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## Biological Conservation

journal homepage: [www.elsevier.com/locate/biocon](http://www.elsevier.com/locate/biocon)

## Road counts expose widespread declines in South African raptors underestimated by atlas data

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## ARTICLE INFO

## Keywords:

Bird of prey  
Citizen science  
Global South  
Monitoring  
Population trends  
Vultures

## ABSTRACT

Checklist-based citizen science surveys are becoming increasingly popular, as they may provide a means to monitor species' distributions and population trends. However, such checklist-based data may be limited in their ability to accurately quantify trends in abundance at large spatial scales and across multiple species. In this study, we (i) explore the population trends of 18 raptors and another eight large terrestrial bird species in central South Africa, using 752 road count transects (totalling 391,789 km), conducted from 2009 to 2025. We then, (ii) compare our road count trends with trend reporting rate estimates derived from a checklist-based survey, the Southern African Bird Atlas Project (SABAP2), for the same species, within the same core area, and over the same time period. Road counts showed that 50% of the species (13 of 26) declined significantly, while only three species (12%) showed significant increases. The remaining ten species (38%) showed no significant trends. In contrast, SABAP2 data showed the opposite pattern with only 13% of the species (3 of 24) significantly declining and 11 species (46%) significantly increasing. The remaining ten species showed no significant trends. Comparing the direction of trends (regardless of significance) between the road counts and the SABAP2 trends, we found that only around half the trends agreed. Among the contrasting trends, almost all showed declining trends from road counts, but increasing trends from SABAP2. Our findings support the hypothesis that using changes in reporting rates from atlas data may not accurately capture abundance trends at large spatial scales and across multiple species. Beyond this comparison, the declining trends observed from road counts, raise concerns over the conservation status of multiple species in a region which is known to host important raptor species' populations.

### 1. Introduction

Monitoring is an essential tool for understanding the ongoing biodiversity crisis, setting conservation priorities, and mitigating severe wildlife loss. Some countries have robust government-supported monitoring programs and citizen science initiatives focused on tracking wildlife populations trends (Chandler et al., 2017; Dupont and Dobson, 2025). However, in many parts of the world, particularly in the Global South, effective monitoring programs are still lacking (Collen et al., 2008). The Global South coincide with regions of the world where countries have historically been economically and politically marginalized and are still in the process of economic development in contrast

with the Global North (World Bank, 2024). Although Global South countries often lack such monitoring programs, they tend to host the world's most biodiverse ecosystems, making it challenging for these regions to make informed conservation decisions (Chandler et al., 2017; Collen et al., 2008). Thus, it is critical to improve the monitoring of biodiversity trends in these regions to prioritize the conservation of key species and ecosystems and to monitor the outcomes of conservation actions (Collen et al., 2008; Helmstedt et al., 2025).

In the Global South, Africa is among the most diverse continents for bird species richness (Mittermeier et al., 1999), but also has among the highest rates of species declines (WWF, 2024). Additionally, threats to biodiversity in Africa are likely to rise as the human population

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<https://doi.org/10.1016/j.biocon.2026.111764>

Received 1 November 2025; Received in revised form 6 February 2026; Accepted 13 February 2026

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increases, with increases of 79% predicted to occur (i.e., from 1.4 to 2.5 billion of people) over the next three decades (United Nations, 2024). Thus, better knowledge and quantitative trend data of biodiversity in Africa is critical to improve evidence for decision-making, particularly as demands on environmental resource increase due to human population and economic growth (Chandler et al., 2017; Collen et al., 2008).

The Southern African Bird Atlas Project 2 (SABAP2) is a citizen science atlas project that uses a checklist-based methodology capturing species' presence/absence data during each survey (Brooks et al., 2022). Thus, this project is ideal for tracking changes in species' distributional range (Nussbaumer et al., 2025). Also, from changes in reporting rates (i.e., from repeated surveys over time), it is possible to monitor changes in species' abundance (Cervantes et al., 2024; Lee et al., 2025; Shaw et al., 2024). For example, Shaw et al. (2024), complemented their raptor trend analyses from long-term road counts across different parts of Africa, with data from SABAP2, which also suggested some major declines in the reporting rates for several raptor species in South Africa. Nevertheless, it has not yet been established whether this checklist-based method accurately quantifies species trends at large spatial scales and across multiple species. However, from simulated data, it has been demonstrated that checklist-based data (i.e., presence/absence) and count data (i.e., abundance) are mathematically related, since the occurrence distribution can be considered simply as abundance censored at 1 (Kéry and Kellner, 2024; Pollock, 2006).

The SABAP2 protocol is similar in nature to other widespread checklist-based citizen science projects such as eBird (Nussbaumer et al., 2025; Sullivan et al., 2014). However, eBird's spatiotemporal data resolution in Africa is largely confined to East (i.e., Kenya) and southern Africa, and even within southern Africa, eBird checklists are clustered in central Botswana, northern Namibia, and south-western and north-eastern South Africa (eBird unpublished data; <https://ebird.org/news/ebird-data-now-included-in-the-african-bird-atlas-project>). In contrast, SABAP2, which has been running continuously since 2007, provides better spatial and temporal coverage in southern Africa (Cervantes et al., 2024), representing one of the most important citizen science monitoring schemes in the region. Therefore, establishing the robustness of checklist-based trends from SABAP2 for detecting population trends is essential, as it remains a vital tool for regional monitoring (Lee et al., 2025). This question has been increasingly pressing, as the scheme is currently being scaled up to the continental African Bird Atlas Project (ABAP; <http://birdmap.adu.org.za/>). Additionally, it has been found that SABAP2 reporting rates were not linearly related to species abundance within the same areas (Lee et al., 2018) which likely reflects that the occurrence distribution will be very different to abundance at the scale of the pentad (81 km<sup>2</sup>) for many bird species (Pacifi et al., 2019).

Raptors are an important component of biodiversity in ecosystems, representing the most mobile predator species in fragmented landscapes and, thus, are essential components of ecosystem resilience (Sekercioglu, 2006; Zuluaga et al., 2022). However, among terrestrial vertebrates, raptor species have some of the fastest declining populations due their large habitat requirements, low population densities, and low reproductive rates which make them highly vulnerable to human impacts (McClure et al., 2023; O'Bryan et al., 2022). Many raptor populations are declining worldwide (McClure et al., 2018). However, in many cases, the magnitude of these declines is not well understood until it is too late (Buechley et al., 2019). Therefore, monitoring is imperative in order to take actions to avoid loss of key raptor species, especially in species-rich developing countries which host the largest number of raptor species but which tend to lack effective monitoring (McClure et al., 2023). In Africa, South Africa has a high raptor diversity with 80 breeding or migratory species, but regionally more than a quarter are threatened or near threatened with extinction (Taylor and Peacock, 2018). However, as much of our knowledge on population trends of South African raptors comes from SABAP2 data (Cervantes et al., 2024; Lee et al., 2025; Shaw et al., 2024), the real trend status of some species may be being underestimated. Thus, a comparison between reporting

rate trends derived from SABAP2 and independently collected abundance trends from the same region are vital to establish how well SABAP2 trends reflect species' population trends.

In this study, we use data from road counts that have been undertaken continually across a large area of central South Africa between 2009 and 2025 to estimate population trends for 18 raptor species and eight other large terrestrial bird species, thereby providing important trend estimates for a large number of species, using a well-established method for monitoring raptor trends (Garbett et al., 2018; McClure et al., 2021; Shaw et al., 2024; Tella et al., 2021). We then compare these trends with trends derived from SABAP2 surveys over the same time period, from well surveyed pentads located within the same core area of our road counts. This comparison aimed to explore the hypothesis that an atlas checklist-based methodology (i.e., presence/absence), may be less precise at detecting population trends than other methodologies based on abundance counts because of the non-linear relationship between abundance and reporting rates at large spatial scales. If this was the case then we predict that declines detected through road transects would be underestimated or undetected from an equivalent analysis of SABAP2 reporting rates.

## 2. Material and methods

### 2.1. Data

#### 2.1.1. Road counts

Counts of raptors and other large terrestrial birds were conducted along road transects in central South Africa, across mainly Nama-Karoo, Savanna, and Grasslands biomes (Fig. 1). Road counts were made by one of the authors driving a 4 × 4 vehicle and varied speeds depending on the driving conditions, but were generally 80 km/h on un-paved roads and 120 km/h on paved roads. All the individual raptors or large terrestrial bird species seen flying or perched were counted along each transect. Species were identified visually or where needed by stopping and using 10 × 42 binoculars. Using a GPS device, the coordinates of the location of each species and number of individuals were recorded.

Most transects started or ended from the same location, near the settlement of Dwaalhoek, Northern Cape (29°58'37.2"S 24°11'42.0"E). Transects were undertaken during routine fieldwork from 27th April 2009 to 25th April 2025. Road count transects were each assigned to a route (*transect group*) based on their spatial overlap, since survey routes were not predefined. Thus, we grouped these *a posteriori* using a Geographic Information System (GIS) developed in QGIS. This process involved the following steps: i) **Buffer Creation**: For each GPS fix (sighting) recorded along a transect, we generated a circular buffer with a 0.09-degree radius (~10 km). ii) **Transect Buffering**: We then dissolved these buffers along an individual transect to create a single consolidated buffer per transect. iii) **Buffer Intersection**: We then calculated the level of spatial overlap between all transect buffers. iv) **Transect Grouping**: We then classified transects with more than 60% intersection overlap as the same route (*transect group*) using graphs theory with the package *igraph* from R (Csárdi and Nepusz, 2006) and assigned a *transect group* identifier to those overlapping transects.

We explored population trends of all species which were observed during 50 or more individual transects. Several species were migratory, occurring only in the austral summer. Trends were modelled for 16 years (i.e., from April 2009 to December 2024) or migratory seasons (i.e., from October 2009 to April 2025) for non-migratory and migratory species, respectively.

#### 2.1.2. Southern African Bird Atlas Project 2 (SABAP2)

SABAP2 data are collected by volunteers that compile cards (i.e., bird check-lists) over a *pentad* (i.e., a 5 × 5 arc minutes grid, ca. 9 × 9 km) following a standardized protocol (see Brooks et al., 2022). We downloaded all the *pentads* (in SABAP2 data; <https://sabap2.birdmap.africa/coverage/project/sabap2>) for each of the 26 species with

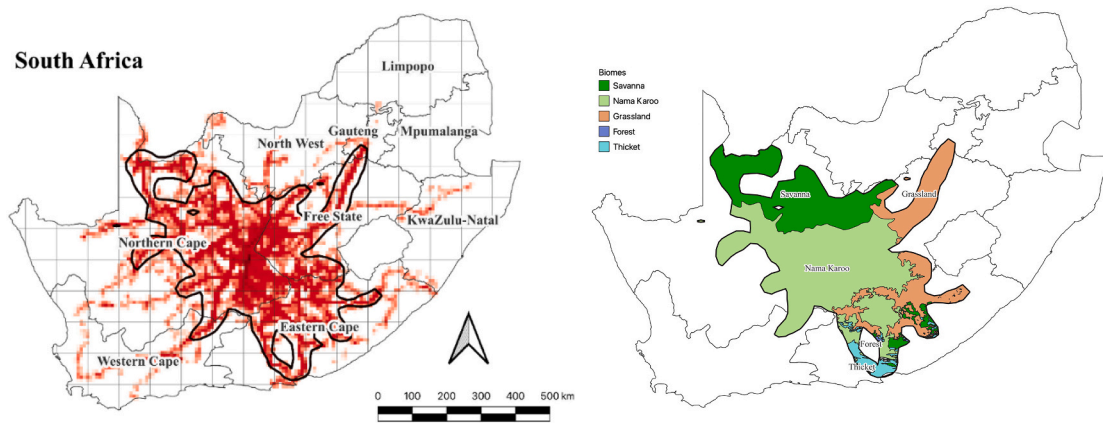


Fig. 1. Map of the study area showing the distribution of all bird observations at a 10 km resolution from road counts conducted between 2009 and 2025 (left), and the biome distribution of the core surveyed area within South Africa (right). The black polygon indicates the core survey area (95% Kernel Density Estimate).

sufficient data from road counts. We estimated our core area based on the 95% Kernel Density Estimate (*hereafter* K95 core area) of all road counts observations by using the functions *getvolumeUD* and *getverticeshr* from the *adehabitatHR* package (Calenge, 2006). This K95 core area polygon covered an area of 298,721 km<sup>2</sup> (Fig. 1). We then extracted all the SABAP2 *pentads* within our K95 core area for each species. The SABAP2 data were extracted between 27th April 2009 and 25th April 2025, thereby matching the time period for our road transect data. For the migratory species, we considered the same months and years as in the road counts data (see above). Following Shaw et al. (2024), we included only full protocol cards (i.e., a minimum of two hours surveying) and *pentads* that had: 1) more than 20 check-lists (i.e., 'cards'); 2) at least five cards between 2009 and 2016 and 2017–2025, respectively; and 3) at least two presences of the species of interest. Where species had less than 25 *pentads* matching our criteria within our core area (Fig. S1), we did not include them in our analysis or comparison, which excluded two species: Pygmy Falcon (*Polihierax semiotquatus*) and Tawny Eagle (*Aquila rapax*).

## 2.2. Statistical analysis

### 2.2.1. Road counts

Generalized Linear Mixed Models (GLMM) were used to explore population trends from our road count data, they were implemented using the *glmmTMB* package (Brooks et al., 2017). For each species, our response variable was the number of individuals counted on each transect, with the log of the distance (km/100) of the transect fitted as an offset. Following the approach of Garbett et al. (2018), we expressed the abundance per 100 km to provide a more useful response variable (rather than per km, because that would generate a very small value). We fitted 'year' (as a continuous variable) as the main explanatory variable. For each species we also explored whether including 'month' of each transect in the model improved the fit of the model, to take into account that some species may show seasonal patterns in their abundance or detectability, and because our road counts were not balanced in sampling effort across all months. For those species with an obvious migratory pattern from their observations, we included counts only from the calendar months in which the species was present (in at least two years; Fig. S2), excluding all calendar months that did not meet these criteria. We then included 'transect group' (see above for the method used to derive this variable) as a random term in the model to account for the lack of independence of counts from the same group. Thus, our models were either:

$$\text{Ind} \sim \text{Year} + \text{offset}(\log(\text{Distance}/100)) + (1 | \text{Transect group})$$

$$\text{Ind} \sim \text{Year} + \text{Month} + \text{offset}(\log(\text{Distance}/100)) + (1 | \text{Transect group})$$

In a similar manner to Garbett et al. (2018), for each species, we explored the best fit for six alternative statistical distributions within both models: zero-inflated or non-zero-inflated Poisson, zero-inflated or non-zero-inflated Negative Binomial, and zero-inflated or non-zero-inflated Negative Binomial with NB2 parameterization (variance =  $\mu(1 + \mu/k)$ ). We then used the *model.sel* function from the *MuMIn* package (Bartoń, 2020) to rank all the models and select the top model for each species based on lowest Akaike's Information Criterion (AIC) value (Table S1). We estimated the trend slope and its 95% confidence interval using the *predict* function from the *Effects* package (Fox, 2003). We estimated the percentage change (PC) over the 16-year study period from the estimated log-linear slope parameter ( $\beta$ ) of the model. Specifically, because the model is parameterized on the log scale, the expected multiplicative change over 16 years is given by  $\exp(\beta \times 16)$ , and the corresponding percentage change is calculated as  $\text{PC} = [\exp(\beta \times 16) - 1] \times 100$ . Wald 95% confidence intervals were obtained by applying the same transformation to the confidence limits of  $\beta$ , which were derived from the estimated variance-covariance matrix of the model parameters (i.e., the inverse of the Hessian matrix). For visualization purposes, we also generated the estimated mean abundance in each specific year, by re-running each final model with 'year' fitted as a categorical variable, and by using the *emmeans* package (Lenth, 2017). In order to check that a shift in migration phenology was not influencing the estimated trend for the three migratory species (Weiser et al., 2025), we compared the trend from our final model against another model with data for the first and last month of the migratory season considered for each species removed, and checked that the trends were not materially different.

### 2.2.2. SABAP2

To explore trends in the SABAP2 data between 2009 and 2025. Species presence/absence (i.e., 1/0) per card was fitted as the response variable and 'year' as the explanatory variable, with 'pentad' fitted as a random term to control for the repeated cards coming from the same pentad. We also fitted an additional model, including both 'year' and 'month' as explanatory variables. For migratory species, we included only the calendar months in which the species was present in our road counts (in at least two years; Fig. S2). The models were the following:

Presence/Absence ~ Year + (1 | Pentad)

Presence/Absence ~ Year + Month + (1 | Pentad)

The best fitting model was again selected using the *model.sel* function from the *MuMIn* package to rank the models and select the top model for each species, based on the lowest AIC value. Lastly, it has been suggested the rapid increase in SABAP2 surveys following the widespread uptake of a web-application (BirdLasser) to submit SABAP2 records may have influenced the quality of the cards submitted (see Lee et al., 2023; Lee and Nel, 2020). Thus, to explore this possibility, we ran an additional analysis, including a variable for 'app period' with two categories: years between 2009 and 2015 and 2016–2025, to see if including that term improved the fit of our best model (i.e., improvement by  $\Delta AIC > 2$ ), and used the model with this extra term where it did so. All statistical analyses were implemented in R version 4.4.0 (R Core Team, 2020).

## 3. Results

### 3.1. Road counts

In total, 752 transects were conducted covering a total distance of 391,789 km. Transect average length was 521 km (range: 80–2300 km). From these surveys, 26 species met our inclusion criteria for the analysis (i.e., observed in  $\geq 50$  transects). Pied Crow (*Corvus albus*), Lesser Kestrel (*Falco naumanni*), and Blue Crane (*Anthropoides paradiseus*) were the most frequently observed species, making up 83% of all individuals counted (i.e., 42%, 23%, and 18% respectively). They were also the most abundant (i.e., 22.03, 20.64, and 9.50 individuals per 100 km, respectively, from the raw counts), and were observed in 97.9%, 43.8%, and 47.6% of all transects (Table 1). In contrast, Spotted Eagle-Owl (*Bubo africanus*), Martial Eagle (*Polemaetus bellicosus*), African Fish-Eagle (*Haliaeetus vocifer*), Tawny Eagle, and Black-chested Snake-Eagle (*Circaetus pectoralis*) were among the least commonly observed species (i.e.,

with less than 0.1% of the total counted individuals) and also the least abundant (i.e., with a means ranging from: 0.02–0.05 ind/100 km) (Table 1). Among the assessed species, three were considered migratory: Amur Falcon (*Falco amurensis*; present from Nov. to March), Lesser Kestrel (present from Nov. to April), and Steppe Buzzard (*Buteo buteo vulpinus*; present from Oct. to April).

#### 3.1.1. Species trends

Half of all 26 species analysed from road count data showed a significant declining trend (50%; 13 of 26). In contrast, only three species (11.5%) showed a significant increasing trend. The remaining species showed a non-significant trend (38.5%; 10 of 26). Of those species with significant declines, all except two species showed an average decline of more than 50% over the 16-year period (Figs. 2 and 3). Among the 10 species which showed a non-significant trend, four showed an increasing slope and six showed a decreasing slope. Several of the species which showed large declines were not classified as either globally or regionally threatened (Table 1). For example, Spotted Eagle Owl, Pygmy Falcon, Amur Falcon, Jackal Buzzard (*Buteo rufofuscus*), and Steppe Buzzard, all showed a decline of  $>50\%$  but are classified as Least Concern (LC), both globally and regionally (Table 1). The trends of the three migratory species were not materially different, with or without the first and last months, indicating that their trends were unlikely to be an artefact of shifting migratory phenology (Table S2).

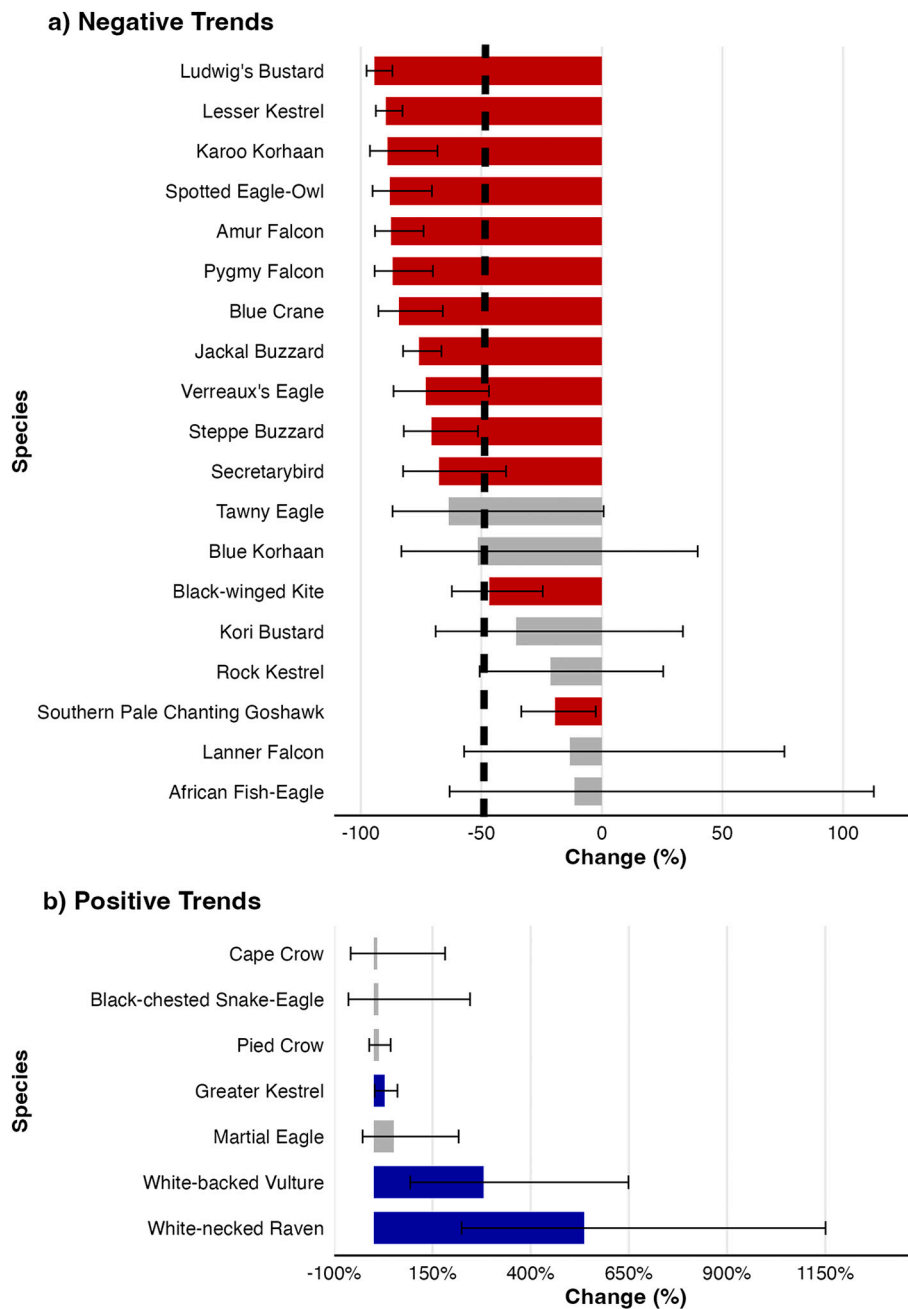
#### 3.2. Comparison between road counts and SABAP2 trends

We estimated trends using the SABAP2 data for 24 species of the 26 species that were analysed using the road count data. The percentage of area covered by SABAP2's pentads was on average 3% (range: 1–6%) of our core area (Table 2, Fig. S1). There was limited agreement between SABAP2's trends and those derived from the road counts. Disregarding the significance of the trends, only 12 of 24 (50%) species had trends

**Table 1**

Descriptive statistics of the assessed species (ranked by relative abundance). Conservation status, total transects, transects with observations, number of individuals recorded, total distance surveyed, and relative abundances are shown. Resident species were analysed between April 2009 and December 2024 (725 transects), while migratory species were analysed during the calendar months when they were present in South Africa between Oct 2009 until April 2025 (see Methods). Global and regional conservation status were sourced from Birdlife International (<https://datazone.birdlife.org/>) and the Red List of Southern African Species (<https://www.birdlife.org.za/red-data-book/> and <https://speciesstatus.sanbi.org/>), respectively. Status categories: Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), and Critically Endangered (CR). Migratory species (+).

Species name	Conservation status		Total transects	Transects with observations		Individuals	Distance	Abundance
	Global	Regional	#	#	%	#	Km	Ind/100 km
Lesser Kestrel ( <i>Falco naumanni</i> ) <sup>+</sup>	LC	VU	384	188	49	45,026	192,932	23.34
Pied Crow ( <i>Corvus albus</i> )	LC	LC	725	710	98	82,888	376,283	22.03
Blue Crane ( <i>Anthropoides paradiseus</i> )	VU	VU	725	345	48	35,749	376,283	9.50
Southern Pale Chanting Goshawk ( <i>Melierax canorus</i> )	LC	LC	725	716	99	10,688	376,283	2.84
Amur Falcon ( <i>Falco amurensis</i> ) <sup>+</sup>	LC	LC	309	98	32	2762	153,950	1.79
Greater Kestrel ( <i>Falco rupicoloides</i> )	LC	LC	725	681	94	6041	376,283	1.61
White-backed Vulture ( <i>Gyps africanus</i> )	CR	CR	725	163	22	3388	376,283	0.90
Steppe Buzzard ( <i>Buteo buteo vulpinus</i> ) <sup>+</sup>	LC	LC	436	226	52	1209	218,267	0.55
Jackal Buzzard ( <i>Buteo rufofuscus</i> )	LC	LC	725	450	62	1874	376,283	0.50
Black-winged Kite ( <i>Elanus caeruleus</i> )	LC	NT	725	378	52	1767	376,283	0.47
Cape Crow ( <i>Corvus capensis</i> )	LC	LC	725	80	11	843	376,283	0.22
Rock Kestrel ( <i>Falco rupicolus</i> )	?	LC	725	249	34	737	376,283	0.20
Ludwig's Bustard ( <i>Neotis ludwigii</i> )	EN	EN	725	186	26	710	376,283	0.19
White-necked Raven ( <i>Corvus albicollis</i> )	LC	LC	725	175	24	632	376,283	0.17
Secretarybird ( <i>Sagittarius serpentarius</i> )	EN	VU	725	186	26	339	376,283	0.09
Pygmy Falcon ( <i>Polihierax semitorquatus</i> )	LC	LC	725	66	9	337	376,283	0.09
Verreaux's Eagle ( <i>Aquila verreauxii</i> )	LC	VU	725	153	21	298	376,283	0.08
Lanner Falcon ( <i>Falco biarmicus</i> )	LC	NT	725	146	20	234	376,283	0.06
Kori Bustard ( <i>Ardeotis kori</i> )	NT	NT	725	139	19	229	376,283	0.06
Blue Korhaan ( <i>Eupodotis caeruleus</i> )	NT	VU	725	63	9	221	376,283	0.06
Karoo Korhaan ( <i>Heterotetrax vigorii</i> )	LC	NT	725	67	9	189	376,283	0.05
Spotted Eagle-Owl ( <i>Bubo africanus</i> )	LC	LC	725	93	13	181	376,283	0.05
Martial Eagle ( <i>Polemaetus bellicosus</i> )	EN	EN	725	121	17	163	376,283	0.04
African Fish-Eagle ( <i>Haliaeetus vocifer</i> )	LC	LC	725	78	11	95	376,283	0.03
Tawny Eagle ( <i>Aquila rapax</i> )	VU	EN	725	54	7	80	376,283	0.02
Black-chested Snake-Eagle ( <i>Circaetus pectoralis</i> )	LC	LC	725	59	8	73	376,283	0.02

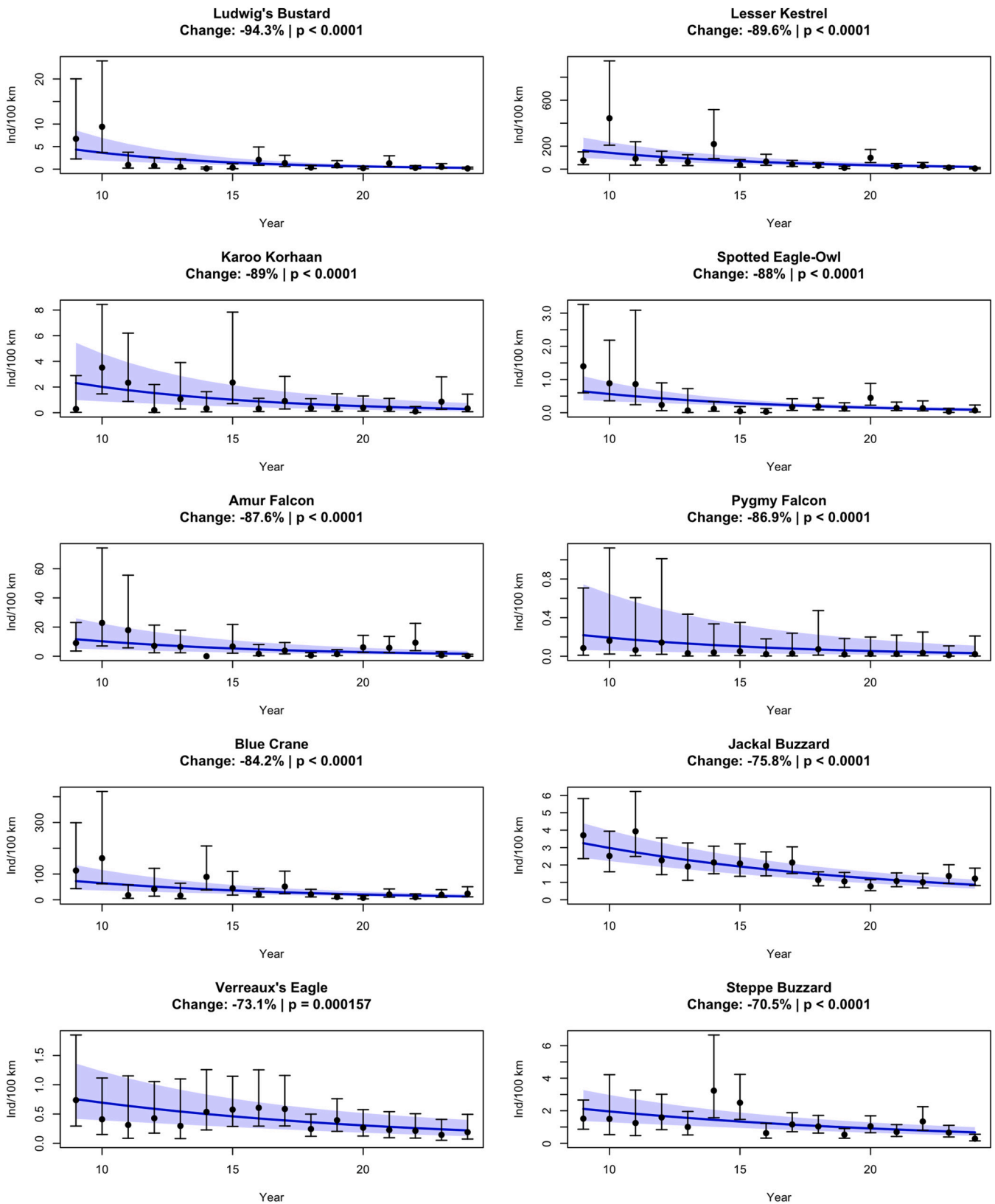


**Fig. 2.** Estimated population change ( $\pm 95\%$  CI) for 26 species from road counts conducted over a 16-year period between 2009 and 2025 in South Africa. (a) Negative and (b) positive trends: significant decreases (red,  $p < 0.05$ ), significant increases (blue,  $p < 0.05$ ), and non-significant changes (grey,  $p > 0.05$ ). The dashed vertical black line indicates a  $-50\%$  population change. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

which agreed in direction across these two surveys (i.e., same slope signs) and of these six (25%) were declining and six (25%) were increasing (Quadrants I and III; Fig. 4). However, among the trends which disagreed (50%, 12 of 24), almost all of them (11 of 12) showed decreasing trends in the road count data yet increasing in SABAP2 (Quadrant VI, Fig. 4), and just for one species it was showed the contrary (Quadrant II, Fig. 4). App period was selected in about a third of the best species' trends models (37.5%; Table 2) decreasing reporting rates.

More than 50% (14 of 24) of the species' trends using SABAP2 data were statistically significant (Table 2), with three declining significantly and 11 increasing significantly. Considering just statistically significant trends in both datasets ( $n = 9$ ), less than 50% of them agreed (i.e., 4 of

9). The species trends which were significant and consistent between the two methodologies included: Amur Falcon and Lesser Kestrel which both showed significant declines, and Greater Kestrel (*Falco rupicoloides*) and White-backed Vulture (*Gyps africanus*) which both showed significant increases (Table 2, Figs. 3 and 4). Among the trends which were significant and inconsistent, all showed decreases according to the road counts but increases from SABAP2 (i.e., Ludwig's Bustard (*Neotis ludwigii*), Blue Crane, Secretarybird (*Sagittarius serpentarius*), Black-winged Kite (*Elanus caeruleus*), and Southern Pale Chanting Goshawk (*Melierax canorus*)).



**Fig. 3.** Population trends (blue line) with 95% CI (blue shaded) from the best-fitting model for 26 species of birds recorded during road counts in South Africa between 2009 and 2025. Percentage change over the entire study period and the significance of the trend are shown above each plot. Points and error bars indicate mean annual counts ( $\pm$  95% CI) per 100 km of transect, estimated by fitting year as a categorical term in the model to capture inter-annual variability. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

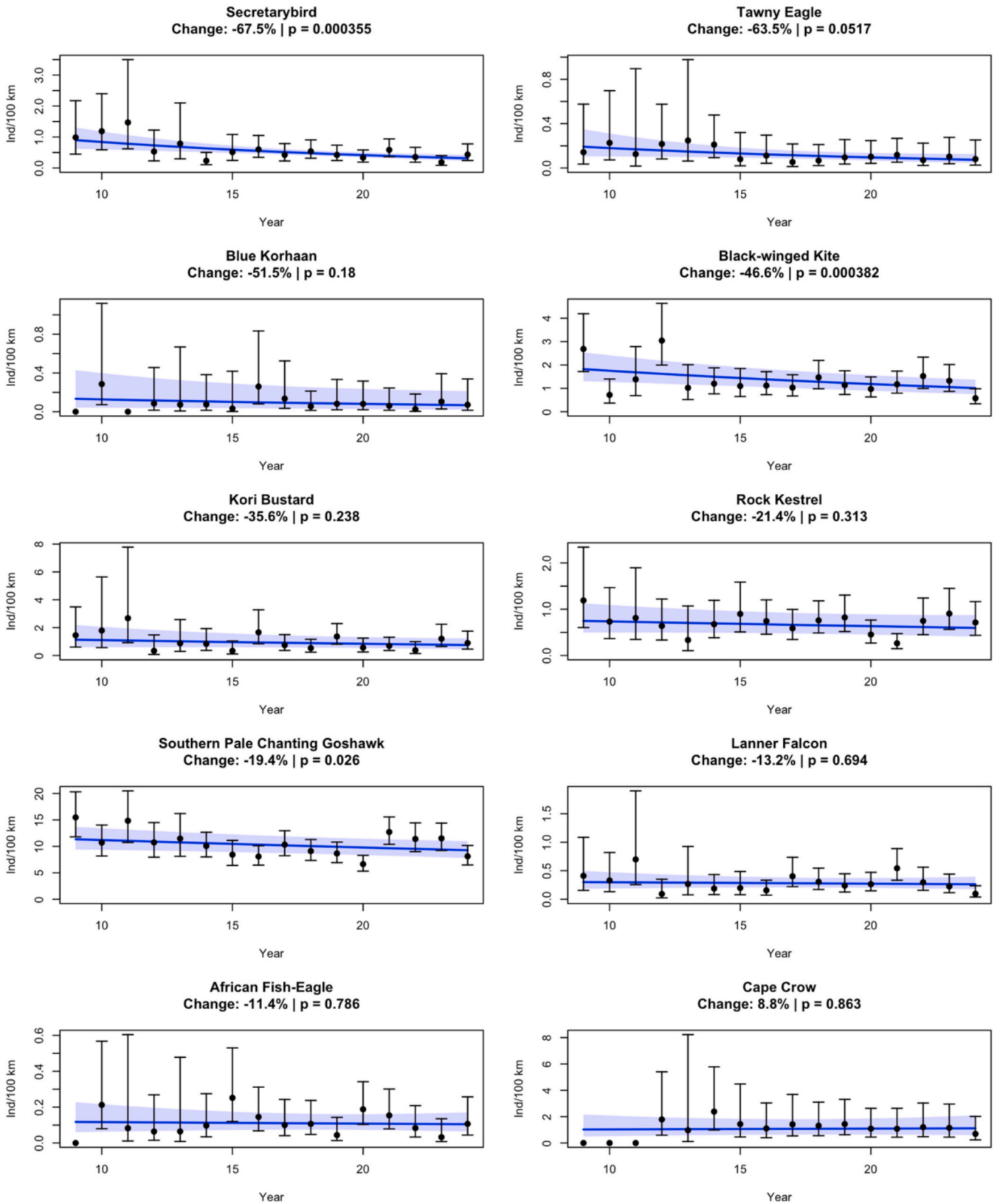


Fig. 3. (continued).

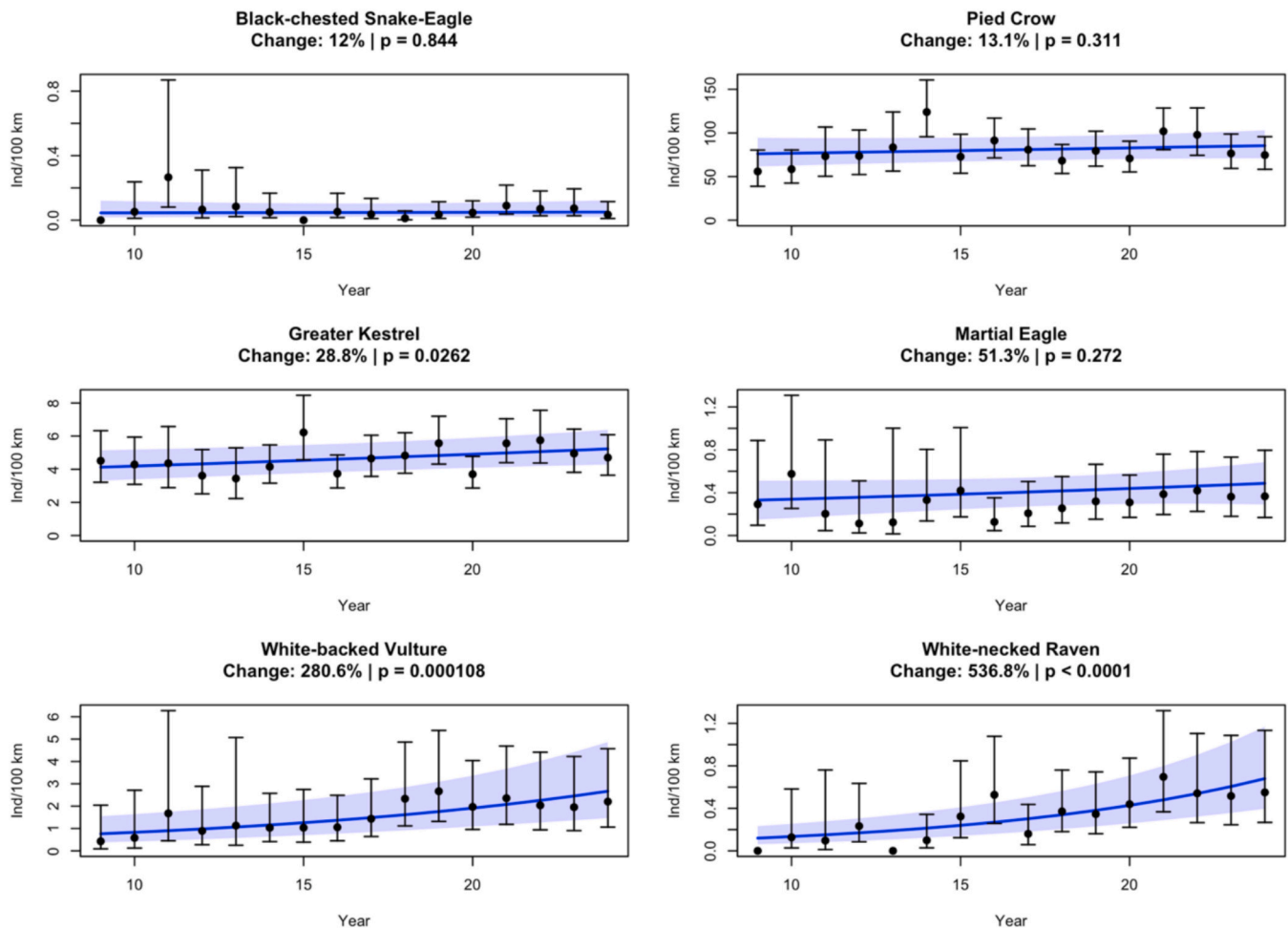


Fig. 3. (continued).

#### 4. Discussion

Our trend analysis of raptors and other large terrestrial birds counted from road transects indicated that 50% of the 26 species showed significant declines over the 16-year period of the study, with 10 raptors and three large terrestrial bird species showing statistically significant declines. The levels of many of these declines were worrying, with most showing declines of over 50%, including many species that are not currently considered globally or regionally threatened. In contrast, only Greater Kestrel, White-backed Vulture, and White-necked Raven (*Corvus albicollis*) showed statistically significant increasing trends. We found support for the hypothesis that check-list based trends (i.e., SABAP2) may be less sensitive to species declines than other abundance-based trends, with only around 50% of trends (slope direction) agreeing with road count trends. In keeping with our prediction, a considerable proportion of significant declines detected through the road count analyses were not detected from our equivalent SABAP2 analysis.

##### 4.1. Road count population trends

We found 10 raptor species declined significantly, with eight species declining by more than 50%. This suggests urgent conservation intervention may be needed for these species. Also, given that currently several of these species do not qualify as threatened either globally or regionally (Table 2), their conservation status should be reappraised.

All three migratory species (i.e., Lesser Kestrel, Amur Falcon, and Steppe Buzzard) showed major declines. This is in keeping with other analysis from the northern hemisphere, which has found that migratory

raptors and non-raptor species are suffering worse declines than residents (Sanderson et al., 2006). Conservation of migratory species is especially challenging, as actions may be required in both the breeding and non-breeding areas as well as along their migration routes where threats may vary (Ferrer-Obiol et al., 2025). Recent results have shown that at least a portion of the Lesser Kestrels that migrate to South Africa come from Asia (i.e., Eastern lineage; Ferrer-Obiol et al., 2025; Rodríguez et al., 2011), where populations are also suspected to be declining (Shaw and Tate, 2025), contrasting with the Western lineage which is thought to have a relatively stable population (Orta and Kirwan, 2020). A similar situation is present for Amur Falcon, a small raptor with one of the longest migratory paths of all raptors; >14,500 km between Asia (i.e., Mongolia and NE China) and Africa (i.e., South Africa) (Meyburg et al., 2017). Despite current conservation efforts, and mitigation of threats in some countries along the species migratory route (Kudalkar and Veríssimo, 2024), our results suggest a severe population decline in the last decade at least for the population migrating to South Africa. In our study, Lesser Kestrel and Amur Falcon were the only two species whose trends were declining and statistically significant in both road counts and SABAP2 analyses. In the case of Steppe Buzzard, there are around seven subspecies, with South African individuals most probably coming from east Europe and west Asia (Orta et al., 2022). Thus, armed conflicts such as the war in Ukraine, or emerging conflicts in the coming decades for example in the Caucasus region, may impact their populations during breeding and/or migratory season (Russell et al., 2024), further complicating their conservation.

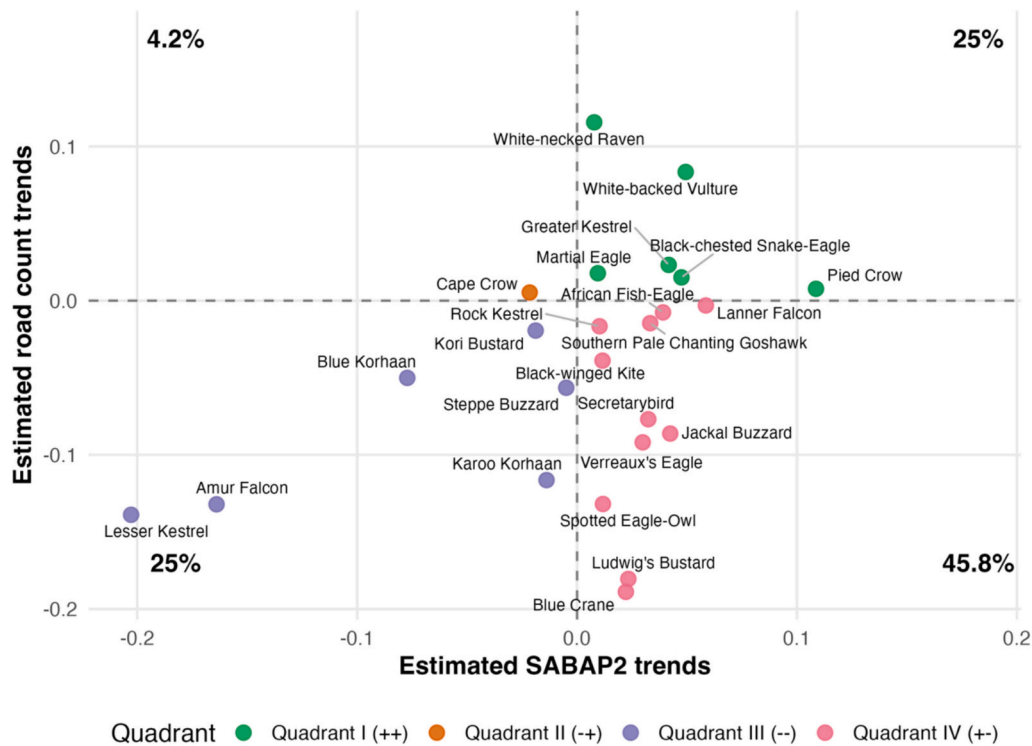
Our trends support other recent analyses of road count data that also suggest widespread population declines of raptors (and very few

**Table 2**

SABAP2 species code, species name, number of pentads used in the SABAP2 analysis, percentage of the core area covered by these pentads, and the final selected model and AICc for 24 of the 26 species analysed using the road count data. Slope estimates and p-values are shown for the Year and App period as explanatory variables. Statistically significant trends (p-value <0.05) are shown in bold.

SABAP2 species code	Species name	Pentads	Core area	Model	AICc	Year		App period	
		#	%			Estimate	p-value	Estimate	p-value
125	Lesser Kestrel <sup>+</sup>	123	3.3	M1	4558.6	<b>-0.203</b>	<b>&lt;0.001</b>	-	-
119	Amur Falcon <sup>+</sup>	134	3.6	M1	4648.4	<b>-0.164</b>	<b>&lt;0.001</b>	-	-
223	Blue Korhaan	62	1.7	M1	3622.0	<b>-0.077</b>	<b>&lt;0.001</b>	-	-
523	Cape Crow	92	2.5	M4	7291.6	-0.022	0.104	<b>-2.367</b>	<b>0.018</b>
217	Kori Bustard	34	0.9	M1	1813.1	-0.019	0.225	-	-
220	Karoo Korhaan	41	1.1	M3	3197.0	-0.014	0.179	-	-
133	Steppe Buzzard <sup>+</sup>	210	5.7	M2	4342.0	-0.005	0.773	<b>-2.811</b>	<b>0.005</b>
524	White-necked Raven	107	2.9	M1	10,901.5	0.008	0.193	-	-
154	Martial Eagle	49	1.3	M2	9905.6	0.009	0.398	<b>-4.271</b>	<b>&lt;0.001</b>
123	Rock Kestrel	163	4.4	M2	12,618.2	0.010	0.306	<b>-4.885</b>	<b>&lt;0.001</b>
130	Black-winged Kite	220	6.0	M2	19,084.6	0.012	0.146	<b>-6.665</b>	<b>&lt;0.001</b>
368	Spotted Eagle-Owl	111	3.0	M1	7631.6	0.012	0.108	-	-
114	Blue Crane	108	2.9	M1	5831.5	<b>0.022</b>	<b>0.014</b>	-	-
218	Ludwig's Bustard	63	1.7	M1	3460.7	<b>0.023</b>	<b>0.043</b>	-	-
142	Verreaux's Eagle	65	1.8	M1	2209.5	0.030	0.058	-	-
105	Secretarybird	130	3.5	M2	7564.2	<b>0.032</b>	<b>0.018</b>	<b>-3.461</b>	<b>0.001</b>
216	Southern Pale Chanting Goshawk	174	4.7	M1	6713.7	<b>0.033</b>	<b>&lt;0.001</b>	-	-
149	African Fish-Eagle	144	3.9	M4	10,546.4	<b>0.039</b>	<b>&lt;0.001</b>	<b>-2.576</b>	<b>0.010</b>
122	Greater Kestrel	90	2.4	M3	3766.6	<b>0.042</b>	<b>&lt;0.001</b>	-	-
152	Jackal Buzzard	130	3.5	M4	9613.4	<b>0.042</b>	<b>&lt;0.001</b>	<b>-4.343</b>	<b>&lt;0.001</b>
146	Black-chested Snake-Eagle	39	1.1	M1	1203.3	<b>0.047</b>	<b>0.017</b>	-	-
165	White-backed Vulture	28	0.8	M2	14,801.9	<b>0.049</b>	<b>&lt;0.001</b>	<b>-2.597</b>	<b>0.009</b>
107	Lanner Falcon	119	3.2	M3	1770.8	<b>0.059</b>	<b>&lt;0.001</b>	-	-
522	Pied Crow	254	6.9	M1	21,074.2	<b>0.109</b>	<b>&lt;0.001</b>	-	-
126	Pygmy Falcon	23	0.62	-	-	-	-	-	-
134	Tawny Eagle	9	0.24	-	-	-	-	-	-

M1: Presence/Absence ~ Year + Month + (1 | Pentad).  
 M2: Presence/Absence ~ Year + Month + App period + (1 | Pentad).  
 M3: Presence/Absence ~ Year + (1 | Pentad).  
 M4: Presence/Absence ~ Year + App period + (1 | Pentad).  
 Migratory species (\*).



**Fig. 4.** Scatter plot of the slopes (i.e., annual estimated population trends) from models fitted using road count and SABAP2 datasets. Top-right (Quadrant I; 25%): trends increasing from both methodologies. Top-left (Quadrant II; 4.2%): trends decreasing from SABAP2 but increasing from road counts. Bottom-left (Quadrant III; 25%) trends decreasing from both methodologies. Bottom-right (Quadrant IV; 45.8%): trends decreasing from road counts but increasing from SABAP2.

increases) across several countries of Africa in recent decades (e.g., Shaw et al., 2024). Our findings of large declines for Secretarybird and Lesser Kestrel were very similar to those reported in Kenya and northern Botswana (Shaw et al., 2024), as well as in both northern and southern Botswana (Mphethe, 2023). Additionally, similar population changes for Secretarybird were detected during winter (but not summer) using road counts within the Nama Karoo (i.e., within a major portion of our core area) during the period immediately before our study period (i.e., -61% between late 1980s and early 2010s; Shaw et al., 2016). This suggests that the decline detected by Shaw et al. (2016) may have continued into the mid-2020s.

For some species, the population trends we estimated from road counts were different from those previously recorded in other regions. For example, while we found Pygmy Falcons declined in South Africa, Shaw et al. (2024) observed an increase in Kenya. Similarly, we found declines in Southern Pale Chanting Goshawk in South Africa but the species was observed increasing in northern Botswana. Black-winged Kite declined by -47% in our study in South Africa, similar to declines seen in many other African regions, except for Northern Cameroon where large increases were observed (Shaw et al., 2024). While Greater Kestrel increased in South Africa, decreases were seen in northern Botswana (Shaw et al., 2024). The White-backed Vulture, a critically endangered species, declined in West Africa, northern Cameroon, Kenya, and northern Botswana (Leepile et al., 2020; Shaw et al., 2024), while we estimated a very substantial increase in South Africa. Our estimates align with the Dronfield population near Kimberley (located within our core area), which has increased substantially in recent years (Murn et al., 2017), and also with a more recent analysis combining road surveys from both northern and southern Botswana (Mphethe, 2023).

Among non-raptors, three species showed severe statistically significant declines: Ludwig's Bustard (-94%), Karoo Korhaan (*Heterotetrax vigorsii*; -89%), and Blue Crane (-84%). However, for all three species, these large declines are principally driven by sporadic high counts in a few years between 2009 and 2015, with no comparable high counts in more recent years, as evident from the annual estimates (Fig. 3). These trends can be compared with those from road count trends between 1980s and 2010s from the Nama Karoo, covering a large part of our core study area (Shaw et al., 2016). Our trends matched those for Ludwig's Bustard and Karoo Korhaan, for which Shaw et al. (2016) reported significant declines in summer and winter. In contrast, however, the trends we observed for Blue Cranes were opposite to the positive trends Shaw et al. (2016) found in both seasons. However, the pattern of an increase until the early 2010s (Shaw et al., 2016) followed by subsequent decrease (this study) are mirrored by the results from Craig (2025), which analysed Blue Crane trends in the Karoo using road count data from the 'Coordinated Avifaunal Roadcounts' (CAR; <https://car.birdmap.africa>), another citizen science scheme in South Africa.

Our road count analyses did not explicitly account for imperfect detection, and therefore false-negative observation errors may have potentially influenced both estimated counts and inferred temporal trends. For example, over the duration of the study, detectability could have changed in a systematic way due to observer-related factors (e.g., declining eyesight or changes in driving speed; McClure et al., 2021). Additionally, landscape modification associated with agriculture and infrastructure development could have influenced visual detectability. However, there is little evidence that habitat in our study area has changed in a meaningful manner in this regard during the last decades (Hoffman et al., 2018).

#### 4.2. Trend comparisons with checklist-based data

Our comparison of trends between road counts (which we deem to be more reliable) and checklist-based surveys suggests that the latter is only capable of detecting around half of the real species' population trends. This conclusion relies on the assumption that our road counts accurately

detect the true trends in abundance, since evidence shows they provide a good proxy of the actual relative densities or abundance of species (Kéry and Kellner, 2024; Pollock, 2006; Tella et al., 2021). In both cases, ignoring or considering the significance of the trends, only around a half of them were in the same direction (i.e., trends increasing or decreasing) between the two survey approaches. The rest of slopes from SABAP2 did not match those of our road counts, with all but one of those different trends being a declining trend detected by the road counts, but an increasing trend detected by SABAP2 (Fig. 4). These patterns support our hypothesis that a checklist-based methodology is less precise for detecting trends in abundance at large spatial scales. This hypothesis was principally based on the finding that the probability of species presence (i.e., reporting rates) was not linearly related to abundance in the same areas (Lee et al., 2018), as would be expected from the mathematical relationships between distribution occurrence and abundance at larger scales (Kéry and Kellner, 2024; Pollock, 2006). Consequently, this suggests that SABAP2, as currently developed, may not accurately capture population trends.

It has been well established that citizen science data has higher observational noise than systematic observation, and that these weaknesses need to be explicitly managed (Isaac et al., 2014; Kelling et al., 2019). Our results support this idea, for example the launch of the BirdLasser App in 2015 for observers to submit their SABAP2's records, has had a profound impact on the numbers of cards submitted (Lee and Nel, 2020), but has also decreased the reporting rates for about one third of the species assessed in this study. Concerns over this issue were previously suggested by Lee and Nel (2020) and represent an important source of bias.

Our findings suggest that using changes in reporting rates from SABAP2 do not accurately quantify population trends in large areas of central Southern Africa. Another recent study incorporated a different metric that can also be obtained from SABAP2 (i.e., species time-to-detection) to analyse Secretarybird trends in southern Africa from SABAP2 data (Brink et al., 2024). Future research could use this approach within our study area to determine whether changes in time-to-detection and/or sequence of observation from SABAP2 data, could better mirror the changes in abundance that we observed. If this still does not improve the agreement between these methods, it may be that SABAP2 will need to be adapted, for example, to record species abundance rather than presence/absence data alone, an approach already adopted by eBird that better reflects population abundance trends (Acevedo-Charry et al., 2025; Sullivan et al., 2014). Another alternative would be split pentads into smaller units (e.g., sub-pentads between 1 and 9 km<sup>2</sup>) for which presence/absence is recorded, because at smaller spatial scales occurrence distribution and abundance will be more similar, meaning that changes in presence/absence data will be more likely to closely reflect abundance trends (Pacifci et al., 2019). At the same time, a higher investment of resources may be used to improve the coverage of road count data in South Africa through CAR (<https://car.birdmap.africa>).

#### 4.3. Conservation implications

For seven species, we could compare our trends with those found in four other countries or regions in Africa (i.e., West Africa, Northern Cameroon, Kenya, and Northern Botswana; Garbett et al., 2018; Ogada et al., 2022; Shaw et al., 2024). Similar to these studies of raptor trends in Africa, in South Africa declining trends were observed across raptors with diverse life history: ranging from large-size mammal specialist residents (e.g., Verreaux's Eagle (*Aquila verreauxii*)), to medium-size generalist (e.g., Jackal Buzzard), to small-size insectivorous migrants (e.g. Lesser Kestrel and Amur Falcon). Considering the diverse requirements of these species, it is challenging to pinpoint any single potential driver through a life-history comparison (Peery et al., 2004).

Raptor declines elsewhere in Africa have been linked to the increases in the human population, agricultural transformation of land (Shaw

et al., 2024), and climate change (Ferrer-Obiol et al., 2025). Within our region, there have been no very obvious changes in land use or large increases in human population densities, during the last 16-year period. However, indirect effects of small-scale or historical land-use changes on raptors and non-raptors bird population (e.g., improving hunter access, poaching, and prey species decreasing) cannot be discarded (Betts et al., 2017; Di Marco et al., 2018; Dupont and Dobson, 2025). Human-raptors conflict may have also increased (e.g., illegal killing of raptors due to perceived or real predation of livestock or due to the desire for renewable energy development; Kendall et al., 2025). Furthermore, there is evidence of the increasing negative effects of climate change and aerial fragmentation (e.g., electrical lines and wind farms; Smarte Anekwe et al., 2024) on wildlife populations in the region over at least the last two decades affecting species survival and productivity (Abrahms et al., 2022; Cunningham et al., 2021; Cunningham et al., 2015; Woodroffe et al., 2017).

Lack of biodiversity monitoring in Africa remains a severe hindrance to evidence-based decision-making in conservation, and we recognize that ABAP projects in several countries of Africa remain as one of the most important biodiversity monitoring tools. Our comparative analysis, although including a considerable number of species, was made with a sample of species with relatively similar traits (i.e., mainly large bodied and open habitat species) and within a specific large area in central South Africa. Further, although based on the best available information, SABAP2 has a very low coverage of pentads ranging from 1 to 6% of our core area. Despite this low coverage, in central South Africa, SABAP2 remains as one of the most important tools available for monitoring birds in this region (Lee et al., 2025). It is likely that in better SABAP2/eBird covered areas, and at smaller spatial scales, different analytical frameworks that require higher spatial and temporal data coverage can be applied (e.g., Acevedo-Charry et al., 2025). Thus, integration between derived ABAP projects (e.g., SABAP2 and Kenya Bird Trends) and eBird can help to bridge this data gap (Nussbaumer et al., 2025), allowing improved species trend monitoring at least across well-covered parts of Africa (e.g., Kenya, Botswana, Namibia, and South Africa). Further comparisons of ABAP/eBird performance with respect to other more systematic methodologies are needed and worthwhile for a higher sample of bird species, in different places and contexts around Africa.

Within Africa, human populations are expected to increase in the next three decades (United Nations, 2024), thus increasing pressure on biodiversity (Fletcher et al., 2024). According to our results, 42% of the assessed species declined by more than 50% in the last 16 years. Given the projected human population growth in Africa (i.e., 79%), and a corresponding rise in demands for resources and energy, threats to these vulnerable species are likely to intensify. It is therefore essential that we have tools to accurately monitor species trends and better understand the impacts these pressures may have on species. This is imperative to understanding the current biodiversity crisis and mitigating the severe loss of wildlife (Fletcher et al., 2024).

Through monitoring, we can identify which species require more urgent attention, while conservation prioritization helps define the right species and places where measures should be developed (Gibbons et al., 2011). However, monitoring and prioritization are only the initial steps in the conservation planning cycle and are therefore insufficient on their own. For example, the Secretarybird—a species with one of the highest population declines in our study—has recently been suggested as a high-priority conservation species in both West (Buij et al., 2025) and Southern Africa (Kendall et al., 2025). Nevertheless, more diagnostic research on the causes of raptor declines is necessary for recommending and testing solutions to conservation problems (Gibbons et al., 2011). Raptor population declines have been linked in Africa to pressures from human population growth, such as expanded farming and poaching (Buij et al., 2025; Kendall et al., 2025; Shaw et al., 2024). Therefore, conservation strategies that consider local communities (Zuluaga et al., 2020) as well as wildlife conservation should be tested and implemented at larger scales across the continent (Buij et al., 2025; Kendall et al.,

2025). Finally, by monitoring effectiveness, we can assess the results of these interventions and refine solutions (Gibbons et al., 2011; Helmstedt et al., 2025).

## 5. Conclusion

Our results reveal that a significant proportion of raptors and other large terrestrial bird species assessed are declining at alarming rates in South Africa, over the last 16 years, with only a few showing increases. The causes of these trends are poorly known although they have been linked elsewhere in Africa to pressures associated with human population increase, such as expanded farming and poaching. Thus, policies to implement human-wildlife integrated strategies that secure the well-being of local communities as well as wildlife conservation are needed. Importantly, we demonstrated that an atlas citizen science checklist-based scheme in South Africa (i.e., SABAP2), fails to detect species population declines in around 50% of cases. Despite this, SABAP2 as well as other similar ABAP related projects in other countries of Africa remain the best monitoring tools currently available. Thus, if monitoring population trends remains a principal goal of ABAP related projects, our findings suggest that: *i*) further research on the performance of checklist-based methodologies are needed; and *ii*) ABAP methodology may need to be reconsidered to shift from presence/absence to counts and/or split pentads by establishing sub-pentads, which may yield stronger correlations with population changes in abundance and better inform trend analyses. Finally, it is vital to maintain and improve monitoring methodologies, especially in less developed but highly biodiverse countries of the Global South, which historically have not had strong monitoring programs. It is essential for making evidence-based decisions averting substantial biodiversity loss.

## CRedit authorship contribution statement

**Santiago Zuluaga:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Megan Murgatroyd:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis, Conceptualization. **Ronelle Visagie:** Writing – review & editing, Resources, Methodology, Investigation, Data curation. **Gareth Tate:** Supervision, Project administration, Investigation, Funding acquisition, Data curation. **Arjun Amar:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors have no financial or non-financial competing interests to declare.

## Acknowledgments

Marc Kéry and one anonymous reviewer for their comments which help to improve the quality of this manuscript. L. Thompson for reviewing an earlier version of the manuscript. Field work was supported by the Charl van der Merwe Trust through the Engangered Wildlife Trust. Data analysis, writing, and publication were supported by a postdoctoral fellowship from The ABAX Foundation and a Juan de la Cierva postdoctoral contract from the Spanish government.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2026.111764>.

## Data availability

<https://doi.org/10.5281/zenodo.18481014>

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