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Serval population status in the Greater Kafue Ecosystem, Zambia

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ABSTRACT

Mesopredators such as servals (*Leptailurus serval*) often receive less funding for research compared to charismatic large carnivores. However, understanding the population dynamics of the species is crucial for evidence-based conservation planning and management. This study investigates serval densities within Zambia's Greater Kafue Ecosystem (GKE). Serval population density was estimated through camera trap surveys and spatially explicit capture-recapture (SECR) at a number of sites, five within the fully protected Kafue National Park (KNP) and six in adjacent Game Management Areas (GMAs), where human pressures are generally greater. The analysis revealed that serval densities in KNP ranged from 2.32 (SE: 1.26, 95 % CI: 0.06 – 4.84) to 5.84 individuals (SE: 1.35, 95 % CI: 3.01 – 7.43) per 100 km2. Serval population density within the GMAs exhibited marginally greater variability, with densities ranging from 1.32 (SE: 0.38, 95 % CI: 0.57 – 2.07) to 6.11 individuals (SE: 1.70, 95 % CI: 2.77 – 9.45) per 100 km2. Our findings suggest slightly higher mean densities within KNP compared to the GMAs, which may be a result of differences in habitat quality and human disturbance. Our study further demonstrates the efficacy of using SECR models on bycatch data from large carnivore surveys to estimate serval densities. Future research could identify the environmental and anthropogenic factors that determine serval densities in the GKE, and a longitudinal study will allow for serval densities to be tracked over time.

1. Introduction

Across Africa, anthropogenic pressures significantly impact both large and small carnivore populations (McKee et al., 2004; Pimm et al., 1995). These include habitat loss and fragmentation (Ramesh & Downs, 2015), animal mortality through human-wildlife conflict (Treves & Karanth, 2003), and prey depletion from bushmeat poaching (Mutti et al., 2023). Large felids, including lions (*Panthera leo*), leopards (*Panthera pardus*), and cheetahs (*Acinonyx jubatus*) typically receive substantial research attention and conservation funding due to their charismatic nature, roles as apex predators and indicators of ecosystem health (Brodie, 2009; Hoeks et al., 2020; Small, 2011). In contrast, smaller felids, such as servals (*Leptailurus serval*), receive relatively less focus despite their ecological role as a mesopredator (Brodie, 2009; Tensen, 2018). By influencing small-mammal populations and associated prey dynamics, servals can contribute to maintaining balance within grassland and wetland ecosystems (Thiel, 2019).

Servals are currently listed as 'Least Concern' on the IUCN Red List (Thiel, 2019). However, the species faces growing threats from urbanisation, agricultural expansion, and habitat degradation (Thiel, 2019). In particular, serval are sensitive to the loss of wetland and grassland habitats, which support high prey densities, (Ramesh & Downs, 2015). Despite these threats, significant data gaps exist for serval, including baseline serval population data across sub-Saharan Africa. Indeed, survey data for serval are only available for populations in South Africa (Loock et al., 2018; Ramesh & Downs, 2013), Zambia (Thiel, 2011),

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Tanzania (Geertsema, 1985; Hardouin et al., 2021), and the Republic of the Congo (Bohm & Hofer, 2018). Addressing this knowledge gap is especially important as there is considerable variation in serval density estimates, with these ranging from 0.63 servals per 100 km^2 in Mudumu North Complex, Tanzania (Edwards et al., 2018), to 101.21 servals per 100 km^2 at an industrial site in Mpumalanga province, South Africa (Loock et al., 2018). This considerable observed variation therefore highlights the necessity for further research to develop accurate, region-specific status assessments.

Camera trapping, combined with maximum-likelihood Spatially Explicit Capture-Recapture (SECR) models, has proven effective for estimating carnivore population densities (Amburgey et al., 2021; Efford, 2011; Henschel et al., 2020; Sollmann, 2018), including felids such as serval (Edwards et al., 2018; Geertsema, 1985; Hardouin et al., 2021; Loock et al., 2018; Ramesh et al., 2016), tiger (*Panthera tigris*) (Karki et al., 2015), jaguar (*Panthera onca*) (Boron et al., 2016), and leopard (Strampelli et al., 2020). SECR models offer a robust approach for density estimation provided individuals can be uniquely identified through unique pelage markings, natural features such as scars, or artificial marks such as ear tags or PIT tags (Borchers & Efford, 2008; Rich et al., 2014). These models incorporate information on the spatial distribution of the captures and camera trap stations (Efford, 2011).

The focal area for this study, the Greater Kafue Ecosystem (GKE), in Zambia, faces significant threats from human encroachment, illegal burning and bushmeat poaching (Namukonde et al., 2017; Namukonde et al., 2023; Vinks et al., 2020; White & Van Valkenburgh, 2022). Moreover, the area does not generate substantial funds from ecotourism and is dependent on conservation aid (Lindsey et al., 2014; Mutti et al., 2023; Vinks et al., 2020; Watson et al., 2015).

Serval occur in the GKE, but data are lacking on serval population distribution and abundance, which are important for conservation decision-making. Our principal objective here was the estimation of serval densities at site level across the focal area, and we were further interested in potential differences in serval densities within Kafue National Park (KNP) and outlying Game Management Areas (GMAs). Finally, we were interested to know if our SECR survey design, primarily

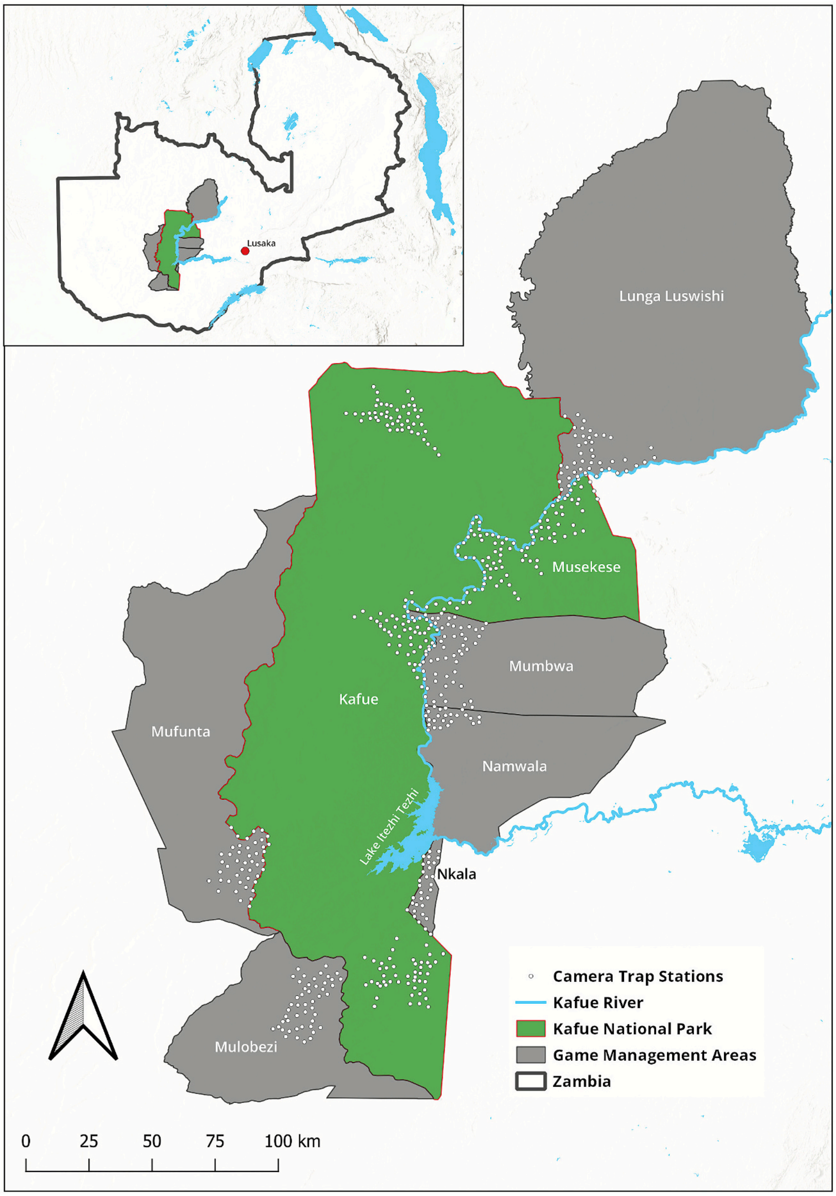

Fig. 1. Camera-trap grids and station locations within Kafue National Park (green) and Game Management Areas (grey) in the Greater Kafue Ecosystem, Zambia. Inset shows the location of the study area within Zambia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

targeting large carnivores, was adequate for the estimation of serval population density.

2. Methods

2.1. Study area

The Greater Kafue Ecosystem in Zambia encompasses Kafue National Park and nine adjacent Game Management Areas. The GKE spans approximately 22 400 km^2 in KNP and 44 000 km^2 across the GMAs (Vinks et al., 2020). The GKE is part of the Kavango-Zambezi Transfrontier Conservation Area (KAZA), a network of protected areas between Zambia, Zimbabwe, Namibia, Botswana and Angola (KAZA TFCA Secretariat, 2019). Our study site includes the KNP, and six (of nine) neighbouring GMAs (Fig. 1).

Within Kafue NP, consumptive use of any fauna or flora is prohibited, although traditional fishing is permitted within designated areas within the park. However, the GMAs are multiple use areas that permit limited settlement and some extractive use of natural resources by local communities (Watson et al., 2015). The GMAs allow trophy hunting as a source of income generation for local communities (Dietz et al., 2023; Watson et al., 2015) and government. There are no fences between KNP and the GMAs, thus allowing wildlife to move freely between these areas.

The ecosystem is characterised by a diverse mosaic of habitats, including miombo woodlands, open grasslands, and riparian zones, with pronounced dry and wet seasons (Dietz et al., 2023; Namukonde et al., 2017). These varied habitats provide a rich ecological landscape supporting diverse wildlife species such as African wild dog (*Lycaon pictus*), spotted hyaena (*Crocuta crocuta*), elephant (*Loxodonta africana*) and numerous antelope. Dense vegetation in wetland areas offers optimal hunting grounds and concealment for servals (Thiel, 2011).

2.2. Camera trap surveys

Independent camera trap surveys were conducted in the dry season from May to November 2023 (Table 1). Eleven camera trap surveys were deployed—five within KNP and one in each of six GMAs (Fig. 1): Lunga-Luswishi, Mufunta, Mulobezi, Mumbwa, Namwala, and Nkala. Camera trap stations were positioned alongside roads and game trails, with the initial aim of maximising large carnivore captures (McKenzie et al., 2012). The survey sites and design details are presented in Table 1.

Across the eleven grids, the number of camera stations per site ranged from 30 to 56 (mean = 47 ± 8 SD), with survey durations averaging 70 days (range = 63–80 days). In total, 36,046 trap-nights were accumulated across all sites. These relatively short survey periods, combined with limited dispersal typical of serval (Thiel, 2011), support the assumption of demographic and geographic population closure during sampling.

Serval home ranges vary widely across southern and central Africa, typically spanning 8–38 km^2 depending on habitat productivity and prey availability (Geertsema, 1985; Ramesh & Downs, 2013; Thiel, 2011). Smaller ranges are typically recorded in wetland and riparian systems, with larger ranges in drier grasslands (Ramesh & Downs, 2013; Thiel, 2011). Given the mean inter-station spacing of 2.6 km (range = 2.1–3.0 km) and grid sizes of 191–866 km^2, several cameras would have sampled individual home ranges, providing sufficient spatial recaptures for reliable SECR estimates.

Dual-camera stations were deployed at each site to facilitate identification at the level of individual, by permitting for example images of both right and left animal flanks (Hardouin et al., 2021; Searle et al., 2021; Searle et al., 2024; Strampelli et al., 2022). Sex was not determined due to insufficient visual indicators in the camera trap images, and SECR models did not include sex as a covariate. Camera traps were set to take images over day and night and still images were taken in preference to moving images. The duration of camera placement (number of days) is provided in Table 1. Overall, survey designs were based on optimising these for the estimation of lion and leopard population density.

2.3. Individual identification

At the conclusion of the surveys, all serval images were extracted to facilitate individual identification, a requirement of SECR modelling. This involved identifying individuals manually via their unique flank patterns (Hardouin et al., 2021; Searle et al., 2021; Searle et al., 2024; Strampelli et al., 2022). The left flank, having the greatest number of captures for the first grid, was used to identify individuals across all grids (Hardouin et al., 2021; Royle et al., 2009). A conservative approach was taken to avoid misidentifications, ensuring that only high-confidence identifications were included in the analysis; if there was some uncertainty about identifying a capture, this was discarded.

The capture history documenting the sampling locations and times of each capture, along with a trap layout file detailing the positions and operational status of each station, was prepared for each grid. Each 24-hour period (midnight to midnight) was considered as a separate sampling occasion (Goldberg et al., 2015). A sample of the Nkala trap history sheet is detailed in the supplementary material.

2.4. Density estimation

Serval population density (number of adult and sub-adult individuals per 100 km^2) was estimated via Maximum Likelihood SECR analysis, using the R package secr v4.6.9 (Efford, 2023), in RStudio version 2023.12.1 (R Core Team, 2023). Two models were tested: Model 1 (secr.0), which assumed constant values for density (D), detection probability at the home range centre (g0), and movement (σ), and Model 2 (secr.road), which allowed g0 to vary with proximity to roads while keeping D and σ constant.

For survey grids where all stations were positioned on roads (Lunga-

Table 1
Survey effort and design metrics for the eleven camera trap grids: survey duration, number of stations, trap-days, inter-station spacing, and survey area (minimum convex polygon).

Sites	Survey Period	Survey duration (days)	Number of stations	Trap days	Average station spacing	Survey area
Kafue Central	May – July 2023	63	51	3074	2.36 km	611 km^2
Kafue South	June – August 2023	65	50	2905	2.61 km	664 km^2
Kafue North	August – October 2023	73	50	3317	2.2 km	468 km^2
Musekese East	August – November 2023	74	48	3265	2.69 km	657 km^2
Musekese West	June – August 2023	76	56	3552	2.59 km	866 km^2
Lunga-Luswishi	October – December 2023	68	50	3095	3.04 km	712 km^2
Mufunta	July – September 2023	66	45	2826	3.01 km	483 km^2
Mulobezi	September – November 2023	63	50	2911	2.55 km	503 km^2
Mumbwa	May – August 2023	80	51	3471	2.7 km	705 km^2
Namwala	June – August 2023	75	30	2208	2.17 km	191 km^2
Nkala	June – August 2023	65	35	1901	2.26 km	229 km^2

Luswishi, Mufunta, Namwala, and Nkala), only Model 1 was applied. Both models used a half-normal detection function, incorporating spatial variation in detection probability and individual movement. Model selection was based on Akaike's Information Criterion corrected for small sample sizes (AICc) (Burnham & Anderson, 2004), and the best-performing model was used to estimate serval density. Final density estimates were derived separately for each survey grid, allowing for comparisons across the different survey sites (Hardouin et al., 2021; Searle et al., 2021; Strampelli et al., 2022).

3. Results

All serval density estimates across the region are provided in Table 2. The highest population density estimates were observed in Namwala GMA and Musekese West (a site in KNP), with estimates of 6.11 ± 1.70 and 5.84 ± 1.35 individuals per 100 km^2 (mean ± SE) respectively (Fig. 2). In contrast, density could not be estimated for the Mulobezi GMA grid because the SECR model failed to converge, likely due to an insufficient number of independent detections and recaptures required for parameter estimation. The lowest estimated density was recorded in Lunga-Luswishi GMA, at 1.32 ± 0.38 individuals per 100 km^2. Relatively high densities were also observed in the Kafue Central and Kafue North grids, in the KNP, with estimates of 5.46 ± 0.93 and 5.37 ± 1.19 individuals per 100 km^2, respectively. Densities ranged from 2.32 to 5.84 individuals per 100 km^2 within the sites in KNP, whilst in the GMAs, densities ranged from 1.32 to 6.11 individuals per 100 km^2 (Fig. 2). The density estimates in relation to their locations within the study site are provided in Fig. 3.

The proportion of individuals detected more than once ('recapture rate') was highest in Kafue Central (60.6 %) and lowest in Kafue South (4.0 %). Model selection identified secr.road as the top-ranked model in five of the survey grids. In contrast, grids where all stations were located along roads were analysed using only the null model (secr.0), as variation in road proximity could not be tested (Table 2). The AICc scores for the sites where both models were run are provided in Table 3.

4. Discussion

Serval densities were broadly comparable between KNP and the surrounding GMAs, with mean values marginally higher in KNP. Variation among sites appeared similar across both management zones. Marginally higher densities in KNP likely reflect the greater level of protection afforded within the park; however, the comparable variation between zones indicates that local habitat characteristics and management intensity remain important determinants of spatial heterogeneity across the GKE. These patterns underscore the importance of continued anti-poaching patrols and habitat conservation in maintaining viable wildlife populations, including for serval (Bohm & Hofer, 2018; Lindsey et al., 2014; Ramesh & Downs, 2013; Thiel, 2019; Watson et al., 2015).

Anthropogenic pressures, notably unregulated burning and agricultural encroachment, are generally greater in the GMAs (Namukonde et al., 2017; Namukonde et al., 2023; Watson et al., 2015). Of interest though, the trends in serval densities parallel those observed in lion populations within the same areas (Strampelli et al., in review), suggesting that large-scale habitat disturbances are affecting multiple trophic levels. Although densities were only marginally higher in the KNP,

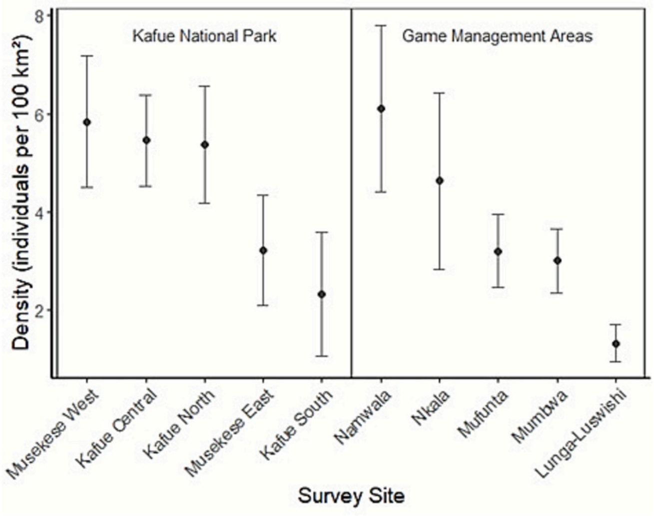

Fig. 2. Grid-level serval density estimates (individuals per 100 km^2) from SECR models for Kafue National Park and Game Management Areas. Error bars represent standard errors.

Table 2
SECR parameter estimates and population metrics for each grid: detection probability at centre (g_0), movement scale (σ), serval density (individuals per 100 km^2), number of identified individuals, recapture rate, and mean detections per individual. ^{a}Recapture rate = proportion of individuals detected ≥ twice.

Sites	Individuals recorded	Recapture rate^a	Average number of detections per individual	Best-fit Model	g0 (Estimate ± SE)	σ (Estimate ± SE)	Density (ind/100 km^2) (Estimate ± SE)
Kafue Central	33	60.6%	4.09	secr.road	0.0389 ± 0.0046	1904.675 ± 96.32	5.46 ± 0.93
Kafue South	25	4.0%	1.40	secr.road	0.0250 ± 0.0090	649.684 ± 163.31	2.32 ± 1.26
Kafue North	23	30.4%	2.87	secr.road	0.0449 ± 0.0103	1306.505 ± 110.22	5.37 ± 1.19
Musekese East	14	21.4%	1.5	secr.0	0.0103 ± 0.0051	2058.846 ± 384.45	3.21 ± 1.12
Musekese West	25	44.0%	2.04	secr.road	0.0125 ± 0.0036	2160.757 ± 248.39	5.84 ± 1.35
Lunga-Luswishi	15	33.3%	2.86	secr.0	0.0128 ± 0.0038	3622.621 ± 430.46	1.32 ± 0.38
Mufunta	21	47.6%	2.76	secr.0	0.0192 ± 0.0043	2212.508 ± 200.45	3.20 ± 0.74
Mulobezi	5	20.0%	2.40	NA	NA	NA	NA
Mumbwa	24	41.7%	2.70	secr.0	0.0111 ± 0.0024	3342.504 ± 326.08	3.00 ± 0.65
Namwala	17	35.3%	2.06	secr.0	0.0085 ± 0.0027	2435.229 ± 360.46	6.11 ± 1.70
Nkala	10	30.0%	1.8	secr.0	0.0150 ± 0.0070	1506.555 ± 315.77	4.63 ± 1.80

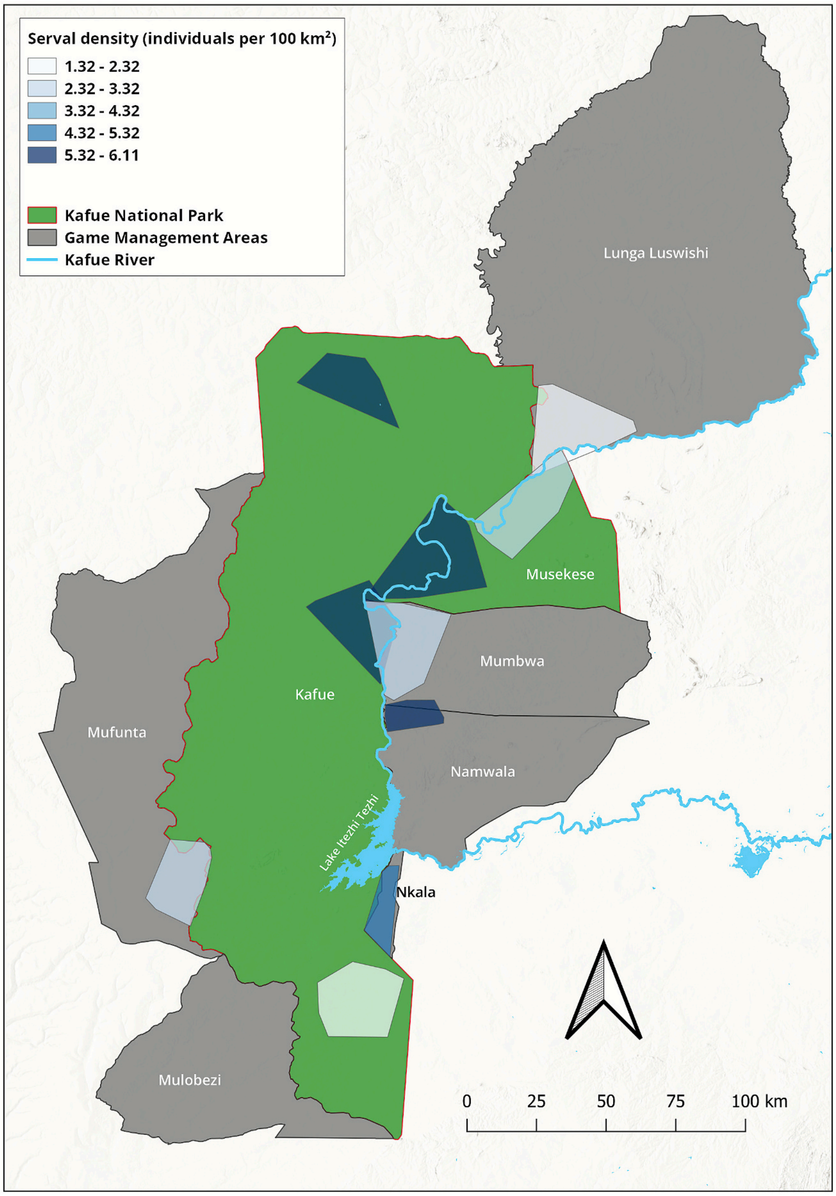

Fig. 3. Spatial distribution of SECR-derived serval density estimates (individuals per 100 km^2) across surveyed grids in Kafue National Park and Game Management Areas. Density estimates are shown as convex hull polygons representing the spatial extent of each camera-trap grid, coloured by estimated serval density.

Table 3
Akaike's Information Criterion corrected (AICc) values for SECR model comparisons (null vs road-covariate model) for grids where both models converged. Lower AICc indicates better model support.

Sites	secr.0	secr.road
Kafue Central	548.185	530.764
Kafue South	145.08	136.44
Kafue North	303.720	290.828
Musekese East	110.673	114.421
Musekese West	240.796	239.714
Mumbwa	318.943	322.561

this trend aligns with the ecological benefits of intact habitat and effective protection. While SECR provides a robust framework for estimating densities, interpretation of small-scale spatial variation should be approached cautiously given the limited number of grids and detections per site.

Expanding anthropogenic expansion are likely to further disrupt habitat connectivity across the GKE. Previous research has cautioned that if current human encroachment trends continue, Zambia's Protected Area Networks could fragment into isolated pockets, exacerbating human edge effects and further threatening wide-ranging species (Watson et al., 2015). Serval associate with wetlands (Ramesh and Downs, 2013), and will likely be impacted if natural grassland and wetlands are lost in the GKE.

The presence of interspecific competitors and apex predators in the GKE has the potential to influence serval densities through competitive dynamics and predation risk (Hoeks et al., 2020; Ripple et al., 2014; Ritchie & Johnson, 2009). Given the comparable range of density estimates between KNP and the GMAs, however, there is no clear evidence that such interactions differ markedly across management zones. Within the GKE, the benefits of a well-protected and connected environment appear to be more crucial for stabilising serval populations than the potentially negative effects associated with higher densities of larger predators (Hoeks et al., 2020; Ritchie & Johnson, 2009).

Although we cannot know from our data the key drivers of serval densities in the GKE, we note the variation of serval densities in past studies across Africa. For example, in Tanzania's Ruaha-Rungwa landscape, serval densities of 5.56 individuals per 100 km^2 in less disturbed areas were reported (Hardouin et al., 2021), although on farmlands in South Africa, serval densities were as high as 6.5 to 7.6 individuals per 100 km^2 (Ramesh and Downs, 2013). Notably Loock et al (2018) observed serval densities at 76.20–101.21 individuals per 100 km^2 in an industrialised site in Secunda in South Africa. Those authors attributed high serval densities to an absence of large predators and mentioned the availability of prey. It may be that serval can indeed adapt to farmlands where prey densities are high, and competition is reduced. It should be said though that snaring and unregulated burning were not likely prevalent on the South African sites recorded in Ramesh and Downs (2013) and Loock et al (2018).

The broadly comparable densities recorded across management zones highlight the importance of maintaining current protection and habitat management efforts throughout the Greater Kafue Ecosystem. Effective measures within KNP—such as habitat preservation, anti-poaching, and anti-encroachment patrols—remain crucial for sustaining serval populations, while similar levels of management and enforcement in the GMAs could further support population resilience (Lindsey et al., 2014; Watson et al., 2015).

Minor differences in serval density among GMA sites likely reflect variation in the intensity of human disturbance, such as burning and agricultural encroachment (Namukonde et al., 2017; Namukonde et al., 2023; Watson et al., 2015), rather than broader ecological instability. Notably, an estimated 20,000 km^2 of natural habitat in the Game Management Areas surrounding the GKE has been lost to agricultural expansion (Hansen et al., 2013). To address these challenges, conservation efforts should focus on mitigating habitat degradation by enforcing stricter land-use regulations and promoting sustainable agricultural practices. Enhancing community-based conservation programmes may empower local populations to protect natural resources whilst increasing their socio-economic standing, thus fostering a sustainable coexistence between humans and wildlife (Dietz et al., 2023; Lindsey et al., 2014; McKee et al., 2004).

The application of SECR models in this study effectively estimated serval densities across a range of habitats and management strategies, thus showing this approach's effectiveness in providing robust density estimates for servals, even when this species is not the primary focus of the survey (Hardouin et al., 2021; Rich et al., 2019; Strampelli et al., 2022).

Our findings thus provide further evidence that data collected through surveys aimed primarily at estimating large carnivore densities in African settings can also be used to effectively monitor serval populations (Hardouin et al., 2021). Density estimation was successful at all sites except one, likely due to insufficient serval capture numbers rather than survey design limitations. This method leverages existing camera trap data, minimising resource expenditure while broadening the scope of wildlife monitoring (Amburgey et al., 2021; Efford, 2011; Rich et al., 2017; Sollmann, 2018). The survey design, which involved placing camera traps along roads and game trails to detect large carnivores, proved equally effective for servals. The secr.road model ranking highly shows that a study design targeting roads, as is often the case for large carnivores, is also suitable for serval (Hardouin et al., 2021; Thiel, 2011, 2019; Webster et al., 2021). This offers a cost-effective monitoring solution for conservation managers with limited resources.

The study's findings highlight several avenues for future research to enhance understanding of serval ecology in the GKE. Prey availability is a crucial factor that warrants detailed examination. Future studies should focus on quantifying the abundance and distribution of serval prey species across diverse habitats, considering seasonal fluctuations which may impact serval foraging behaviour and habitat use (Ramesh & Downs, 2013, 2015). Additionally, the impact of habitat fragmentation on serval movement should be explored to identify critical corridors that maintain connectivity (Henschel et al., 2020; Herrmann et al., 2008). Examining the interactions between servals and other predators can provide insights into the competitive dynamics that shape serval populations (Marneweck et al., 2021; McKee et al., 2004; Ripple et al., 2014; Ritchie & Johnson, 2009).

Furthermore, while the method employed was effective in estimating serval population density, integrating environmental covariates into SECR models could further refine understanding of habitat preferences and factors influencing serval distribution, leading to more accurate density estimates (Hardouin et al., 2021; Searle et al., 2021; Sollmann et al., 2012; Strampelli et al., 2020).

Long-term monitoring of serval populations is crucial for evaluating the effectiveness of conservation interventions and understanding how environmental changes influence serval ecology (Nichols & Williams, 2006; Parmesan, 2006). Establishing longitudinal studies that track population trends over time will provide critical data for adaptive management strategies (Lindenmayer & Likens, 2010). Furthermore, investigating bycatch data of servals from previous years could provide valuable insights into population trends from the past to present day. Predictive models can simulate future environmental scenarios, guiding proactive conservation planning to ensure the resilience of serval populations and their habitats (Guisan & Thuiller, 2007; Thorn et al., 2011).

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CRediT authorship contribution statement

Kyle Marshall: Writing – review & editing, Writing – original draft, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Lochran W. Traill:** Writing – review & editing, Supervision. **Kim Young-Overton:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Xia Stevens:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Will Donald:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Davies Bubala:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Lucky Mulenga:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Mutakatala Kaponde:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Blessing Samalesu:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Edwin Phiri:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Andrew B. Mulenga:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Twakundine Simpamba:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Adrian Kaluka:** Resources, Project administration, Investigation, Funding acquisition, Data curation. **Paolo Strampelli:** Writing – review & editing, Supervision, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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