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Percy FitzPatrick Institute of African Ornithology
DST/NRF Centre of Excellence

Submitted in full fulfilment of the requirements for the degree of

Master of Philosophy in Conservation Biology

QUANTIFYING NATIONAL ABUNDANCE CHANGES OF RAPTORS ACROSS BOTSWANA USING REPEAT ROAD SURVEYS

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DECLARATION

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ABSTRACT

Raptors are a group of carnivorous birds experiencing considerable population declines across the globe. Despite these declines, many raptor populations remain poorly monitored across most of their ranges and, as with most biodiversity, this is especially true in developing countries, including most countries within Africa. In Botswana, conservationists are growing increasingly concerned about the population trends of many raptor species, especially vultures. Fortuitously, Botswana has over 55,000 km of raptor road transect surveys originally conducted between 1991-1995. Over two decades later, researchers repeated some of those surveys (c. 21,000 km) in the northern part of Botswana, which revealed declines across multiple raptor species. To complete these re-surveys at a national level, we undertook a repeat of the raptor transect surveys conducted in the southern half of Botswana, covering c. 22,000 km of transects. We then estimated country-wide abundance changes for all species of regularly occurring raptors by combining these two re-surveys. We explored changes for 30 species, 19 (63%) of which exhibited significant changes. Fifteen species (50%) declined significantly, and 4 (13%) species increased significantly, while 11 species (37%) showed non-significant declines. Most species displayed similar population trends between the national analysis and the northern re-surveys. Those re-surveys revealed significant declines in 48% of the 29 species examined. The Lappet-faced Vulture (*Torgos tracheliotus*) showed significant declines of 61% in the northern re-surveys, but in the national analysis, revealed non-significant increases of 27%. White-backed Vultures (*Gyps africanus*) also revealed significant increases of 28% in the national analysis compared to declines shown in the northern re-surveys. Whilst our re-surveys suggest similarly worrying trends of many raptor species as the northern re-surveys did, we noted increasing population abundance trends for three of the most threatened vulture species. Future research should explore whether certain environmental data (e.g., human modification, climate change, etc.) are associated with the declines of these species, to better understand the drivers for these declines.

1. INTRODUCTION

Wildlife populations are declining globally (Dirzo et al., 2014), and this decline occurs across a wide variety of species, including large-mammal herbivores and carnivores, amphibians, and birds. These declines disrupt many ecosystem functions and services (Daskin & Pringle, 2018) and may act as indicators of environmental health and ecosystem integrity (Rosenberg et al., 2019). For example, between 1970 and 2010, populations of mammals, birds, reptiles, amphibians, and fish worldwide dropped by over 50% (Ceballos et al., 2017). Anthropogenic factors associated with increasing human population and development principally drive these global changes in wildlife populations (Taylor-Brownid et al., 2019; Ogutu et al., 2011).

Raptors are a group of carnivorous birds that have exhibited declining trends in abundance across the globe (McClure et al., 2018). A review of the conservation status of raptors divulged that 18% of raptors globally are threatened with extinction, with old-world vultures particularly at risk (McClure et al., 2018). Raptors occur at low densities relative to birds at other trophic levels (Solanou et al., 2022), and they also tend to have relatively slow reproductive rates; thus, their populations may be more susceptible to persecution (Deikumah, 2020) and anthropogenically related changes in the environment (Fuller & Mosher, 1981). However, across most of their ranges, populations remain poorly monitored (McClure et al., 2022) and, as with most biodiversity, this is especially true in developing countries, including most countries within Africa (Moussy et al., 2022).

Among all raptors, old world vultures have shown the largest population declines (McClure et al., 2018), including widespread decreases detected in many African vulture species across the continent (Krüger et al., 2014; Ogada, Botha, et al., 2016). The rapid decline of African vulture populations has led conservationists to suggest that the species is now facing an 'African vulture crisis' (Ogada, Botha, et al., 2016; Krüger et al., 2014). An assessment from the IUCN showed that six out of the 11 vulture species found in Africa declined by an average of 62% over 30 years (IUCN, 2017). In recent years, the conservation status of White-backed (*Gyps africanus*), White-headed (*Trigonoceps occipitalis*), Rüppell's (*Gyps rueppellie*), and Hooded (*Necrosytes monachus*) Vultures has worsened from Endangered to Critically Endangered, whereas the Lappet-faced Vulture (*Torgos tracheliotus*) has becomeEendangered (BirdLife Data Zone, 2023). The Cape Vulture (*Gyps coprotheres*) was downgraded to Vulnerable. Illegal poisoning represents the most prevalent threat to vultures and other scavenging raptors in Africa (Murn & Botha, 2018; D. Ogada, Botha, et al., 2016). Poisoning incidents have killed thousands of vultures in Botswana and the surrounding regions in recent years and have likely led to localized declines (Boikanyo & Leepile, 2018).

Botswana is an important country for both raptors in general and vultures in particular. The country supports several threatened species, including the Critically Endangered White-backed Vulture, White-headed Vulture, and Hooded Vulture, and the Endangered Secretary Bird (*Sargittarius serpantarius*), Martial Eagle (*Polemaetus bellicosus*), Bateleur Eagle (*Terathopius ecaudatus*), and Lappet-faced Vulture. Herremans and Herremans-Tonnoeyr (2000) explored raptor abundance across Botswana using road transects and showed that the abundance of many species of raptors decreased the further away one got from protected areas, with some being more sensitive than others. They suggested that the reduction in biomass and biodiversity (i.e., raptor prey species), due to structural changes in vegetation through overgrazing by livestock, represented the most likely reason for the lower abundance of raptors on unprotected land (Herremans & Herremans-Tonnoeyr, 2000).

Road transects represent important legacy data for monitoring changes in raptor populations (McClure et al., 2021). Garbett et al. (2018) repeated a portion of the historical transects of Herremans and Herremans Tonnoeyr (2000), but only in the northern part of Botswana. These re-surveys revealed widespread declines in many raptor species, with 14 of 29 species showing declines. However, surveys from Garbett et al. (2018) only covered approximately 37% of the transects covered by Herremans and Herremans-Tonnoeyr’s (2000) original surveys. Southern Botswana is hotter, drier, and more arid than the north, and it is unknown whether the results from Garbett et al. (2018) reflect the trends of raptors from the south of the country as well, and thus, nationally.

In this study, we undertake a repeat of the raptor road transects in southern Botswana that Herremans and Herremans-Tonnoeyr (2000) conducted historically. We then combine our data from the south with similar data collected in northern Botswana (Garbett et al., 2018) to derive a country-wide estimate of the abundance change for all species of regularly occurring diurnal raptors.

2. METHODS

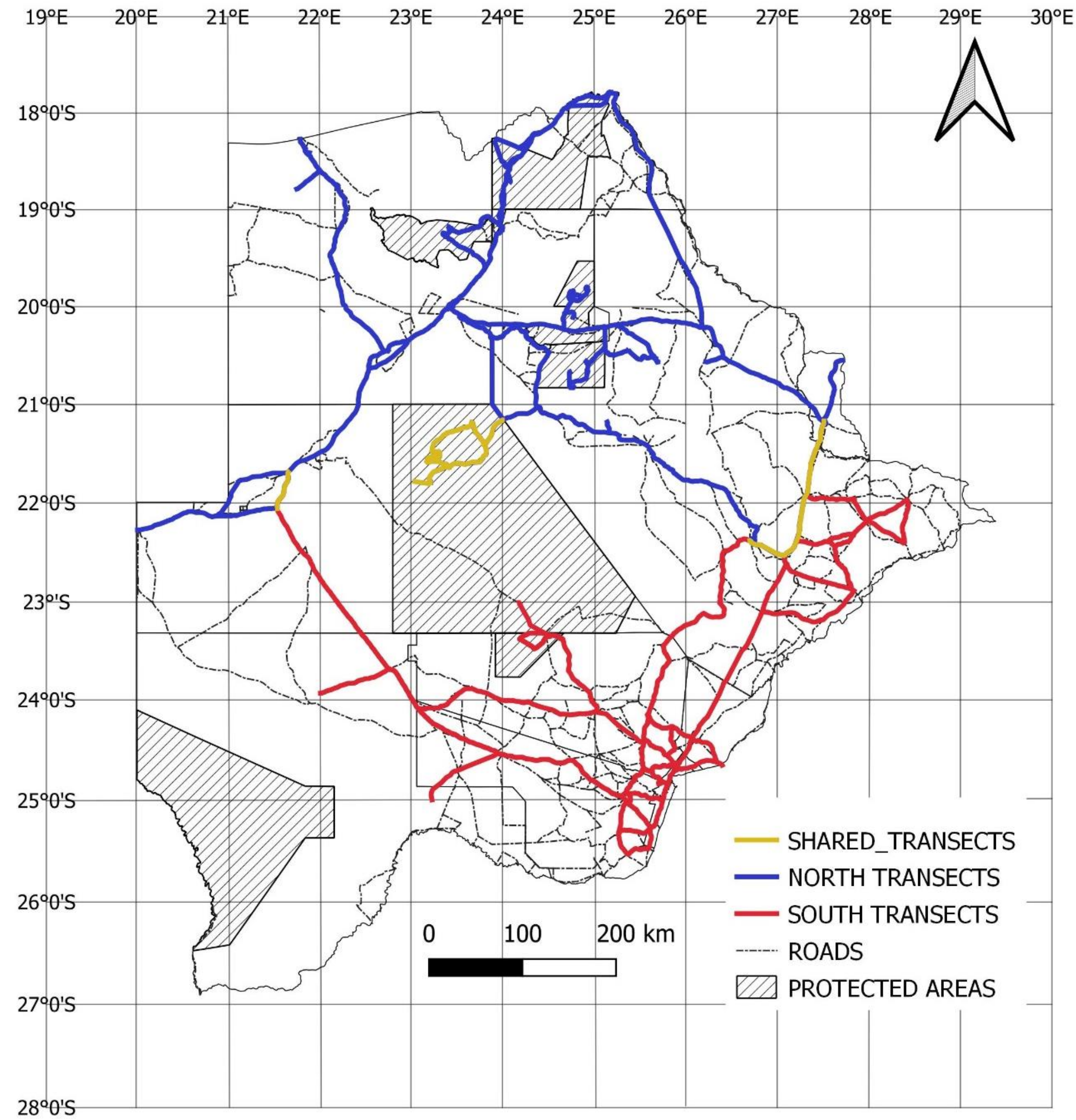
2.1 Study Area

Botswana has a surface area of 580,000 km^2 (FAO: Botswana, 2019) and has one of the lowest densities of people in the world (with only 2.3 million or 3.97 people/km^2). The country devotes some of the highest proportion of land of any African country to wildlife conservation (c. 40%), with around half designated for protected areas and half as wildlife management areas (WMAs) (Mbaiwa, 2005). Around half of the country is communal land, with agriculture (mostly free-ranging livestock rearing) being the most predominant land use outside protected areas (Central Statistics Office, 2013).

Rainfall has been decreasing in Botswana in recent years (Areola & Sebego, 2011), it occurs in the Austral summer between November and April (the wet season), and ranges from an average of 250 mm in the southwest to 650 mm in the north and northeast (WorldBank, 2021). The wet season has high temperatures (18 – 45 °C), rain typically ceases between May and October (the dry season), and temperatures are much lower between May and August (-5 – 25 °C). Our survey area covers the southern region of Botswana, or approximately 340,000 km^2. The original surveys conducted by Herremans and Herremans-Tonnoeyr (2000) in the mid-1990s encompassed the entire country and covered a total of 55,577 km of transects, with 26,000 km of those conducted in the south. By combining these surveys with northern re-surveys (Garbett et al., 2018), we assessed change in abundance of raptors across Botswana.

Figure 1. Map of the study area showing the raptor road transects routes first completed by Herremans & Herremans-Tonnoeyr (200) across Botswana. Transects are color-coded according to whether they were covered in the northern Botswana surveys of Garbett et al. (2018) (blue), were part of the southern Botswana surveys (this study) (red) or were surveyed by both studies (yellow). The map also shows protected areas across the country, along with primary and secondary roads. The map is divided into 100 km x 100 km degree grid squares

(DGS) as shown by the latitude and longitude lines in the figure below. The counts from each transect were separated into their appropriate DGS, which constituted the unit of analysis.



2.2 Road Surveys

We followed the methods used by Herremans and Herremans-Tonnoeyr (2000) and Garbett et al. (2018) raptor road transects surveys. The driver and passenger both functioned as observers, conducting the transects and recording all diurnal raptors sighted, including perched or flying birds. The principal observer was at times the driver as well, whilst the second observer varied throughout all southern transects. Each transect route followed the original routes of Herremans and Herremans-Tonnoery (2000), but distances slightly varied due to changes in road networks over time and interpretation of original transect route descriptions (no GPS coordinates were available 20 years ago during the original surveys). We conducted the surveys in both the dry (October – May) and wet (April – August) seasons in 2019, 2020, and 2021, matching the timing of specific transects (i.e., the months in which they were conducted) as closely as possible to when Herremans and Herremans-Tonnoeyr (2000) conducted their surveys. We repeated individual transects multiple times.

At each raptor sighting, we recorded GPS coordinates and observation times for further reference and to allow more efficient archiving of the data. We drove transects during daylight hours between 06h30 and 18h30 for wet season and 07h30 and 17h00 for dry season. As with the study by Herremans & Herremans-Tonnoeyr (2000), we recorded all raptors seen with the naked eye, only stopping, and using binoculars (8x42) and a digital camera with a 500 mm optical zoom to help with species identification where needed. During the surveys, we drove at a maximum speed of 20 km/h on dirt/sand tracks, and 60 km/h on tarred roads.

We subdivided count data along each transect into the appropriate Degree Grid Square (DGS), which covered 100 km x 100 km blocks (Figure 1). These DGSs were the original unit of measurement used to collect data during the first survey and used in the analysis of Garbett et al (2018), therefore we choose to continue using it for consistency of methods. The DGSs are sometime referred to as 'blocks' in the rest of this thesis.

2.3 Statistical Analysis

We categorized the data into two time periods: "Early" Herremans & Herremans-Tonnoeyr, 2000) and "Late" (combined repeat surveys: 2016-2018 (Garbett et al. 2018) and 2019 –

2021). We used the same analysis as Garbett et al. (2018). We used R version 3.3.0 (R Core Team, 2016) to conduct a generalized linear mixed model (GLMM) using the 'glmmTMB' package (Cavieres, 2022) to derive changes for 30 different raptor species and test for significant differences between the two survey periods. We used GLMMs due to the models' suitability to the data, which included non-independent observations (from different transects conducted in the same DGS's). GLMMs incorporate random effects that account for this. GLMMs handle repeated measures efficiently by allowing for modelling dependencies and capturing how population trends change over time, as our data runs over 20 years. Our data did not follow a normal distribution, thus we used GLMMs which can accommodate various distributional families (e.g., Poisson or Negative Binomial distributions for count data,) and link functions, together with covariates of interest. The models controlled for the differing lengths of transects conducted within each DGS by including the log of the transect length (km) as an offset. We fitted DGS block (block- another term used to refer to unit in which the transects were divided – i.e., into the 100 km x 100 km squares/blocks) as a random term in the model to account for the lack of independence of samples from the same blocks. We then implemented separate models for each species, fitting their count along each DGS transect survey as the response variable, with the period (early or late) as an explanatory variable. We also assessed whether the season (wet/dry) of the survey (2 levels categorical variable) was also associated with variation in species abundance. Where this 'season' term was significant, we included it as a covariate in the subsequent model for that species.

Count data are often Poisson or negative binomial distributed and can also frequently be zero-inflated (Lindé et al., 2011). Identifying the correct distribution can strongly influence the outcome of any model that examines change. Thus, before fitting our final model to examine the changes in abundance, we explored the best-fitting distribution for each species. Like Garbett et al. (2018), we explored three distributions: Poisson, negative binomial, or negative binomial 2 with NB2 parameterization (variance = $\mu (1 + \mu / k)$) (Kleiber & Zeileis, 2016), where μ = population mean, and k = the number of times an event occurs in an interval. Additionally, we explored evidence of zero inflation for each distribution. Thus, we explored which of the six models provided the best distribution using the 'glmmTMB' package (Cavieres, 2022) and used Akaike's Information Criterion (AIC) within the 'bblme' package (Bjørnstad et al., 2017) to rank the models and thereby select the final model with the most appropriate distribution for the data (Table S1). In the final model, we examined the significance for the 'Period' term in each analysis using the 'car' (Companion to Applied Regression) package (Fox & Weisberg, 2011). Throughout, we express the mean abundance as the number of birds observed per 100 km with 95% confidence intervals (CIs) in each period. We estimated these estimates and their 95% confidence intervals (CI) using the EMMEANs package(Searle et al., 1980).

We then subdivided counts along separate transects, into those transects attributed to different DGS, which acted as our unit of survey. A few routes contained very few km's of transects, but only in one of the two study periods, and in such cases, we removed the transects from the final analysis. The Southern surveys included 90 separate transects, which we then subdivided into 247 separate transects within each of the 100 km x 100 km DGSs.

1. RESULTS

In total we covered a combined 42,568 km of transects, 20,712 km in the north and 21,856 km in the south (Table 1). These transects occurred in 41 separate DGSs. The number of blocks that contained birds varied between species, from a minimum of only 6 blocks for Dickinson's Kestrel (*Falco dickinsoni*), 7 blocks for African Marsh Harriers (*Circus ranivorus*), 8 blocks for Cape Vultures (*Gyps coprotheres*) and 9 blocks for Greater Kestrels (*Falco rupicoloides*) up to a maximum of 39 blocks for White-backed Vultures, 38 blocks for Bateleur Eagles (*Terathopius ecaudatus*) and 37 for Black-chested Snake (*Circaetus pectoralis*) and Tawny Eagles (*Aquila rapax*). Within both the early and late period, the most frequently counted species was the White-backed Vulture. In the early surveys, Herremans & Herremans-Tonnoeyr (2000) observed a total of 13,945 raptors over 55,000 km across Botswana. More than two decades later, we counted a combined total of 9,141 raptors (Table 1). Herremans & Herremans-Tonnoeyr (2000) counted a total of 0.25 raptors per km and we counted 0.21 raptors per km, representing a change of 16% fewer raptors counted in our surveys.

Table 1. Summary of distances (km), number of transects driven (separated by 1-Degree Grid square; DGS), percentages, and number of raptors observed in early (Herremans & Herremans-Tonnoeyr's 2000 surveys) and late surveys (this study and Garbett et al., 2018).

	Total km driven	No. of transects driven by DGS	Av.no of km driven per transect	No. of raptors observed
Early surveys (1991-1995)	55,005	775	71	13,945
Northern late surveys (2015-2016)	20,712	243	85.2	4,465
Southern late surveys (2019-2021)	21,856	247	88.5	4,671
Combined late surveys (2015-2016 & 2019-2021)	42,568	490	87	9,141

1.1 Changes in species abundance between 1991-95 and 2015-16 and 2019-2021

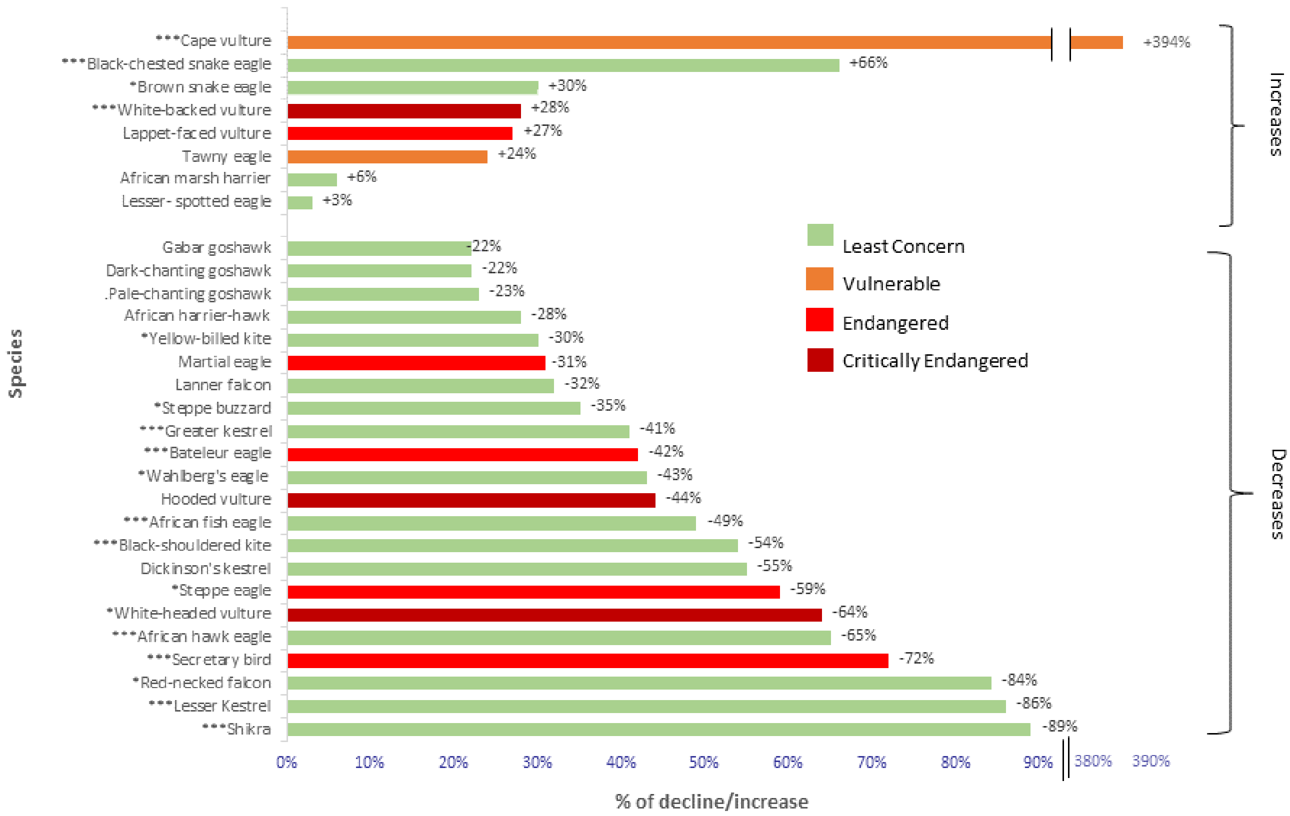
Across Botswana, of the 30 examined raptor species, 15 (50%) declined significantly between the two periods (early and late) (Fig. 2.). Eight of these 15 species reported highly significant declines ($P < 0.001$), while the other seven species showed marginally non-significant declines (P 0.1 >< 0.05).

Eight species showed increases, four of which were significant (Fig. 2; Table 2). Four species of eagles revealed some population increases, but only two showed significant increases: Brown Snake Eagle (*Circaetus cinereus*) at 32% and Black-chested Snake Eagle (*Circaetus pectoralis*) at 63%. Two vulture species also had significantly high increases: Cape Vulture at 397% and White-backed Vulture at 28%.

The White-backed Vulture was the most abundant and regularly observed species out of all 6 highly abundant species (Fig. 6). It increased from 6.5 birds observed per 100 km in the early period to 8.3 birds in the late surveys. The Yellow-billed Kite (*Milvus aegyptius*) followed in terms of frequency of observation, although it experienced a decline from 3.0 birds observed per 100 km in the early period to 2.1 birds per 100 km in the late surveys. Of the medium-density species, the African Fish Eagle was the most abundant in the early period but declined from 0.09 birds per 100 km to 0.05 birds in the late surveys.

Among low-density species, the Tawny Eagle was the most abundant species in both the early and late survey periods, with an increase from 0.49 birds observed per 100 km in the early surveys to 0.61 birds in the late period. Two other eagle species (Brown Snake Eagle and Black-chested Snake Eagle) also displayed increases from the early period to the late period. The Secretary bird had a significantly large decline from 0.11 birds in the early period to 0.03 birds observed per 100 km in the late surveys.

Figure 2. Percentage transects abundance of 30 diurnal raptor species in Botswana between the early road transect surveys (1991 - 1995) and the late surveys (2015 - 2016 & 2019 - 2021). Fifteen species showed significant declines, whereas three species showed significant increases. * = *P*≤ 0.05, ** = *P*≤ 0.001 and *** = *P*≤ 0.0001. Species bars are color-coded based on their IUCN global conservation status (see the legend).



1.2 Abundance changes of raptor groups

i) Vultures

We sighted the White-backed Vulture most frequently by far of all species of vultures (and of all species of raptor), with almost 10 times more sightings than Lappet-faced Vultures (Fig. 6). The White-headed, Hooded, and Cape Vultures were among the least frequently observed vulture species (Fig. 7, Table.2).

We examined changes in the abundance of five vulture species. Of these, the White-headed Vulture showed a significant (t = 6.2, $P \leq 0.05$) decline of 64%, while the Hooded Vulture demonstrated a non-significant decline of 44%. Two species had highly significant ($P \leq 0.001$) increases; the White-backed Vulture at 28%, (t = 7.4, $P < 0.001$) and the Cape Vulture at 394%

(Fig 2), (t = 25.8, $P < 0.001$). The Lappet-faced Vulture showed a marginally non-significant increase of 27% (t = 2.8, $P = 0.09$).

Further exploration of the Cape Vulture data confirmed population increases for the species. In the early period, researchers sighted the species in only 8 DGSs and 15 transects, while researchers in the later period saw these vultures on 37 transects. Researchers in the first period recorded a maximum count of only 14 – one of only two observations with over 10 individuals, whereas we sighted a maximum count of 75 in the late period and recorded 19 transects during which we saw over 10 individuals.

ii) Large Eagles

The Bateleur, Tawny, and Brown Snake Eagles were the most abundant large eagle species in both periods (Figs. 6 and 8). From the ten eagle species explored, two showed significant increases: the Black-chested Snake Eagle (*Circaetus pectoralis*) at 66% and Brown Snake Eagle at 30%. The Tawny Eagle showed a marginally non-significant increase of 24% (t = 3.5, $P = 0.06$). Five species showed significant declines, including the Bateleur Eagle at 42%, African Fish Eagle (*Haliaeetus vocifer*) at 49%, and African Hawk Eagle (*Aquila spilogaster*) at 65%. The Martial Eagle showed a non-significant decline of 31%.

iii) Migrants

Of the migrant species, the Yellow-billed Kite was by far the most abundant species and the second most abundant of all species (Fig. 6). Several other migrant species showed significant population trends; two intra-African migrants showed significant declines, Wahlberg's Eagle (*Hieraaetus wahlbergi*) at 43% (t = 5.9, $P = 0.015$) and Yellow-billed Kite at 30% (t = 4.3, $P = 0.037$). Three of four Palaearctic migrant species declined significantly: Steppe Eagles (*Aquila nipalensis*) at 59%, Steppe Buzzards (*Buteo vulpinus*) at 35%, and Lesser Kestrels (*Falco naumanni*) at 86%. Lesser Kestrels displayed the greatest decline for all migrant species (Fig. 2). In contrast Lesser-spotted Eagles (*Clanga pomarina*), only observed in 6 and 7 DGS's in the early and late period respectively, showed a very small a non-significant increase of 3%.

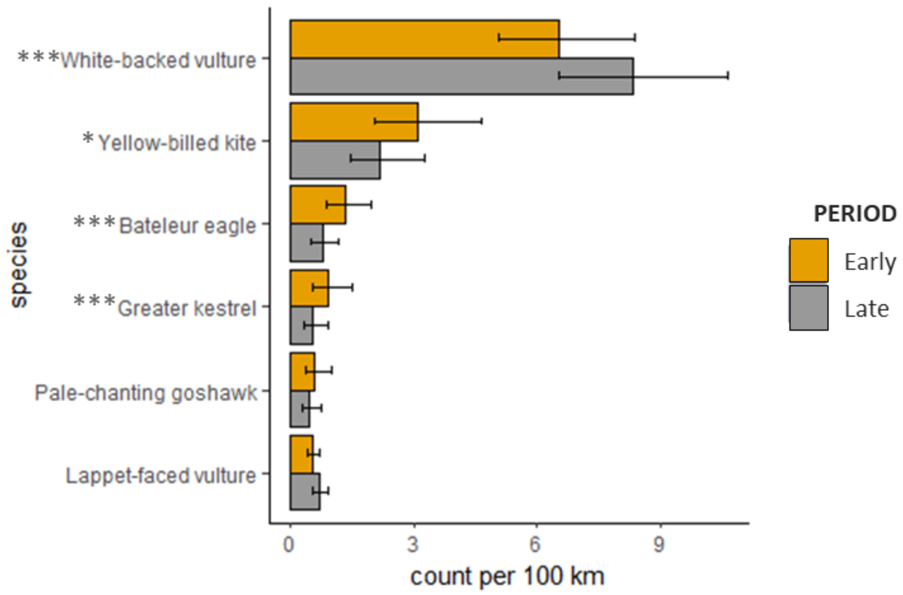


Fig. 6. High density species observed per 100 km from the Early (1991-1995) and Late period (2015-2016 and 2019 -2021). Values shown are the means, both significant and non-significant results shown: * = p ≤ 0.05, ** = p ≤ 0.001, *** = p ≤ 0.0005 and upper confidence limits.

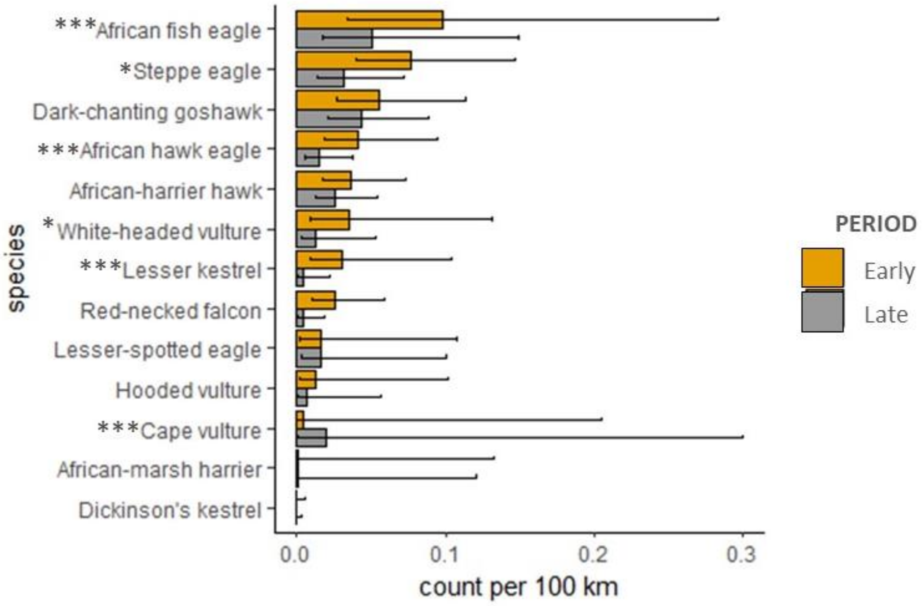


Fig. 7. Counts medium-density species observed per 100 km, including the means, significant and non-significant results shown: * = p ≤ 0.05, ** = p ≤ 0.001, *** = p ≤ 0.0005 and upper confidence limits for both Early (1991 - 1995) and Late period (2015 - 2016 and 2019 - 2021). The Upper confidence interval for Cape vulture was adjusted manually to 0.3 to enable to it fit in the plot area (true 95% CL was 0.919), this species is the only one in this category increasing between the two survey periods despite it not being the most abundant.

i) Resident small and medium-sized raptors

The Pale Chanting Goshawk (*Melierax canorus*) and the Greater Kestrel (*Falco rupicoloide*) were the most abundant resident, medium-sized raptor species seen. Three of the four resident falcon species showed significant declines, including the Red-necked Falcon (*Falco chicquera*) at 84%, Greater Kestrel at 41%, and Lanner Falcon (*Falco biarmicus*) at 32%. Dickinson's Kestrel (*Falco dickinsoni*) demonstrated a non-significant decline of 55%. Pale Chanting Goshawks displayed a nearly significant decline of 23% (t = 3.7, *P* = 0.055).

Two small raptor species showed significant declines in abundance: Black-winged Kite (*Elanus axillaris*) at 54% and Shikra (*Accipiter badius*) at 89% (Fig. 2). The Shikra was the species with the largest decline across all the raptors examined.

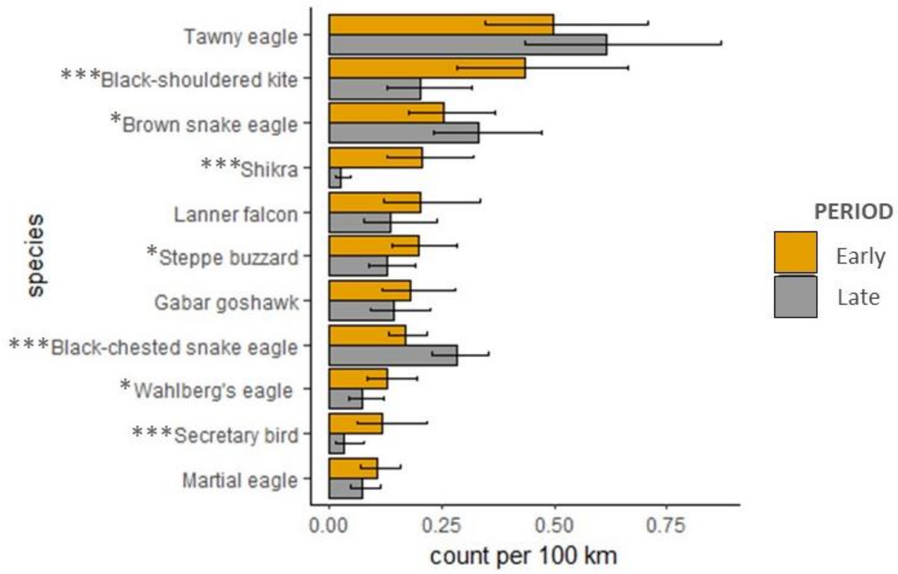


Fig. 8. Counts of low-density raptor species observed per 100 km from both the Early (1991-1995) and Late Period (2015 - 2016 and 2019 - 2021). Values shown are the means, both significant and non-significant results shown: * = p ≤ 0.05, ** = p ≤ 0.001, *** = p ≤ 0.0005 and upper confidence limits.

Table 2. Estimated mean number of individuals per/100 km with 95% confidence intervals (shown in brackets) in each period (early and late) for each of the 30 species where change was analysed. Estimates were produced using the EMMEANS package from a Generalized Mixed Model with season fitted as an additional co-variate where significant (*). Sample size (n) for each species in each of the early and late surveys, as well as the significance (*P*) of abundance change between the two surveys, is shown. Species were grouped by either family, size, or migratory status species. Species with significant changes in abundance are indicated in bold font.

Species	IUCN Status	% Change	Early, Birds/100km	n	Late, Birds/100km	n	df	x^2	p
VULTURES									
White-headed Vulture	**CR**	**-64%**	**0.035 (0.0093-0.1315)**	**66**	**0.0126 (0.003-.0528)**	**24**	**1**	**6.2**	**0.0128**
Lappet-faced Vulture	EN	+28.9%	0.54 (0.419-0.715)	291	0.696 (0.535-0.904)	292	1	2.7935	0.0949
African White-backed Vulture	**CR**	**+28%**	**6.53 (5.08-8.39)**	**3493**	**8.34(6.53-10.65)**	**3686**	**1**	**7.4188**	**0.0065**
Cape Vulture	**VN**	**+394%**	**0.00395(0.000076- 0.205)**	**49**	**0.01952(0.000415-0.919)**	**552**	**1**	**25.8288**	**0.0001**
Hooded Vulture	CR	-44%	0.01253(0.001549-0.1014)	157	0.00697(0.000852-0.0571)	35	1	1.2881	0.2566
LARGE RAPTORS									
Bateleur Eagle	**EN**	**-42%**	**1.313(0.877- 1.96)**	**991**	**0.764(0.506-1.15)**	**471**	**1**	**25.8456**	**0.0001**
Martial Eagle	EN	-31%	0.1044(0.0693-0.158)	60	0.0718(0.0451-0.114)	35	1	2.429	0.1194
Tawny Eagle	VN	+24%	0.496(0.347-0.709)	275	0.615(0.433-0.872)	324	1	3.5437	0.06
African Fish Eagle	**LC**	**-48.1%**	**0.0978(0.0338-0.283)**	**297**	**0.0508(0.0173-0.149)**	**113**	**1**	**11.5401**	**0.0007**
Brown Snake Eagle	**LC**	**+30%**	**0.255(0.177-0.367)**	**167**	**0.332(0.233-0. 473)**	**170**	**1**	**4.1583**	**0.0416**
Black-chested Snake Eagle	**LC**	**+66%**	**0.17(0.133-0.217)**	**92**	**0.283(0.228-0.352)**	**116**	**1**	**11.8052**	**0.0006**
African Hawk Eagle	**LC**	**-65%**	**0.0412(0.01808-0.094)**	**55**	**0.0145(0.00557-0.0377)**	**12**	**1**	**7.7846**	**0.0057**

Species	IUCN Status	% Change	Early, Birds/100km	n	Late, Birds/100km	n	df	x^2	p
Secretary Bird	**EN**	**-72%**	**0.115(0.0608-0.2179)**	**95**	**0.032(0.0138-0.0742)**	**17**	**1**	**13.5295**	**0.000**
SMALL-MEDIUM RESIDENT RAPTORS									
Black-winged Kite	**LC**	**-54%**	**0.434(0.284-0.663)**	**209**	**0.2(0.126-0.318)**	**116**	**1**	**13.7112**	**0.0002**
Shikra	**LC**	**-89%**	**0.2039(0.1292-0.3218)**	**144**	**0.0234(0.0117-0.0468)**	**13**	**1**	**47.1113**	**0.0001**
Pale chanting Goshawk	**LC**	**-23%**	**0.577(0.343-0.97)**	**373**	**0.446(0.264-0.753)**	**377**	**1**	**3.674**	**0.0555**
Dark chanting Goshawk	LC	-22%	0.0559(0.0274-0.1137)	54	0.0437(0.0214-0.0891)	34	1	0.9438	0.3315
Gabar Goshawk	LC	-22%	0.181(0.1176-0.279)	82	0.142(0.0902-0.223)	43	1	1.2821	0.2577
African Harrier Hawk	LC	-28%	0.0363(0.0179-0.0737)	34	0.0259(0.0123-0.0545)	17	1	1.23	0.2672
African Marsh Harrier	LC	+6%	0.00119(0.000010-0.132)	10	0.00126(0.000013-0.121)	7	1	1.1888	0.2758
FALCONS									
Lanner Falcon	LC	-32%	0.2(0.12-0.335)	144	0.136(0.0777-0.238)	152	1	2.6644	0.1029
Greater Kestrel	**LC**	**-41%**	**0.901(0.537-1.513)**	**709**	**0.535(0.315-0.908)**	**459**	**1**	**23.2254**	**0.0001**
Red-necked Falcon	**LC**	**-84%**	**0.02519(0.01069-0.0593)**	**19**	**0.00392(0.00082-0.0187)**	**2**	**1**	**6.0078**	**0.0144**
Dickinson's Kestrel	LC	-53.2%	0.0000855(0.00000126-0.0058)	22	0.000040(0.000000598-0.00275)	6	1	3.39	0.1744

Species	IUCN Status	% Change	Early, Birds/100km	n	Late, Birds/100km	n	df	x^2	p
MIGRANTS									
Steppe Eagle	**EN**	**-58.2%**	**0.076(0.0402-0.1463)**	**74**	**0.0318(0.0141-0.0715)**	**19**	**1**	**5.0408**	**0.0249**
Steppe Buzzard	**LC**	**-35%**	**0.198(0.138-0.283)**	**374**	**0.129(0.0871-0.191)**	**160**	**1**	**5.5099**	**0.0191**
Lesser Kestrel	**LC**	**-86%**	**0.0302(0.008814-0.1039)**	**183**	**0.00439(0.000881-0.0219)**	**7**	**1**	**7.4956**	**0.0063**
Yellow-billed Kite	**LC**	**-30%**	**3.08(2.04-4.65)**	**5923**	**2.17(1.45-3.26)**	**1118**	**1**	**4.3424**	**0.0374**
Wahlberg's Eagle	**LC**	**-43%**	**0.126(0.0816-0.195)**	**105**	**0.072(0.0432-0.12)**	**38**	**1**	**5.9496**	**0.0149**
Lesser spotted Eagle	LC	+4.4%	0.016(0.00244-0.1076)	163	0.0167(0.00281-0.0999)	10	1	0.0009	0.9767

The IUCN Red List conservation status of each species was included (LC = least concern, NT = near threatened, VU = vulnerable, EN = endangered, CR = critically endangered). Estimates are derived from a GLMM model fitted with either a zero-inflated or non-zero-inflated negative binomial or Poisson distribution. The percentage of decline/increase was calculated using the species sample size from the raw data in the early and late surveys.

2. DISCUSSION

Our analysis expands on the work of Garbett et al., (2018), which resurveyed raptors in the north of Botswana, to make inference about changes of raptors at the national scale. Across Botswana, 15 (50%) of the 30 examined raptor species declined significantly between the two periods (early and late) (Fig.2). Many of these 15 species showed very large, significant declines, with 12 species showing significant declines of more than 40%. Our results were similar to those found by Garbett et al., (2018), which found that 14 of their 29 species had declined significantly.

We did, however, find some differences between the changes outlined by Garbett et al., (2018) (for only the North) and our results (which included surveys from both the North and the South). For example, Garbett et al., (2018) found that only three species showed increases, and all three were significant increases. In contrast, we found eight species with increases, with 4 species showing significant increases. Two of these species showed increased both in northern Botswana and for the country-wide assessment, those being the Black-chested and Brown Snake Eagles. The combined data revealed increases considerably larger (66% and 30%, respectively) compared to increases of only 15% and 12%, respectively, from only northern Botswana (Garbett et al., 2018). Thus, our results provide further confirmation that these two species are doing well across Botswana.

The trend of Lappet-faced Vultures differed dramatically between our national analysis and Garbett et al.'s (2018) northern only study. Garbett et al. (2018) found a significant decline of 61%, whereas, with the addition of the southern surveys, our results suggested a non-significant increase in abundance across Botswana. Differences in abundance between northern and southern Botswana become apparent from a crude comparison between the northern only and southern re-surveys and explain this change in trend between the two studies. For example, many more individuals of this species were recorded the southern repeat surveys (n = 217) compared to the northern repeat surveys (n = 75) (Garbett et al., 2018). Other considerable differences were seen in the frequency of observation between the northern and southern surveys, for example, the Hooded Vulture had 32 records in the northern re-surveys as compared to only 3 records observed in the southern re-surveys. The

Bateleur Eagle was also should considerably difference in the regions, we recorded 61 individuals of, whereas the northern re-surveys had >200 records of the same species.

In the national analysis, Shikra had the highest significant declines out of all 30 species examined; 89%, followed by the Lesser Kestrel and Red-necked Falcon. In their paper on declines of Common Kestrels (*Falco tinnunculus*) due to predation by Northern Goshawks (*Accipiter gentalis*), Anderson et al., (2013) found a significantly negative relationship between Common Kestrel populations and the increase of Northern Goshawks. Their study revealed that many kestrel adults were killed prior to their breeding season, and this could limit their populations. We gathered no data to suggest a similar occurrence may be happening in Botswana, but intraguild predation or competition has been recorded for other small Accipiters in Africa and has been shown to influence the occurrence of smaller accipiter species (Little & Navarro, 2019). Thus, predation may represent a cause of decline in populations of small raptors in our study. Loss of food availability also impacts small raptors and can impact the numbers of small accipiter (Newton, 1991), thus local changes in habitat quality and prey base remain a potential cause of the decline in the abundance of Shikra.

Good quality habitats support many breeding small raptors, the destruction of these habitats due to elevated overgrazing in highly vegetated lands negatively affects populations of small raptor species (Amar et al., 2011) by impacting the structural diversity of natural habitats (Kairis et al., 2015; Wang et al., 2020). Domesticated livestock encroachment into protected areas and WMAs is also increasing in Botswana (Muñoz, 2013; Winterbach et al., 2015). Livestock encroachment has resulted in deterioration of important habitat structures for wildlife, particularly trees species important for nesting raptor species. Declines of raptors in other areas of Africa, haven been associated with human population growth and development, heavy use of pesticides, especially to control locust outbreaks, and overhunting that suppresses major food sources (Thiollay, 2006).

Notably, many of the species showing large declines were migrants, with 5 of the 6 species investigated showing significant negative declines. Climate change poses threats for migratory species that spend different parts of their annual life cycles in different parts of the world (Cotton, 2003; Sillett et al., 2000). For example, for some species shifts in the phenology of their prey in Europe increased much more rapidly than changes in the migration timing, leading to mistimed reproduction (Both & Visser, 2001; Cotton, 2003). The success and survivorship of migrant species depends on the timing of arrival at breeding or wintering grounds, achieving these is a key determinant of reproduction and species longevity (Cotton, 2003). However, changes in range size and avoidance of areas with decreasing productivity could lead to shifts (Balbontín et al., 2008). These changes may have affected the population abundance of some migratory species in our study. Climate change impacts African raptor populations profoundly but has received relatively little attention thus far (Phipps et al., 2017) despite needing further investigation. This is particularly relevant for countries like Botswana, as very little information exists on the impacts of climate change on many wildlife species, raptors included.

We also noted differences in Hooded Vulture counts in each survey, with only 3 individuals recorded during our surveys in southern Botswana, while Herremans & Herremans-Tonnoeyr (2000) observed no Hooded Vultures in the south in the early surveys. They instead recorded 157 birds in the northern part of Botswana. Garbett et al., (2018), on the other hand, recorded 32 individuals in the north. Our results revealed that the Hooded Vulture showed a non-significant decline of 44%. Hooded Vultures are a Critically Endangered species, endemic to Sub-Saharan Africa. Considerable research has found population declines of the Hooded Vulture in recent years due to a combination of habitat destruction, persecution by humans, and exposure to toxic chemicals (Daboné et al., 2022, 2023; Ogada & Buij, 2011; Teklemariam & Afework, 2021). A 2016 study quantified the decline of Hooded vultures over 31 years (from 1980) in the Greater Limpopo Trans-Frontier Conservation Area (GLTFCA) (Ogada & Buij, 2011). That study revealed an 85% decline of Hooded Vultures over the 31 years period. Additionally, the species lost an estimated 70% of its range across Africa during the same period (Ogada & Buij, 2011). Nyirenda et al., (2017) and Roxburgh & McDougall (2012) Nyirenda et al., (2017) and Roxburgh & McDougall (2012) & McDougall (2012) revealed 80% population declines of the Hooded Vulture in Zambia between 2000 and 2018, with the species disappeared in some parts of the country, with populations in the western and eastern provinces declining by more than 90%. Overall, several studies suggest that Hooded Vulture populations are declining significantly, and these trends are a large concern for the species' survival. Buechley, Girardello, et al., (2022) and Ogada & Buij, (2011) also outline population declines across protected areas in Namibia, Botswana, and South Africa, including the Greater Limpopo Trans-Frontier Conservation Area, the Kgalagadi Trans-frontier Park, and the Kruger National Park, respectively. Habitat loss is likely a major factor in the decline of the Hooded Vulture population, as the species relies on open grasslands and savannas for foraging and nesting (Nyirenda et al., 2017). Human disturbance, such as agricultural activities, can also disrupt the vultures' nesting and foraging activities. Illegal hunting is another major threat in different parts of Africa, as poachers often target the Hooded Vulture for its feathers and meat (Buechley, Murgatroyd, et al., 2022; Nyirenda et al., 2017; Saidu & Buij, 2018).

Our national analysis suggested a significant decline of 64% for White-headed Vultures. Several studies consider the White-headed Vulture to be widespread at low densities but uncommon, especially in Botswana and Mozambique (Murn et al., 2016), a narrative that we also noted during our southern re-surveys. Major declines in abundance have also been recorded in Kenya (Virani et al., 2011). The Kruger National Park in South Africa held the largest population across South Africa (Murn et al., 2013). No published data exists on White-headed Vultures breeding outside protected areas across the African continent (Murn et al., 2016), but the species is sensitive to human disturbance especially outside protected areas. A continental assessment by Ogada et al., (2015) found that the species declined by >90% in recent decades. Murn et al., (2016) stated that the global population estimates of White-headed Vultures declined by 27-60% over the last 25 years, with c.7,000-12,000 individuals remaining. Thus, the White-headed Vulture is recognized as a species of high conservation priority (Buechley, Girardello, et al., 2022; Murn et al., 2016; Salewski, 2021; Smallie & Virani, 2016) and our study results strongly support that conclusion.

One eagle species that is declining through its global African range is the Endangered Martial Eagle (IUCN, 2017), however in our study we found that it showed non-significant declines of 31%. This trend might be because Botswana has larger protected areas compared to other countries in the continent, and Thiollay (2006) and Herremans & Herremans-Tonnoery (2000) suggested that this species relies heavily on protected areas for its survival. This species was also experiencing non-significant declines in the northern surveys (Garbett et al., 2018), at 52%. Amar and Cloete (2018) quantified Martial Eagle declines in South Africa and discovered declines across the country, with larger declines outside protected areas (64%), and smaller declines at 42% inside protected areas. South Africa has many powerlines compared to

Botswana, which might be a factor impacting Martial Eagle abundance outside protected areas in South Africa as investigated by Amar & Cloete (2018) and van Eeden et al., (2017).. In West Africa, Thiollay (2006) also conducted raptor road surveys and found large raptor population declines, especially for vultures and large eagles, Martial eagles had a 50% decline in protected areas. Researchers have attributed the declines of Martial eagle population to a loss of prey species, including large mammals, across its range and persecution by livestock farmers (Amar & Cloete, 2018; Thiollay, 2006). Botswana, unfortunately, lacks data on the persecution of the Eagle by livestock farmers and the use of its parts for traditional purposes. Thiollay (2006) discovered declines in four eagle species in their study area in West Africa, contrary to our results for the Brown Snake Eagle, Tawny Eagle, and African Hawk Eagle, by 86% - 93%.

Garbett et al., (2018) found similar levels of decline for most species inside and outside of protected areas, with only two species showing changes in abundance that differed significantly inside and outside of protected areas: Bateleur Eagles and Brown Snake Eagles, respectively. But like our study, Garbett et al., (2018) also found that three species of eagles displayed relatively small significant increases: Tawny Eagle at 6%, Brown Snake-Eagle at 15%, and Black-chested Snake-Eagle at 12%. Alternatively, the Secretary Bird experienced significant declines at 78%, compared to our national results of 72%, as did the Bateleur at 53% compared to our 42% National decline, and African Hawk Eagles at 87%, as opposed to our National 65% decline. Thus, many of these species that were first identified as declining based on the northern surveys have now been confirmed to be declining at a national level.

Compared to the analyses in the north only, we examined an additional species, the Cape Vulture, which mainly occurs in and around colonies in the eastern part of the country that Garbett et al. (2018) did not cover. This species showed a highly significant increase of over 300% (Figure 2). The Cape Vulture showed the largest increase in abundance of all vulture species we examined. Another vulture species also had unexpected significant increases of 28%, the White-backed Vulture. These population increases may have resulted from increased habitat quality across the country, which creates opportunities for sustainable nesting colonies of White-backed Vulture and likely attracts many individuals to these areas. Botswana recently introduced a bill that regulates the use of veldt products, restricting cutting down of trees to only individuals who have acquired permits to do so (Mphinyane et al., 2018, Botswana Government, 2006). However, this does not mean that all White-backed Vultures in Botswana are breeding birds. Despite the threat of poaching through poison use, large carcasses like those of Elephants provide food for vultures, as one carcass can provide food for hundreds of vultures. Increased road networks may also play a role in the improving population of some vulture species, car travel at high speeds, causing more collisions with crossing wildlife and especially livestock. These road kills provide an easy food source for large groups of vultures. Finally, vulture restaurants also provide food for many raptor species (Gilbert et al., 2007; Kane et al., 2015), and Botswana has several of these. Our results of an increase in White-backed Vultures were still surprising however, not least because of the findings from Leepile et al. (2018) which showed the high level of local poisoning in an around Botswana and large declines in breeding numbers and productivity at one large colony.

Vulture declines are recorded globally; Asia reported >95% declines (Bowden, 2009; Loveridge et al., 2019), while in Africa the last three decade revealed declines in some vulture species that are listed as Endangered, Critically Endangered, etc. (Buechley & Şekercioğlu, 2016; Ogada, Botha, et al., 2016; Ogada et al., 2012). Thiollay (2006) reported a 45% decline in vultures in Burkina Faso, West Africa. Many vulture species have died as unintended victims of poisoning that targets predators and carnivorous scavengers, such as hyenas and jackals, as the vultures feed on the poisoned carcasses of these animals (Duriez et al., 2019). Continent-wide, traditional medicine highly values vulture body parts (Africa, 2007; The World Bank, 2015; Saidu & Buij, 2018) (Africa, 2007; Saidu & Buij, 2018). People consult with traditional healers to find solutions to their health issues and vulture body parts are used as key healing components (Williams et al., 2021). Regulation of veterinary drug use and rising awareness of the negative impacts of carbofuran and diclofenac on vultures likely helps vultures, as does better carcass removal and disposal methods that help alleviate the spread of poisons via contaminated carcasses (Deikumah, 2020).

The most prevalent threat to scavenging raptors in Africa and vultures remains illegal poisoning (whereby people lace carcasses with poison) (Ogada et al., 2015, 2016; Murn and Botha, 2017). In recent years, poisoning incidents have killed thousands of vultures in Botswana and the surrounding regions (Murn & Botha, 2018; Birdlife, 2017; Santangeli et al., 2016; Roxburgh & McDougall, 2012, Leepile et al. 2022). Poisoning can wipe out huge numbers of large scavenging raptors, such as vultures and eagles, that rely heavily or wholly on carrion for food. These population declines appeared evident in the decreases that we observed for these groups of raptors. Poisoning by poachers represents an increasing danger to scavenging raptors, threatening individuals both inside and outside of protected areas (Murn & Botha, 2016; Ogada et al., 2016; Ogada, 2014, Viraniet al., 2011). In Botswana, poaching appears to be increasing, like other targeted and non-targeted poisoning of vultures (Botswana Goverment, 2015). Multiple cases of mass poisoning have occurred at game reserves and national parks in the country, where poachers kill large mammals like elephants, rhinos, etc. and then laced the carcasses with poison to kill raptors that act as sentinels to law enforcement officers (Murn & Botha, 2018; Ogada, 2014b). Given the scale of the loss of White-backed Vultures from previous frequent mass poisoning events (Murn & Botha, 2018), we expected this species to have declined. However, we observed the complete opposite, a 28% significant increase, suggesting that populations may be faring better in Botswana than in other areas of Africa (Ogada, Shaw, et al., 2016).

Human populations are increasing more rapidly in Africa than any other region of the world (Amar & Cloete, 2018; World Bank, 2015). This growth will continue to exert unprecedent pressures on the continent's wildlife, causing declines in species' populations and extinction in others (Blom et al., 2004; Hunt et al., 2017; O'Bryan et al., 2022; Taylor-Brownid et al., 2019). Raptors are vulnerable to environmental changes and thus known to act as good indicators of change in environmental quality (Donázar et al., 2016).

Study limitations

Between the two survey periods (early and late), different observers identified birds throughout the survey. This means that period and observer are to a degree confounded, and it could be argued that any effect of period could be attributed to observer differences. For example, Herremans & Herremans-Tonnoery (2000) may have been better observers than the surveyors in Garbett et al., (2018) and this study. However, we believe this unlikely, as several species are hard to miss, easy to identify, and difficult to confuse with other species, but these species still showed declines. For example, the African Fish Eagle and Secretary Bird are conspicuous species and are hard to mis-identify, yet still showed large significant declines. However, one weakness of our study is that the surveys in northern Botswana were conducted in 2016 (Garbett et al., 2018), while the continuation of these surveys in the southern part of the country occurred several years later, starting in 2019, making the surveys further apart in time. This difference in survey times may have influenced declines of certain species. For example, the years 2019- 2021 saw a rise in poisoning events that led to mass deaths of many raptor species. Additionally, the years between the early surveys and late surveys have seen many changes that influenced numbers counted along road transects, independently from overall population changes. For example, in recent years more roads are now tarred, and this could have attracted vultures toward roads to feed on the higher numbers of road kills, as there is increased high speed vehicle movement. Thus, even if numbers had not increased across the country numbers counted along the roads may have increased. There are also more electric lines and pylons along roads and across undeveloped lands, these attract raptors to perch on them when hunting, when they roost, and for other activities. This could have also increased counts irrespective of national trends. It is also important to recognise that this resurvey only managed to estimate the trends for 30 raptor species in Botswana; thus, there are many other species of raptor for which we were unable to explore their trends including several owl species. Different survey techniques will be needed to understand the trends of these species, and whether past data exists to enable such resurveys is not clear.

Future research

Future research should address potential drivers of the changes in raptors abundance we observed, as well as explore correlates of change using environmental data. Human footprint and population growth are some environmental factors that could be impacting abundance of raptor populations. Encroachment of livestock into wildlife areas is a result of rapid human population growth. Other environmental variables that impact raptor populations include climate change, different anthropogenic influences like developments of infrastructure, roads with high-speed limits, electric pylons that raptors perch on during active and non-active periods. These variables may be used to explore different hypotheses like whether they have led to the decline of species or not.

Conclusions

A main goal behind understanding the status of individual raptor species is ensuring that conservation measures directed at each species are relevant and appropriate, relative to the availability of resources. Rigorous and systematic monitoring programs ensures robust knowledge for understanding species' trends (Nielsen et al., 2009). However, such monitoring rarely occurs in most African countries owing to insufficient resources and capacity, meaning that many African raptor species lack adequate population assessments locally, regionally, and globally (McClure et al., 2022). For example, our surveys in Botswana revealed significant declines in many species currently classified as least concern. These surveys should form the basis for a re-evaluation of the conservation status of species on the IUCN Red list. Additionally, our surveys permitted determining national trends for species of global conservation concern, including four species of vultures: White-backed Vulture, White-headed Vulture, Lappet-faced Vulture, and Hooded Vulture, and four large eagle species listed as Endangered, including the Steppe Eagle, Secretary Bird, Martial Eagle, and Bateleur. Using data from this study, the Botswana government and conservation societies can direct measures at species that need immediate protection. Continuous awareness building, creating positive outlooks towards vultures and other raptors and their roles in the ecosystem and biodiversity protection are some measures that can help conserve vulture species.

Annex 1. Species acronyms and IUCN status

Abbreviation		Species name	IUCN status
YBK	=	Yellow-billed Kite	LC
BLSHKI	=	Black-winged Kite	LC
PCGH	=	Pale chanting Goshawk	LC
DCGH	=	Dark chanting Goshawk	LC
GAGH	=	Gabar Goshawk	LC
SHIKRA	=	Shikra	LC
AFHAHA	=	African Harrier-Hawk	LC
SEC	=	Secretary Bird	EN
GRKES	=	Greater Kestrel	LC
LESKES	=	Lesser Kestrel	LC
DIKES	=	Dickinson's Kestrel	LC
RNFAL	=	Red-necked Falcon	LC
LAFAL	=	Lanner Falcon	LC
STBUZ	=	Steppe Buzzard	LC
AMHA	=	African Marsh Harrier	LC
BE	=	Bateleur Eagle	EN
BCSNEA	=	Black-chested Snake Eagle	LC
BRSNEA	=	Brown Snake Eagle	LC
TAEA	=	Tawny Eagle	VN
MAEA	=	Martial Eagle	EN
WAEA	=	Wahlberg's Eagle	LC
LSEA	=	Lesser spotted Eagle	LC
STEA	=	Steppe Eagle	EN
AFHAEA	=	African Hawk-Eagle	LC
FIEA	=	African Fish Eagle	LC
WBV	=	African white-backed Vulture	CR
LFV	=	Lappet-faced Vulture	EN
WHV	=	White-headed Vulture	CR
HV	=	Hooded Vulture	CR
CV	=	Cape Vulture	VN

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Supplementary material

Table S1: Summary of results for the best-fitting model distributions (ΔAICc < 2) for comparison of raptor survey data from early (1991–1995) and late (2015–2016) and (2019-2021) road surveys in Botswana. (−) = nonconvergent model. Heading abbreviations: ZFPOISS, non-zero inflated Poisson glmmTMB, ZTPOISS, zero-inflated Poisson glmmTMB, ZTNB, zero-inflated negative binomial glmmTMB with default “NB2” parameterization (variance=μ (1+μ / k), ZTNB1, zero-inflated negative binomial glmmTMB with default “NB1” (variance=φμ), ZFNB, non-zero-inflated negative binomial glmmTMB with default “NB2” parameterization (variance=μ (1+μ / k), ZFNB1, non-zero-inflated negative binomial glmmTMB with default “NB1” (variance=φμ). PE = models with period as the explanatory variable; asterisk * indicates top-fitting models for the same species as Garbett et al. (2018). Numbers in bold indicate the top-fitting distributions (i.e., those with ΔAICc < 2). LESKES=Lesser Kestrel, SHIKRA=Shikra, RNFAL=Red-necked Falcon, SEC=Secretary Bird, DIKES=Dickinson's Kestrel, AFHAEA=African Hawk Eagle, CV=Cape Vulture, WHV=White-headed Vulture, STEA=Steppe Eagle, STBUZ=Steppe Buzzard, FIEA=African Fish Eagle, WAEA=Wahlberg's Eagle, BE=Bateleur Eagle, HV=Hooded Vulture, BLSHKI=Black-winged Kite, YBK=Yellow-billed Kite, GRKES=Greater Kestrel, MAEA=Martial Eagle, PCGH=Pale-chanting Goshawk, AFHAHA=African Harrier-Hawk, DCGH=Dark-chanting Goshawk, LAFAL=Lanner Falcon, GAGH=Gabar Goshawk, LSEA=Lesser spotted Eagle, BCSNEA=Black-chested Snake Eagle, BRSNEA=Brown Snake Eagle, WBV=White-backed Vulture, AMHA=African Marsh Harrier, LFV=Lappet-faced Vulture, TAEA=Tawny Eagle.

Species	Model distributions					
	ZFPOISS	ZTPOISS	ZTNB	ZTNB1	ZFNB	ZFNB1
YBK	20745.4	12718.7	**1.2***	190.2	**0.00**	234.3
BLSHKI	237.10	60.00	2.00	15.10	**0.00***	18.2
PCGH	219.20	132.70	2.00	23.4	**0.00***	26.1
DCGH	5.30	**0.40**	2.4	**1.40**	2.00	**0.00***
GAGH	146.60	47.40	2.00	26.50	**0.00***	26.10
SHIKRA	59.10	38.90	27.70	30.70	**0.00***	30.90
AFHAHA	18.40	**0.00**	NA*	**0.10**	2.10	**0.20***
SEC	87.50	7.00	9.00	**0.00**	11.60	3.8*
GRKES	535.2	338.5	19.1	2.00	17.1	**0.00***
LESKES	784.50	200.20	2.00	7.00	**0.00***	6.70
DIKES	7.30	**0.60**	2.00	2.6	**0.00***	4.30

RNFAL	16.90	6.50	5.10	NA	3.10*	**0.00**
LAFAL	502.90	150.90	2.00	56.5	**0.00***	49.1
STBUZ	808.10	191.60	2.00	36.2	**0.00***	46.90
AMHA	2.40	**0.00**	NA*	NA*	**0.50**	**0.60**
BE	760.6	483.5	6.5	**0.00***	4.5	2.00
BCSNEA	4.40*	4.80	6.00	2.00	4.00	**0.00**
BRSNEA	41.4	19.6	14.8	**1.2**	12.8	**0.00***
TAEA	237.70	134.1	39.2	**0.00***	37.2	**0.00***
MAEA	17.9	8.6	2.00	3.2	**0.00**	**1.2***
WAEA	92.8	3.20	**0.40**	**0.00**	**0.30***	6.10
LSEA	1112.3	104.1	2.00	7.30	**0.00***	5.30
STEA	102	9.5	2.00	**1.00**	**0.00***	5.3
AFHAEA	68	29.00	20.90	**0.20**	18.90	**0.00***
FIEA	374.60	102.90	16.20	**0.00***	14.50	28.10
WBV	13997.00	8580.30	145.00	13.60	143.00	**0.00***
LFV	941.4	312.9	31.6	**1.9**	29.6	**0.00***
WHV	198.2	65.10	25.80	2	23.8	**0.00***
HV	301	79.50	**1.60**	5	**0.00**	8.50*
CV	1359.1	494.4	8.6	**0.00**	6.6	4.2