibia and South Africa, Ludwig's and Kori Bustards experience a heavy toll from collisions with power lines, while the smaller korhaans (also Otidae) are impacted to a lesser extent. Both Ludwig's and Kori Bustards are threatened red data species in both Namibia (Simmons *et al.* 2015) and in South Africa (Taylor *et al.* 2015) with the main cause of mortality being collisions with power lines. Solutions are clearly needed to protect all bustard populations from further decline.

The idea presented here arose from work trying to mitigate a 460 km length of 400 kV line that Namibia's power utility, NamPower, proposes to construct through prime bustard, vulture and raptor habitat. The daunting task of mitigating this line with bird diverters to avoid fatalities of threatened birds, but with the knowledge that collisions were still certain to occur, prompted the consultants (Sustainable Solutions Trust 2015, Birds and Bats Unlimited 2018) to look for novel alternatives. In this way we could not only test a new mitigation, but also test it against the efficacy of traditional diverters to understand if they are required at all. If bird flight diverters are found to be unnecessary then utility companies may opt to use the methods proposed here. Our aim is to describe a novel method to reduce bustard collision mortalities that is likely to benefit other collision-prone species too, to give theoretical reasons why we believe it will work, and to request researchers and environmental specialists to test our method with unmitigated lines.

METHODS

Data for this analysis were drawn from two sources: (i) power line surveys on four different capacity power lines conducted in southern Namibia over 15 months in 2012-13 (Pallett in prep.); (ii) mortalities recorded on two power line surveys in the Western and Northern Cape, South Africa in 2014 and 2017. The objective was to assess the distribution of collisions within a span, relative to the total span length of any power line. We therefore selected incidents with the following criteria:

a) Certainty that the incident was a collision. Any dead large bird found close to a power line was assumed to have collided with it. In some cases, a collision could be confirmed by the presence of broken wing or leg bones, and occasionally the exact site of the collision could be verified by one or two small body feathers stuck to an overhead conductor where the impact had occurred;
b) Presence of a relatively fresh carcass or a single concentration of body feathers snagged in the vegetation in one place. We assumed that the location of the carcass or main concentration of feathers was close to where it hit the conductor, fell and died, and represented the best estimate of where the collision occurred. Bird remains that were scattered over a wide area without any noticeable concentration in one spot, or that were only a small part of the bird such as a wing or a leg, were not included in the data set, as these could have been carried away from the main carcass by scavengers;
c) Lateral distance from the centre of the power line less than 30 m. Carcasses further away were rejected on the basis that they could have been moved there by crippling (where an injured bird had fallen to the ground and moved away before dying) or by scavengers carrying the carcass to a new location. The further away from the power line, the more likely this was a factor, and the less confidence we could place in the location of the actual collision;
d) Incidents that could be attributed to one power line only. Collisions that occurred in places where there were two or more power lines closer than 0.5 km together were rejected, as it was impossible to identify which power line caused the incident.

Namibian surveys

The systematic surveys in southern Namibia were conducted by JP on 81-95 km sections of four voltages of power lines (Pallett in prep.). The lines had capacities of 66, 132, 220 and 400 kV, and surveys were carried out every three months over a 15-month period, with the first survey used as a clearing survey.

South African surveys

These data derived from a repeat survey of a 50 km section of power line by RES and M Martins along the 400 kV Aries-Helios power line near Kenhardt, and a once-off 7 km power line survey of the Aurora-Juno 400 kV line near Strandfontein on the west coast.

Monitoring protocol

The monitoring protocol on all the surveys was as follows: the survey routes traversed relatively even ground (not deeply broken or rocky, where carcasses could easily be missed) over open plains with low and/or sparse vegetation, where detectability was relatively constant. While some carcasses of small birds were found, the searching method was directed at birds larger than a Pied Crow (*Corvus albus*) (mass 500 g, total length 50 cm) – which would usually

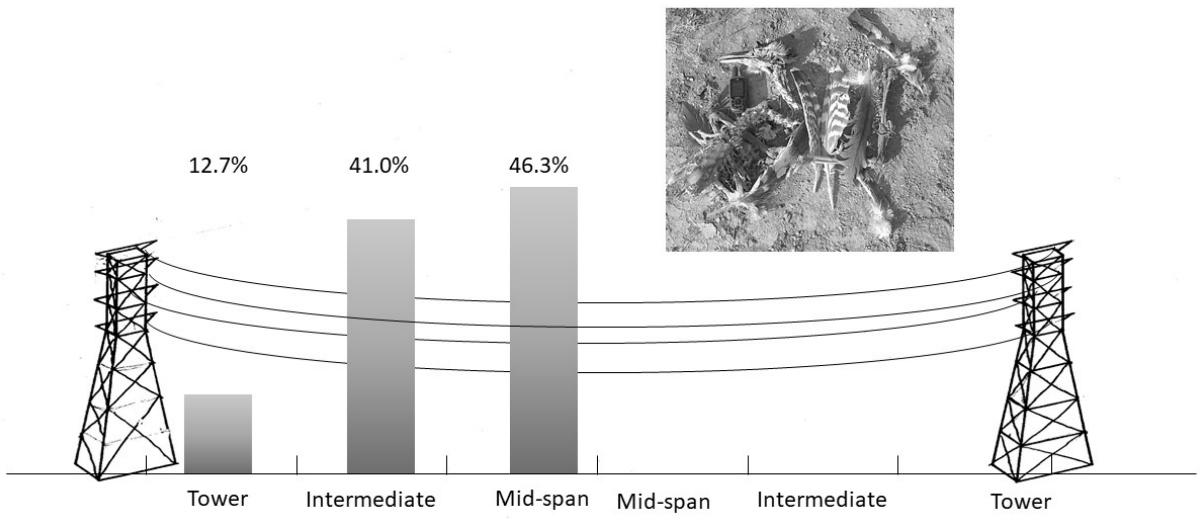


Figure 1: *Percentage of large bird collisions in relation to position within the span on power lines. Records combine those for southern Namibia (n = 100) and the Northern and Western Cape, South Africa (n = 34) and indicate that most large bird deaths (87.3%) occur away from towers*

produce enough evidence to be visible within the search zone. The observers drove slowly (10-20 km/h) on the track beneath the power line, with the driver and passenger searching ahead and approximately 30 metres to left and right. All bird carcasses or other evidence of a power line-related incident were recorded, noting the species as far as it could be identified. The coordinates were recorded on a GPS device and photographed at the place where the majority of the body feathers were found. All bird remains were cleared away to prevent recounting on future surveys in Namibia or left *in situ* to judge permanency of remains in South Africa.

Note that while most surveys were repeat surveys, no adjustment for scavenger removal was required as our aim was to record where the carcass was found relative to the towers, not the rate of mortality per kilometre for the species located.

Data analysis

Transmission lines and their towers are visible on Google Earth images, so we measured the span where each collision occurred and noted the location of the collision within the span. Each collision in the data set was categorised according to its position within the span, divided into thirds (Figure 1): the central third forming the Mid-span, the two sixths closest to the towers forming another third, labelled Tower, and the two sixths in between labelled Intermediate.

We compared the ratio of selected versus rejected incidents to test whether the selection criteria introduced any bias into the results. A chi-square test with Yates correction (for more than two categories) was used.

RESULTS

Of the 327 mortalities that were recorded, 134 (41.0%) were noted as confirmed collisions with accurate locality coordinates (Table 1). The overall proportions of Mid-span: Intermediate: Tower for those carcasses which were selected for this analysis, were not significantly different from those which were rejected [$\chi 2$ (df = 2, n = 327) = 1.376, $p > 0.1$]. Under all the transmission lines surveyed we found a bias towards more large bird collisions in the mid-span of the lines and on either side of the mid-span. In our samples, 87.3% of 134 carcasses occurred under the mid-span and intermediate sections, and only 12.7% occurred around the towers (Figure 1 and Table 1). Even though the length of an average span differs widely when comparing lines of lower versus higher capacity, smaller proportions of collisions occurred at the towers, for all the power line types.

The diversity of birds making up the collision fatalities is shown in Appendix 1. The dominant victims were Ludwig's Bustard and Kori Bustard, which together comprised 83.6% of all the collisions. The proportion of their collisions occurring in the middle sections compared to the tower rose to 90.2 : 9.8% when considering only these two bustards.

DISCUSSION

The results from this study are very clear: bustards and other large collision victims on Namibian power lines are more likely to hit the central sections of the line but tend to avoid colliding with the towers. This is mirrored by a 3-year study in South Africa's Karoo where bustards were also much more likely to collide with the mid-span of transmission lines (72%) and

Table 1: *Distribution of collision carcasses among different sections of power line spans in Namibia and South Africa.*

Power lines surveyed	**Number of collisions along different sections of the power line span**			
	Average span length (m)	Mid-span	Inter-mediate	Tower
66 kV line between Lüderitz and Rosh Pinah, southern Namibia (5 surveys, 95 km each)	198.5	3 (37.5%)	4 (50.0%)	1 (12.5%)
132 kV line west and east of Warmbad, southern Namibia (5 surveys, 81 km each)	321.2	9 (50.0%)	4 (22.2%)	5 (27.8%)
220 kV line south of Keetmanshoop, southern Namibia (5 surveys, 91 km each)	414.5	16 (42.1%)	19 (50.0%)	3 (7.9%)
400 kV line south-east of Keetmanshoop, southern Namibia (5 surveys, 81 km each)	453.4	17 (47.2%)	14 (38.9%)	5 (13.9%)
400 kV line near Kenhardt, Northern Cape, RSA (2 surveys, 56 km each)	360.7	8 (57.1%)	5 (35.7%)	1 (7.1%)
400 kV line near Strandfontein, Western Cape, RSA (1 survey, 7.1 km)	334.0	9 (45.0%)	9 (45.0%)	2 (10.0%)
Total (134 collisions)		**62**	**55**	**17**
Overall percentages		**46.3%**	**41.0%**	**12.7%**

did so at a very high rate of approximately 1.0 bustard/km/year (Shaw 2013).

The collision fatalities in the two countries indicate the same trend: that bustards and other collision-prone species likely fail to see the mid-sections of power lines, but do avoid the towers supporting the lines, most of the time.

It is this ability to see (or hear) the tower and avoid it that is the core of the new mitigation proposed here. By aligning two power lines close together in parallel and staggering the tower of one line to align with the mid-span of the adjacent line, bustards will more likely detect and avoid both power lines.

We suggest that bustards are more likely to detect the towers, because (i) they are larger than the conductors and (ii) we noted in our extensive surveys that the wind often whistled through the lattice structure and, for some towers, loose plates or fittings often vibrated with considerable noise. If the birds are detecting the sound rather than the structure itself, this in itself could be exploited to increase the signature of the structure (or the bird diverter) to get around the poor vision of these collision-prone species.

No precise predictions can be made from this idea but the theoretical reduction in collision rate can be calculated by referring to Figure 2. Assuming two separate power lines cause 100 collisions each, the proportion of collisions per section of line will be as shown in Case 1, as deduced from our distribution of collision incidents amongst the span sections. If the power lines are arranged close together with the towers optimally staggered as illustrated in Case 2, the total collisions will be reduced to 66.6. This is because bundling the two power lines close together theoretically creates the effect of only one power line, and the tower of each line should help to mutually reduce the fatalities in the worst section of the adjacent line. The total collision rate on both lines is 33.3% of the total in Case 1.

Is there any field evidence for this effect? A small sample with “naturally” staggered towers was sampled in two surveys of a section of 220 kV and 400 kV lines running parallel and 58 m apart in South Africa’s Karoo region in 2018 (Figure 3). No avian fatalities were recorded in 14 km of either the 220 kV or the 400 kV line, compared to one bustard fatality in 11 km of a nearby non-staggered 400 kV line in the same habitat. This provides a hint that bundling lines together and staggering the towers could help to reduce bird collision rates. This principle is best suited to lines of similar height. Evidence is needed from other situations, where unequal power lines run in parallel, as it is conceivable that an approaching bird might first see the shorter line, fly over it then collide with the higher line behind it.

If this novel mitigation proves successful it will be especially useful for proposed power lines that cross large areas known to be inhabited by highly collision-prone groups such as bustards, Secretarybird and flamingos. To our knowledge it has not been proposed before and has never been tested.

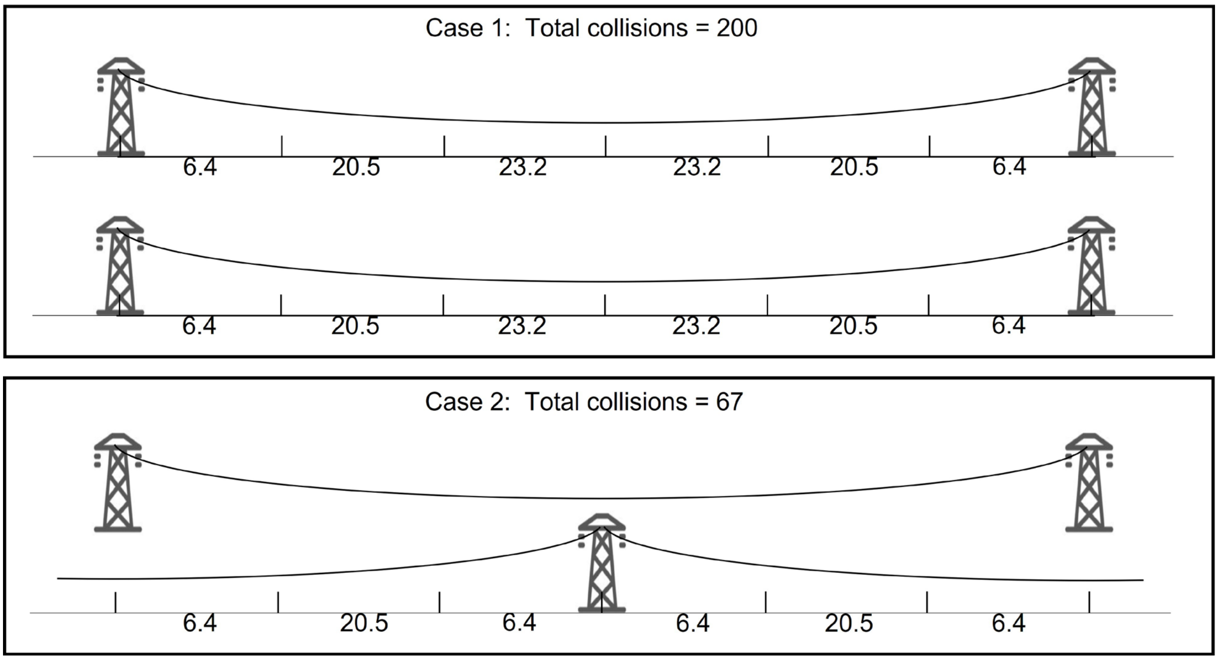


Figure 2: *Schematic representation of the theoretical reduction in collision rate from bundling power lines together and staggering the towers. The number of collisions in each section of the span is shown, derived from the proportions recorded under power lines sampled in Namibia and South Africa. Case 1 represents the situation of two separate power lines, causing 200 collisions. Case 2 represents two power lines bundled close together with staggered towers.*

Wherever new power lines are to be erected, mitigation measures should include bundling lines together in a narrow corridor, irrespective of design or size, rather than distancing them apart in separate lines. Secondly, where two types of power line are the same (as in the case that prompted this initiative) every effort should be made to position the towers in a maximally staggered arrangement. A similar but reduced benefit of fewer collisions is expected even on lines of different sizes (such as a 220 and a 400 kV line together, as in Figure 3), but logically the amount of staggering will vary due to the different span lengths of the two lines. That is, some parts will have their towers closely aligned, and other parts will have them staggered with the mid-span of one line adjacent to the tower of the other. There will also be practical elements on the ground which might make it difficult to achieve optimum staggering in hilly terrain, but the principle is to aim for the maximum offset of one tower against the other.

What we presently do not know is (i) whether this theoretical prediction will work in practice and (ii) whether the bustards approaching the mid-span of one line will see the tower of the adjacent line behind the mid-span and take evasive action. If they do take evasive action, then this method has the potential to reduce bustard deaths by 67%. Individual circumstances, such as the angle of approach toward the lines, and the distance between two parallel lines, are expected to contribute to the efficacy of the staggering effect.

Figure 3: *An example of a 400 and a 220 kV power line in parallel with staggered towers showing the greater visibility of the lines with a tower placed opposite the mid span.*

To test these ideas, we propose to set up a monitoring programme on target power lines in Namibia over 460 km before and after construction of a parallel staggered line (with a control line of equal size) to compare collision and fatality rates. We expect *a priori* that fatality rates will be about two-thirds lower compared with the pre-staggered line and the controls.

We also expect that the staggered towers idea will mitigate avian collisions better than simply two lines of equal voltage bundled together with their towers aligned. This is because the conductors are still equally unlikely to be seen by collision-prone birds whether there are two or more (Shaw 2013).

We request researchers and environmental avian specialists to collect systematic data on bustard and other collision-prone bird fatalities along power lines that by chance exhibit the staggered tower effect outlined here. Ideally the fatality rate should be compared with simultaneously collected avian fatalities along un-staggered lines of the same voltage in similar habitat. This will give a first order assessment of the efficacy of this potential new mitigation measure.

Already these methods are being discussed and recommended in South African power-supply circles. It is our hope that staggered towers on adjacent lines will reduce the need for any other form of avian collision-mitigation and thereby be favoured by power utilities to reduce start-up costs involved with affixing spirals or dynamic markers and the maintenance of such mitigations.

ACKNOWLEDGEMENTS

We thank all those with whom this idea was discussed or field work assistance provided including Dr Jessica Shaw, Peter Bridgeford and Marlei Martins. Max Weylandt and Dr Colleen Seymour assisted with the statistics. We are also grateful to NamPower employees Pierre van Niekerk, Hansie Peens, Bertie Steyn, Johnny Nanyome, Ebro Kooper and David Plaatz, and Karl-Heinz Wagner for the personal communication. Their sharing of knowledge and ideas helped greatly in our own thoughts. JP thanks the NamPower-Namibia Nature Foundation Strategic Partnership, and the Namibian Chamber of Environment for logistical and financial support. RES was supported by various Independent Power producers during survey work for renewable energy facilities. We thank reviewers Jessica Shaw, Holger Kolberg and Peter Ryan for valuable comments.

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Appendix 1

Numbers of birds that collided with sampled power lines in Namibia and South Africa, with the relative position within a span where the collisions occurred. Data from the power line surveys described in Methods.

	Mid-span	**Intermediate**	**Tower**	**Total**
Ludwig's Bustard *Neotis ludwigii*	37	34	9	80
Kori Bustard *Ardeotis kori*	14	8	2	24
Unidentified large bustard	3	5	0	8
Karoo Korhaan *Eupodotis vigorsii*	2	0	1	3
Northern Black Korhaan *Afrotis afraoides*	2	1	1	4
Southern Black Korhaan *Afrotis afra*	0	1	0	1
Lappet-faced Vulture *Torgos tracheliotos*	0	1	0	1
White-backed Vulture *Gyps africanus*	1	0	1	2
Secretarybird *Sagittarius serpentarius*	0	2	1	3
Martial Eagle *Polemaetus bellicosus*	1	1	0	2
Greater Kestrel *Falco rupicoloides*	0	0	1	1
Lesser Flamingo *Phoeniconaias minor*	1	0	0	1
Unidentified flamingo	0	1	0	1
Pied Crow *Corvus albus*	0	1	1	2
Unidentified duck	1	0	0	1
Total	62	55	17	134