Check for updates

African Journal of Ecology

WILEY

RESEARCH ARTICLE

Effects of Water Impoundments on the Distribution and Activity of Elephants in the Southern Kruger National Park

B. B. Twala[1] | S. P. Ngcobo[1] | R. A. McCleery[2] | T. Dalu[3] | C. Dutton[4] | S. M. Ferreria[5,6] | L. Munyai[3,7] | A. Subalusky[4] | M. D. Voysey[8] | C. Coetsee[5,9] | B. Wigley[5,9,10] | D. M. Parker[1]

[1]UMP-Oppenheimer Research Chair in Biodiversity Conservation, School of Biology and Environmental Sciences, University of Mpumalanga, Mbombela, South Africa | [2]Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida, USA | [3]Aquatic Systems Research Group, School of Biology and Environmental Sciences, University of Mpumalanga, Mbombela, South Africa | [4]Department of Biology, University of Florida, Gainesville, Florida, USA | [5]Scientific Services, SANParks, Skukuza, South Africa | [6]Department of Nature Conservation and Marine Science, Cape Peninsula University of Technology, Cape Town, South Africa | [7]Aquatic Systems Research Group, Department of Water and Sanitation, University of Limpopo, Polokwane, South Africa | [8]Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts, USA | [9]School of Natural Resource Management, Nelson Mandela University, George, South Africa | [10]Plant Ecology, University of Bayreuth, Bayreuth, Germany

Correspondence: S. P. Ngcobo (sam.p.ngcobo@gmail.com)

Received: 27 November 2025 | **Revised:** 14 January 2026 | **Accepted:** 20 January 2026

Keywords: artificial dams | camera traps | diel activity patterns | ecological management | elephants | habitat degradation | Kruger National Park (KNP) | seasonal distribution

ABSTRACT

Artificial water impoundments (reservoirs) in African savannahs can significantly influence the distribution and behaviour of water-dependent species, particularly elephants (*Loxodonta africana*). Our study investigates the impact of such water sources on the spatio-temporal distribution and activity patterns of elephants in the southern Kruger National Park, South Africa. We conducted a paired catchment camera trap study between 2023 and 2024, comparing 11 dammed and 11 undammed seasonal drainages over two seasons (wet and dry). Our aim was to evaluate how water impoundments affected elephant space use, activity levels, and their diel behaviour. Our findings reveal that water impoundments have a strong influence on elephant activity, particularly during the dry season when elephants frequently clustered around these water sources. Moreover, the interaction between season and proximity to water played a key role in shaping elephant activity patterns. Our study highlights the need to consider the ecological implications of water provisioning strategies in wildlife management. We recommend promoting landscape heterogeneity and minimising potential adverse effects on vegetation and other species.

1 | Introduction

The distribution and behaviour of large herbivores in African savannahs are shaped by the complex interplay of vegetation, water availability and temperature, with both biotic and abiotic factors influencing their spatio-temporal patterns (Redfern et al. 2003; Valeix et al. 2011; Chamaillé-Jammes et al. 2016; du Plessis et al. 2021; Mlambo et al. 2024). For example, elephant (*Loxodonta africana*) movements are highly complex and exhibit strong seasonal patterns, driven by factors, such as water availability, food resources and overall climatic conditions (Wato et al. 2018; Beirne et al. 2020; du Plessis et al. 2021; Mlambo et al. 2024). For elephants, water availability and season are particularly important in determining their use of the landscape (Dunkin et al. 2013). During the dry season (May–August), elephants and other large herbivores often experience nutritional stress due to declines in forage quality and quantity (Ruggiero 1992; Woolley et al. 2009; Sach et al. 2019). At the same time, artificial water impoundments may constrain the natural movement of such water-dependent species

© 2026 John Wiley & Sons Ltd.

(Thrash and Derry 1999; Redfern et al. 2003; Smit et al. 2007). Elevated temperatures, particularly during the dry season, increase thermoregulatory demands, making elephants more reliant on nearby water sources for cooling (Dunkin et al. 2013; Mole et al. 2016; Rozen-Rechels et al. 2020). Together, these pressures drive elephants to cluster around permanent water sources, particularly artificial reservoirs, during the dry season.

Elephants typically gather in higher densities around water sources, where they can better cope with significant water loss through cutaneous evaporation and respiration, particularly during hot periods (Dunkin et al. 2013; Pontzer et al. 2020). To manage body temperature, elephants engage in water-related behaviours such as splashing and mud bathing, which help them regulate heat and maintain thermal balance (Dunkin et al. 2013; Mole et al. 2016; Thaker et al. 2019). These behaviours occupy approximately 10% of an elephant's daily routine (Mole et al. 2016) and play a crucial role in heat loss. Additionally, non-evaporative mechanisms, such as seeking out shade and using their large ears to disperse heat, further support thermoregulation (Phillips and Heath 1992; Dunkin et al. 2013; Mole et al. 2018; Wijayanto et al. 2023).

In southern Africa, the scarcity of perennial water sources compels elephants and other large herbivores to undertake seasonal migrations (albeit partial) between water and forage areas (Chamaillé-Jammes et al. 2013; Tshipa et al. 2017; Purdon et al. 2018; Bennitt et al. 2022; Sianga et al. 2024). These movements can allow the vegetation adequate time to recover following intensive use by elephants (Owen-Smith 1996; Skarpe et al. 2004; Purdon et al. 2018). However, the widespread creation of artificial water impoundments (hereafter, reservoirs) has disrupted these natural movement patterns in many areas, intensifying elephant and other herbivore activity near artificial water sources (Shannon et al. 2009; Sutherland et al. 2018). Consequently, piospheres (i.e., regions where vegetation pressure increases due to the concentration of herbivores) can be created (Wilson et al. 2021). Piospheres routinely lead to vegetation degradation and a subsequent reduction of biodiversity and ecosystem heterogeneity (Van Langevelde et al. 2017; Mpalo et al. 2024).

Historically, Kruger National Park (KNP) implemented an extensive water-stabilisation programme that created over 300 artificial boreholes, 50 earth reservoirs, and several dammed rivers between the 1930s and 1980s to ensure a reliable year-round network of water throughout the park (Smit et al. 2007). The dense network of water led to a decline in herbivore diversity and changes in forage composition, which resulted in a major policy shift in the 1990s (Thrash et al. 1993; Smit et al. 2007). Instead of stabilising low-density antelope populations, the water-stabilisation programme had unintended negative impacts on rare species such as roan antelope (*Hippotragus equines*), sable antelope (*Hippotragus niger*) and tsessebe (*Damaliscus lunatus*) by enabling common, water-dependent grazers like zebra (*Equus burchellii*) and wildebeest (*Connochaetes taurinus*) and their predators to expand into formerly dry refugia (Smit et al. 2007). This shift intensified competition for forage and predation pressure on these selective grazers, ultimately contributing to their population declines during drought periods (Grant et al. 2002; Smit et al. 2007). Thus, when reservoirs are poorly or haphazardly distributed, they can result in intensive use of certain areas, heighten thermal stress and impose additional ecological pressures (e.g., vegetation degradation, herbivore community disruption) on the surrounding environment (Redfern et al. 2003; Mole et al. 2018; Mpalo et al. 2024).

Despite growing interests in the ecological implications of artificial water impoundments, few studies have explicitly examined how they influence elephant movement and activity patterns in relation to seasonality (Loarie et al. 2009; Shrader et al. 2010; Sutherland et al. 2018; Huang et al. 2022). Previous research has largely focused on natural water-driven migration patterns (Owen-Smith 1996; Purdon and van Aarde 2017; Van Langevelde et al. 2017), highlighting elephants' long-distance movements and dynamic use of forage across seasons. However, less attention has been paid to how individual reservoirs influence elephant space use and daily activity dynamics. For example, Loarie et al. (2009) observed that artificial water sources can shift elephant populations toward previously underutilised areas, particularly during dry periods. Similarly, Bohrer et al. (2014) demonstrated that the presence of artificial water impoundments in Kenya altered elephant foraging behaviour, allowing them to expand into drier regions during the dry season. Here, we examine how individual reservoirs alter elephant activity compared to adjacent undammed drainages, which is crucial for our understanding of the direct effects of reservoir additions to landscapes, and the impacts that drainage removal—an ongoing management intervention in KNP—might have on ecological processes.

We applied a paired-catchment camera-trap design, comparing reservoir and non-reservoir sites across a 2.25 km gradient along three random transects at each of 22 sites in the southern KNP, South Africa. This approach allowed us to disentangle the direct effects of water availability, distance to water, and seasonality on elephant spatial distribution and diel activity patterns, providing a nuanced understanding of how reservoir provisioning shapes elephant landscape use. Our study seeks to investigate the spatio-temporal effects of reservoirs on elephant distribution and activity in the southern KNP. Specifically, we addressed the following questions: (1) How does reservoir presence influence elephant spatial distribution across the landscape? and (2) How does the interaction between seasonality and water availability shape elephant daily (diel) activity patterns? We hypothesised that, during the dry season, elephants would concentrate their activity near reservoirs and reduce movement distances, driven by their increased reliance on these water sources for hydration and thermoregulation. In contrast, during the wet season, we expected elephants to disperse more widely as natural water sources are more readily available.

2 | Materials and Methods

2.1 | Study Area

Our study was conducted in the southern region of KNP, in the eastern Lowveld of South Africa (Figure 1), a 19,633 km^2 protected area located between 22°32′–25°32′ S

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

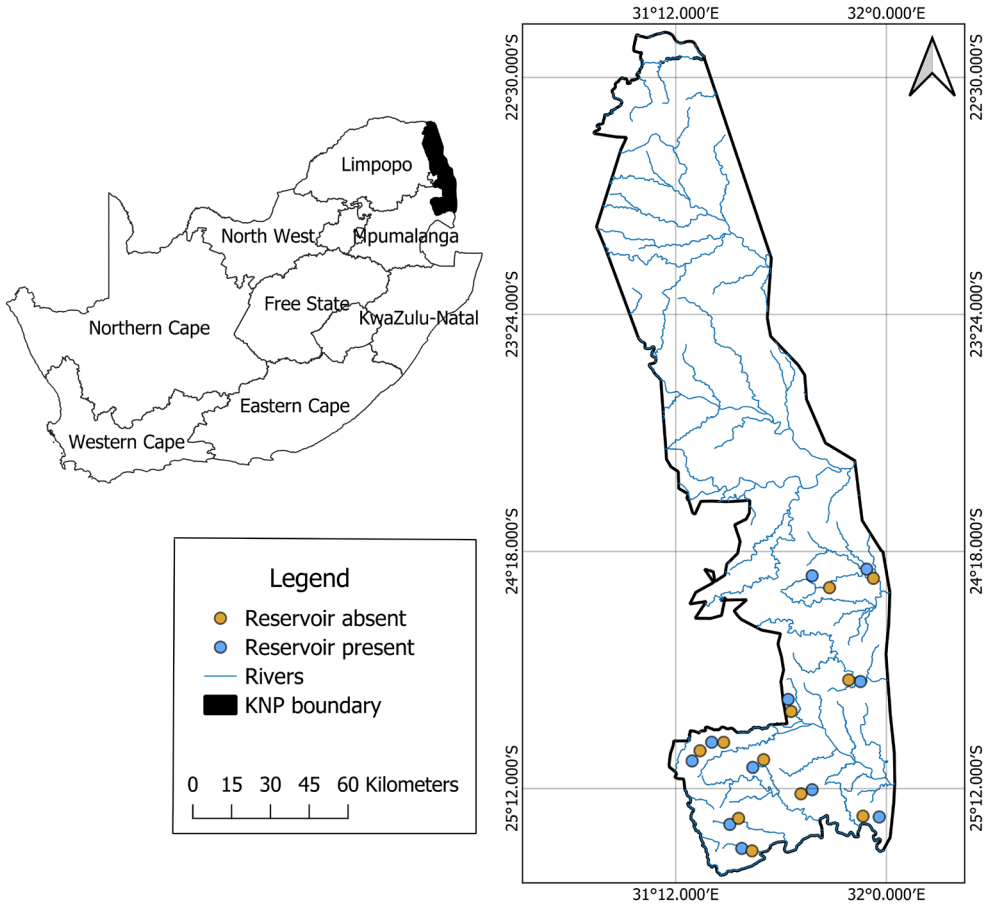

FIGURE 1 | Map showing the spatial distribution of 11 paired sampling sites ($n = 22$) in the southern section of Kruger National Park, South Africa. Each pair comprises an artificial water impoundment (reservoir) and a nearby (< 6 km) site situated along a comparable undammed natural drainage.

and 30°50′–32°02′ E, bordering Mozambique and Zimbabwe (Sutherland et al. 2018). The KNP is renowned for its exceptional biodiversity, hosting at least 20 large mammal herbivore species (LMH, > 20 kg) and populations of megaherbivores (> 1000 kg), including elephants, common hippopotamus (*Hippopotamus amphibius*), white rhinoceros (*Ceratotherium simum*), black rhinoceros (*Diceros bicornis minor*) and southern giraffe (*Giraffa giraffa*), which vary widely in body size and dietary preferences. The KNP has, at the course scale, been divided into 35 unique landscapes, shaped by underlying geology, with Karoo sediments separating granite and gneiss formations. In the southern region, granitic soils support woodlands dominated by *Combretum* and *Senegalia* species, while the basaltic soils are home to *Sclerocarya caffra* and *Senegalia nigrescens* (Ferreira et al. 2018). There is a natural gradient of soils from less fertile granitic soils in the west to more fertile basaltic soils in the east.

The KNP experiences a semi-arid subtropical climate, with hot and rainy summers (September–March) and cooler, dry winters (June–October), receiving an average annual rainfall of 500 to 700 mm (Venter et al. 2003; Hijmans et al. 2005; Smit et al. 2007). In the southern region, ephemeral water sources often dry up during the winter months, leaving only perennial rivers (i.e., Sabie and Crocodile) and artificial waterbodies (waterholes and reservoirs) available for use by wildlife (Thrash 1998; Smit 2013; Sutherland et al. 2018). With three perennial rivers, most of the southern region of KNP lies within 6 km of a natural water source during an average year (Smit and Grant 2009). Much of the artificial water provision infrastructure was established in the 1960s to increase access to grazers (e.g., zebra, wildebeest and Cape buffalo (*Syncerus caffer*) whose historic migratory routes were blocked by fencing (Owen-Smith 1996; Smit et al. 2007)). Although approximately half of these reservoirs were later closed due to concerns over elephant congregation and negative effects that led to the decline of rare antelope species, there are still at least 40 active reservoirs in southern KNP (Sutherland et al. 2018; Smit et al. 2020).

Within this broader region, our study was conducted using 11 paired catchments in seasonal drainages ($n = 22$ in total). Each pair included one catchment with a human-made reservoir or impoundment providing permanent water, and a matching undammed catchment in a similar drainage (Figure 1). The sites were chosen to cover the range of reservoir sizes throughout the southern section of KNP. We selected reservoirs with differing levels of artificial surface water (ASW) across both granitic and basaltic soils, located at least 3 km from a perennial river. Wet season sampling began on the 10th October 2023, following the rainy season's onset on 20th September (as defined by Wigley et al. 2024). Dry season sampling started on the 15th May 2024, after 40 days of negligible (< 10 mm) rainfall (Figure 1).

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

2.2 | Data Collection

Data were collected during the wet season (October to November) of 2023 and dry season (May to July) of 2024. Camera traps (Browning, Strike Force and Dark Ops) were deployed along three transects, placed at distances of 50, 250, 500, 1000 and 2250 m from both reservoir and non-reservoir sites. Cameras were housed in protective metal casings at a standard height of 70 cm, and any vegetation within a 15-m radius of the detection zone was cleared. Cameras were operated for 10–14 days per location, with malfunctioning or disturbed units being noted upon retrieval. To maximise animal detections, camera traps were positioned within 5 m of the designated sampling point (i.e., the central point of each survey location) and oriented toward a focus point approximately 4 m away, where animal activity was expected to occur (Espartosa et al. 2011). A total of 15 camera traps were placed along each transect, resulting in 330 camera stations (22 sites sampled seasonally: 11 reservoirs and 11 non-reservoirs). The cameras were set to capture three images per burst with a 1-min recovery time between bursts, optimising battery life and memory capacity, as recommended by Sutherland et al. (2018). Infrared flashes were used for night-time captures, and each image recorded the time and date of the capture. Total camera trapping effort amounted to 3120 camera days in the wet season (2023) and 3460 in the dry season (2024).

2.3 | Data Analysis

Species identification and image classification were performed using the Traptagger platform (Wildeye Conservation). Traptagger was also used to organise and analyse the metadata, including the date, time, location and number of elephants detected (Verschueren et al. 2024). The camTrapR package (Niedballa et al. 2016) was used to convert image data into activity metrics, estimating the time elephants spent at each location (Figure 2). Independent detections were defined as the maximum number of elephants detected within a 60-min window before a new detection was recorded (Burton et al. 2015).

Generalised Linear Mixed Models (GLMM) were employed, using the glmmTMB package, to analyse our data (Bolker 2019). These models were used to assess whether elephant spatial distribution (defined as the maximum number of elephants detected per 1-h at each camera station) could be explained by season (wet vs. dry), site type (reservoir vs. non-reservoir as a categorical variable), distance from the nearest reservoir (continuous in metres, log-transformed), and the interaction between season and site type, and season and distance (Nakagawa and Schielzeth 2013; Sutherland et al. 2018). A mixed-effects model was applied to account for fixed effects (site type) and the random effect of site pair, as reservoir and non-reservoir sites were sampled in paired locations within the same area. We used pair identity as a random effect to isolate the influence of reservoirs on elephant activity and to account for factors that might influence the difference in activity between paired sites (e.g., soils, climate, distance for other water sources, reservoir size). The data were fitted to a negative binomial distribution, and an offset term was used to adjust for variations in camera deployment time across sites.

Model selection was based on the Akaike Information Criterion with a correction for small sample sizes (AICc) (Burnham and Anderson 2002), and the most parsimonious model was selected (Table 1). Distance to reservoirs was log-transformed in all models due to the uneven distribution of distances (ranging from 50 to 2250 m). The model with the lowest AICc was considered the best fit for explaining elephant distribution patterns.

To evaluate the diel activity patterns of elephants, kernel density estimation was used on the time-of-detection data (expressed in hours after sunrise) using the density() function in R. This method was chosen for its ability to estimate the probability density function, allowing for a more detailed analysis of the distribution of elephant activity times compared to conventional histograms (Węglarczyk 2018). Separate density curves were generated for detections near reservoirs and away from them for both the wet and dry seasons.

Kolmogorov–Smirnov (KS) tests were conducted to compare the overall activity of elephants between the wet and dry seasons. To assess the degree of temporal overlap between the two seasons, we quantified activity overlap using the coefficient of overlap (Dhat1), estimated with the overlap package in R (Meredith and Ridout 2014). Overlap values range from 0 (no overlap) to 1 (complete overlap). We generated 95% confidence intervals using 1000 bootstrap iterations to quantify uncertainty around overlap

FIGURE 2 | Elephants captured on camera trap footage at a sampling site in the southern section of Kruger National Park, South Africa, with a reservoir present.

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 | Candidate models predicting elephant spatial distribution in southern Kruger National Park, South Africa, ranked by AICc values. Models include combinations of season, site type (reservoir vs. non-reservoir), and distance from the nearest reservoir (log-transformed), as well as their interactions.

Model	df	Log likelihood	AICc	Delta AICc (ΔAICc)
Season * Distance + Distance * Reservoir	8	−1768.672	3553.6	0
Season * Reservoir + Distance * Reservoir	8	−1769.876	3556	2.41
Distance * Reservoir + Season	7	−1771.431	3557	3.46
Season * Distance + Reservoir	7	−1773.748	3561.7	8.1
Season * Reservoir + Distance	7	−1773.985	3562.2	8.57
Season + Reservoir + Distance	6	−1775.931	3564	10.42
Null	3	−1787.743	3581.5	27.94

estimates. All statistical analyses were conducted in R version 4.4.1 (R Core Team 2023).

3 | Results

3.1 | Effects of Reservoirs on Elephant Activity

The individual effects of season and distance did not significantly influence elephant distribution (Table 2). However, distance had a marginally significant negative effect on elephant presence, suggesting that elephants were less likely to be found farther from reservoirs. In contrast, the presence of reservoirs significantly increased elephant presence in the greater catchment, with elephants more frequently detected at reservoirs than in adjacent undammed sites, in both the wet and dry seasons (Table 2). A significant interaction between season and distance to reservoirs revealed that during the wet season, the negative effect of distance was weaker, indicating that elephants ranged farther from water sources when water was more freely available in the landscape. Additionally, a significant negative interaction between distance to water and reservoir presence (Table 2) showed that elephants were more concentrated near water at reservoirs, especially during the dry season, compared to adjacent undammed watersheds. Overall, elephant spatial distribution was most strongly associated with the presence of reservoirs and proximity to water, with seasonal variations modulating these effects to some degree (Figure 3).

3.2 | Diel Elephant Activity Patterns

During the wet season, elephants at reservoirs (blue line) showed peak activity earlier in the day (6–10 h after sunrise), whereas those at non-reservoir sites (orange line) were most active later (8–11 h after sunrise) (Figure 4A). In the dry season, this temporal pattern switched, with elephants at reservoirs maintaining higher activity levels later in the day (5–15 h after sunrise), while those at non-reservoir sites were primarily active earlier (5–8 h after sunrise) (Figure 4B). These seasonal shifts were statistically significant; however, diel activity patterns remained largely overlapping between seasons, with Dhat1 values of 0.885 and 0.899, respectively (Table 3).

TABLE 2 | Conditional GLMM results (β estimates, SE, z values and p-values) assessing the effects of season, distance to water, reservoir presence and their interactions on elephant detections in southern Kruger National Park, South Africa.

Conditional model	Estimate	Std. error	z	p
Intercept	**−7.576**	**1.197**	**−6.330**	**<0.001**
Season	−1.885	1.320	−1.427	0.153
Distance	−0.336	0.176	−1.912	0.056
Reservoir	**4.305**	**1.183**	**3.640**	**<0.001**
Season: Distance	**0.453**	**0.201**	**2.247**	**0.025**
Distance: Reservoir	**−0.597**	**0.189**	**−3.163**	**0.002**

Note: Statistically significant predictors ($p < 0.05$) are shown in bold.

4 | Discussion

Our findings reveal that reservoirs have a pronounced effect on elephant spatial distribution and activity patterns, especially during the dry season when surface water availability becomes scarce. Elephants tended to concentrate around these reservoirs, often extending their activity into the later hours of the day. This shift likely reflects both their dependence on water and behavioural adaptations to manage thermal stress (Shannon et al. 2009; Mole et al. 2016). The changes in diel activity also suggest that the presence of reservoirs may support continued elephant activity during the hottest parts of the day by providing a reliable water source (Mole et al. 2016). Additionally, the strong interaction between season and proximity to reservoirs reveals that elephants preferentially use areas near artificial water sources when natural water is limited. This behaviour aligns with previous studies showing that elephants tend to congregate around dependable water sources during dry periods (Chamaillé-Jammes et al. 2007; Loarie et al. 2009; Purdon and van Aarde 2017). Taken together, these findings highlight the ecological importance of artificial water sources in shaping both the spatial and temporal patterns of elephant behaviour, emphasising their relevance for developing effective savannah management strategies (Bucciarelli et al. 2024).

The spatial extent of elephant response to water was moderated by season and annual water availability. During the dry season, elephants concentrated their activity within 0–500 m of reservoirs, with detections declining sharply beyond 1000 m. In contrast, during the wet season, elephant activity was more evenly

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

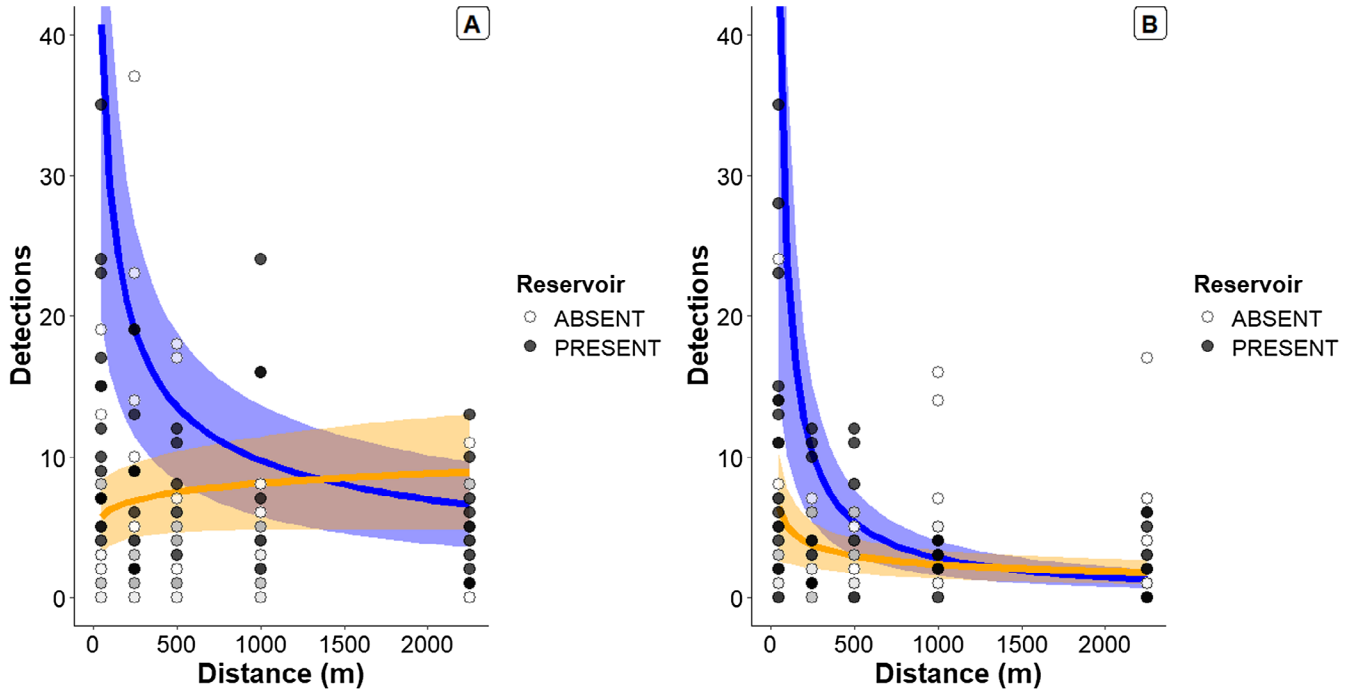

FIGURE 3 | Variation in elephant detections/spatial distribution at sites with reservoirs (filled circles) and without reservoirs (open circles) during the (A) wet and (B) dry seasons. Detections represent the maximum number of elephants recorded in 1-h intervals.

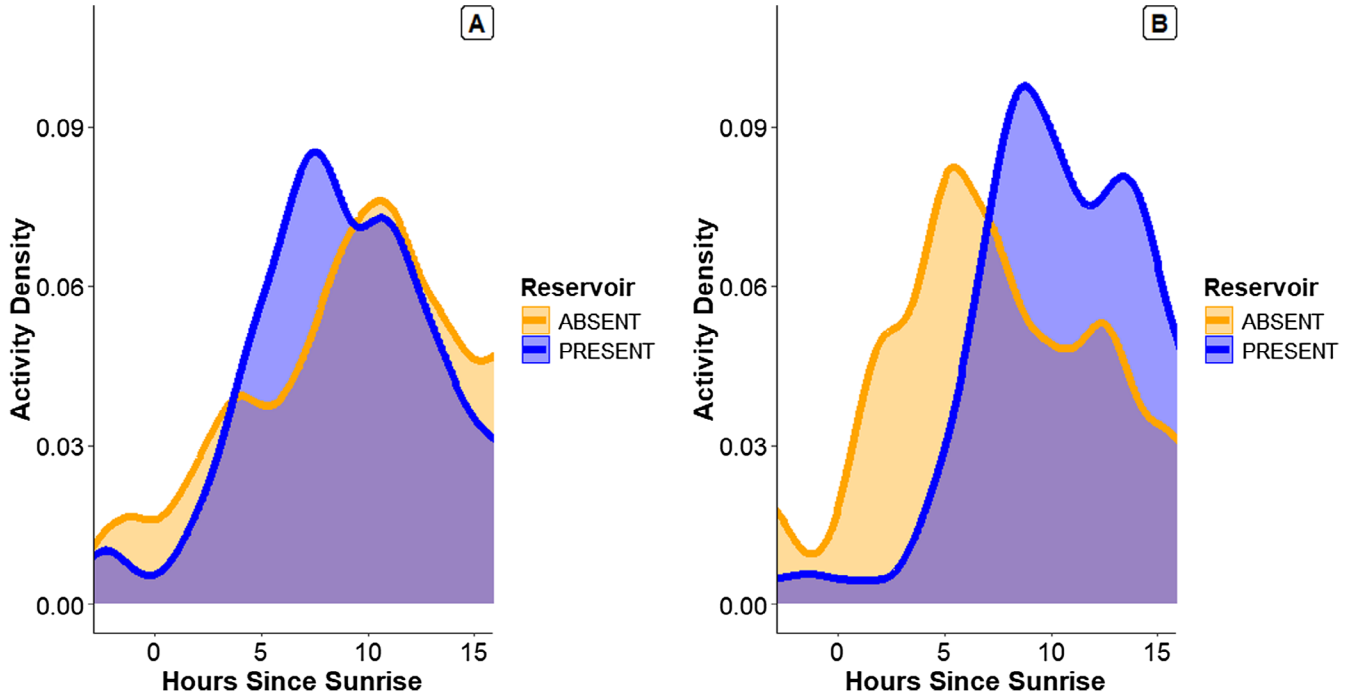

FIGURE 4 | Comparison of diel elephant activity patterns at sites with and without reservoirs during the (A) wet and (B) dry seasons, accounting for seasonal changes in light availability (sunrise/sunset). The *y*-axis shows kernel density estimates of detection times, representing relative activity levels throughout the day (hours since sunrise).

distributed, extending up to 2000 m from reservoirs. Their spatial response contracted to within 500 m during dry periods and expanded to 1500 m during wetter conditions. Thus, elephant activity was strongly associated with reservoir presence and distance to water. Although this variation in response of elephants across our paired sites may have been due to soils, climate and distance from other water sources, we found no indication that the reservoir size influenced elephant activity. After we showed statistically that there was no relationship with reservoir size, we included reservoir presence vs. absence as a fixed term in our models. This result was not unexpected, given that elephants in KNP have been shown to prioritise water quality over quantity (Ndlovu et al. 2018), even though larger reservoirs may accommodate more individuals at a single point.

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 3 | Statistical comparisons of diel elephant activity patterns in the wet and dry seasons in Kruger National Park (2023–2024), showing overlap estimates with 95% confidence intervals (CI).

Season	Dhat1	CI_Lower	CI_Upper	KS_*p*_value
Wet	0.885	0.884	0.931	< 0.001
Dry	0.899	0.881	0.928	< 0.001

Our results indicate that reservoirs serve as key focal points for elephants, particularly during the dry season. The concentration of elephants around these water sources is likely driven by their dual need for hydration and thermoregulation, which is especially critical given their high metabolic demands (Dunkin et al. 2013; Mole et al. 2016). Previous research has shown that reservoirs can constrain elephant movement and contribute to habitat degradation through overuse (Shannon et al. 2009; Landman et al. 2012; Wilson et al. 2021). Our study further corroborates these findings, showing that elephants are more likely to cluster around reservoirs during the dry season, as naturally available water becomes increasingly scarce. Additionally, the observed increase in daytime activity at these impoundments underscores the reliance of elephants on these water points, likely for heat dissipation (Dunkin et al. 2013; Thaker et al. 2019).

The diel activity patterns observed in our study support the hypothesis that elephants adjust their behaviour in response to both ecological and physiological pressures. Consistent with Polansky et al. (2013), our findings suggest that elephants optimise their activity to minimise thermal stress and reduce energy expenditure. Notably, elevated activity levels at reservoirs during the hottest parts of the day indicate that these sites likely provide critical thermoregulatory benefits (Smith et al. 2024). Although diel activity patterns showed substantial overlap between wet and dry seasons (as reflected by the Dhat1 values), suggesting overall consistency, elephants appeared to fine-tune their behaviour in line with environmental conditions. Similarly, Loarie et al. (2009) observed comparable temporal shifts, with elephants at reservoirs showing peak activity in mid-morning and late afternoon during the dry season, while those at non-reservoir sites were most active near sunrise. In arid regions, elephants often adopt a crepuscular pattern, travelling more at night during the dry season than in the wet season to avoid daytime heat (Loarie et al. 2009). These behavioural adjustments underscore the role of water availability in shaping temporal activity. Overall, our results align with the findings of Purdon and van Aarde (2017), who showed that in KNP the distribution of water impoundments means that elephants are almost always within proximity to permanent water. The influence that water impoundments have on elephant activity in the dry season is profound (Viljoen 1989; Smit et al. 2007; De Beer and van Aarde 2008; Thomas et al. 2012).

4.1 | Implications for Conservation and Management

From a conservation and management perspective, our findings emphasise the importance of reassessing the role of artificial water impoundments and their distribution within protected areas, such as KNP. The concentration of elephant activity around reservoirs, especially during the dry season, raises concerns about potential habitat degradation and vegetation loss. Intensive use of areas surrounding water sources may lead to overgrazing, vegetation degradation and the formation of piospheres (Wilson et al. 2021). Over time, such piospheres can reduce vegetation heterogeneity and disrupt overall ecosystem structure (Owen-Smith 1996; Brits et al. 2002; Derry 2004; Smit et al. 2007; Loarie et al. 2009; Mpakairi 2019; Abraham et al. 2021; Mpalo et al. 2024). Although approximately half of the reservoirs in KNP were closed between 1994 and 1999 (Smit et al. 2007), at least 40 active reservoirs remain in the southern portion of the park and continue to influence the distribution and behaviour of large herbivores (Sutherland et al. 2018; Smit et al. 2020).

To mitigate these effects, more strategic or rotational water provisioning strategies may be necessary. Such approaches could encourage a more variable distribution of elephants across the landscape, thereby reducing pressure on localised areas and promoting a more heterogeneous environment. This approach is crucial for maintaining biodiversity and enhancing ecosystem resilience. However, we did not explicitly investigate the impacts of reservoir-associated elephant activity on vegetation structure or ecosystem processes, and we therefore recommend that future research test these effects directly.

Future research should build on our findings by incorporating fine-scale analyses of elephant movement and resource selection, alongside long-term monitoring of vegetation. It should also investigate the impacts of this extended elephant footprint around water reservoirs on vegetation structure and other components of floral and faunal biodiversity. Additionally, it is crucial to consider other ecological factors, such as social behaviour and predation risk, to gain a more comprehensive understanding of the drivers shaping elephant distribution and activity patterns. These insights will be vital for developing sustainable management strategies that balance the ecological requirements of elephants with those of other species and the broader ecosystem.

Acknowledgements

This research work was supported by a Fulbright Fellowship, SANParks, the University of Florida International Center, and The University of Mpumalanga. We are grateful to the game guards and technicians that assisted us with the collection of field data. L.M. acknowledges funding from the National Research Foundation Thuthuka grant (TTK230508103682). T.D. acknowledges funding from the National Research Foundation (TTK240409213108).

Funding

This work was supported by Fulbright Fellowship. National Research Foundation (TTK230508103682, TTK240409213108).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

References

Abraham, J. O., E. R. Goldberg, J. Botha, and A. C. Staver. 2021. "Heterogeneity in African Savanna Elephant Distributions and Their Impacts on Trees in Kruger National Park, South Africa." *Ecology and Evolution* 11: 5624–5634. https://doi.org/10.1002/ece3.7465.

Beirne, C., A. C. Meier, G. Brumagin, et al. 2020. "Climatic and Resource Determinants of Forest Elephant Movements." *Frontiers in Ecology and Evolution* 8: 96. https://doi.org/10.3389/fevo.2020.00096.

Bennitt, E., J. Bradley, H. L. Bartlam-Brooks, T. Y. Hubel, and A. M. Wilson. 2022. "Effects of Artificial Water Provision on Migratory Blue Wildebeest and Zebra in the Makgadikgadi Pans Ecosystem, Botswana." *Biological Conservation* 268: 109502. https://doi.org/10.1016/j.biocon.2022.109502.

Bohrer, G., P. S. Beck, S. M. Ngene, A. K. Skidmore, and I. Douglas-Hamilton. 2014. "Elephant Movement Closely Tracks Precipitation-Driven Vegetation Dynamics in a Kenyan Forest-Savanna Landscape." *Movement Ecology* 2: 1–12. https://doi.org/10.1186/2051-3933-2-2.

Bolker, B. 2019. "Getting Started With the glmmTMB Package (Version 9)." CRAN R-Project Vignette.

Brits, J., M. W. Van Rooyen, and N. Van Rooyen. 2002. "Ecological Impact of Large Herbivores on the Woody Vegetation at Selected Watering Points on the Eastern Basaltic Soils in the Kruger National Park." *African Journal of Ecology* 40: 53–60. https://doi.org/10.1046/j.0141-6707.2001.00344.x.

Bucciarelli, J. R., S. L. Pimm, R. M. Huang, et al. 2024. "Local Elephant Movements, Turning Angles, and Water Access Across a Rainfall Gradient in Southern Africa." *Biological Conservation* 296: 110669. https://doi.org/10.1016/j.biocon.2024.110669.

Burnham, K. P., and D. R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. Springer New York.

Burton, A. C., E. Neilson, D. Moreira, et al. 2015. "Wildlife Camera Trapping: A Review and Recommendations for Linking Surveys to Ecological Processes." *Journal of Applied Ecology* 52: 675–685. https://doi.org/10.1111/1365-2664.12432.

Chamaillé-Jammes, S., A. Charbonnel, S. Dray, H. Madzikanda, and H. Fritz. 2016. "Spatial Distribution of a Large Herbivore Community at Waterholes: An Assessment of Its Stability Over Years in Hwange National Park, Zimbabwe." *PLoS One* 11: e0153639. https://doi.org/10.1371/journal.pone.0153639.

Chamaillé-Jammes, S., G. Mtare, E. Makuwe, and H. Fritz. 2013. "African Elephants Adjust Speed in Response to Surface-Water Constraint on Foraging During the Dry-Season." *PLoS One* 8: e59164. https://doi.org/10.1371/journal.pone.0059164.

Chamaillé-Jammes, S., M. Valeix, and H. Fritz. 2007. "Managing Heterogeneity in Elephant Distribution: Interactions Between Elephant Population Density and Surface-Water Availability." *Journal of Applied Ecology* 44: 625–633. https://doi.org/10.1111/j.1365-2664.2007.01300.x.

De Beer, Y., and R. J. van Aarde. 2008. "Do Landscape Heterogeneity and Water Distribution Explain Aspects of Elephant Home Range in Southern Africa's Arid Savannas?" *Journal of Arid Environments* 72: 2017–2025. https://doi.org/10.1016/j.jaridenv.2008.07.002.

Derry, J. F. 2004. "Piospheres in Semi-Arid Rangeland: Consequences of Spatially Constrained Plant-Herbivore Interactions." Doctoral thesis, University of Edinburgh.

du Plessis, K., S. B. Ganswindt, H. Bertschinger, et al. 2021. "Social and Seasonal Factors Contribute to Shifts in Male African Elephant (*Loxodonta africana*) Foraging and Activity Patterns in Kruger National Park, South Africa." *Animals* 11: 3070. https://doi.org/10.3390/ani11113070.

Dunkin, R. C., D. Wilson, N. Way, K. Johnson, and T. M. Williams. 2013. "Climate Influences Thermal Balance and Water Use in African and Asian Elephants: Physiology Can Predict Drivers of Elephant Distribution." *Journal of Experimental Biology* 216: 2939–2952. https://doi.org/10.1242/jeb.080218.

Espartosa, K. D., B. T. Pinotti, and R. Pardini. 2011. "Performance of Camera Trapping and Track Counts for Surveying Large Mammals in Rainforest Remnants." *Biodiversity and Conservation* 20, no. 12: 2815–2829. https://doi.org/10.1007/s10531-011-0110-4.

Ferreira, S. M., C. Greaver, Z. Nhleko, and C. Simms. 2018. "Realization of Poaching Effects on Rhinoceroses in Kruger National Park, South Africa." *African Journal of Wildlife Research* 48: 1–7.

Grant, C. C., T. Davidson, P. J. Funston, and D. J. Pienaar. 2002. "Challenges Faced in the Conservation of Rare Antelope: A Case Study on the Northern Basalt Plains of the Kruger National Park." *Koedoe* 45, no. 2. https://doi.org/10.4102/koedoe.v45i2.26.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis. 2005. "Very High Resolution Interpolated Climate Surfaces for Global Land Areas." *International Journal of Climatology* 25: 1965–1978. https://doi.org/10.1002/joc.1276.

Huang, R. M., R. J. van Aarde, S. L. Pimm, M. J. Chase, and K. Leggett. 2022. "Mapping Potential Connections Between Southern Africa's Elephant Populations." *PLoS One* 17: e0275791. https://doi.org/10.1371/journal.pone.0275791.

Landman, M., D. S. Schoeman, A. J. Hall-Martin, and G. I. Kerley. 2012. "Understanding Long-Term Variations in an Elephant Piosphere Effect to Manage Impacts." *PLoS One* 7: e45334. https://doi.org/10.1371/journal.pone.0045334.

Loarie, S. R., R. J. van Aarde, and S. L. Pimm. 2009. "Fences and Artificial Water Affect African Savannah Elephant Movement Patterns." *Biological Conservation* 142: 3086–3098. https://doi.org/10.1016/j.biocon.2009.08.008.

Meredith, M., and M. Ridout. 2014. "Overview of the Overlap Package." R. Proj, 1.

Mlambo, L., E. Adam, M. D. Shekede, and J. Odindi. 2024. "The Influence of Biophysical Characteristics on Elephant Space Use in an African Savanna." *Ecological Informatics* 82: 102724. https://doi.org/10.1016/j.ecoinf.2024.102724.

Mole, M. A., S. Rodrigues D'Araujo, R. J. van Aarde, D. Mitchell, and A. Fuller. 2016. "Coping With Heat: Behavioural and Physiological Responses of Savanna Elephants in Their Natural Habitat." *Conservation Physiology* 4: cow044. https://doi.org/10.1093/conphys/cow044.

Mole, M. A., S. Rodrigues D'Araujo, R. J. van Aarde, D. Mitchell, and A. Fuller. 2018. "Savanna Elephants Maintain Homeothermy Under African Heat." *Journal of Comparative Physiology B Biochemical, Systemic, and Environmental Physiology* 188: 889–897. https://doi.org/10.1007/s00360-018-1170-5.

Mpakairi, K. S. 2019. "Waterhole Distribution and the Piosphere Effect in Heterogeneous Landscapes: Evidence From North-Western Zimbabwe." *Transactions of the Royal Society of South Africa* 74: 219–222.

Mpalo, M., L. V. Basupi, and G. M. Tsidu. 2024. "Impacts of Wildlife Artificial Water Provisioning in an African Savannah Ecosystem: A Spatiotemporal Analysis." *Land* 13: 690. https://doi.org/10.3390/land13050690.

Nakagawa, S., and H. Schielzeth. 2013. "A General and Simple Method for Obtaining R^2 From Generalized Linear Mixed-Effects Models." *Methods in Ecology and Evolution* 4: 133–142. https://doi.org/10.1111/j.2041-210x.2012.00261.x.

Ndlovu, M., A. Pérez-Rodríguez, E. Devereux, M. Thomas, A. Colina, and L. Molaba. 2018. "Water for African Elephants (*Loxodonta africana*): Faecal Microbial Loads Affect Use of Artificial Waterholes." *Biology Letters* 14: 20180360. https://doi.org/10.1098/rsbl.2018.0360.

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Niedballa, J., R. Sollmann, A. Courtiol, and A. Wilting. 2016. "camtrapR: An R Package for Efficient Camera Trap Data Management." *Methods in Ecology and Evolution* 7: 1457–1462. https://doi.org/10.1111/2041-210X.12600.

Owen-Smith, N. 1996. "Ecological Guidelines for Waterpoints in Extensive Protected Areas." *South African Journal of Wildlife Research* 26: 107–112.

Phillips, P. K., and J. E. Heath. 1992. "Elephant (*Loxodonta africana*)." *Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology* 101: 693–699.

Polansky, L., I. Douglas-Hamilton, and G. Wittemyer. 2013. "Using Diel Movement Behavior to Infer Foraging Strategies Related to Ecological and Social Factors in Elephants." *Movement Ecology* 1: 1–11. https://doi.org/10.1186/2051-3933-1-13.

Pontzer, H., R. Rimbach, J. Paltan, E. L. Ivory, and C. J. Kendall. 2020. "Air Temperature and Diet Influence Body Composition and Water Turnover in Zoo-Living African Elephants (*Loxodonta africana*)." *Royal Society Open Science* 7: 201155. https://doi.org/10.1098/rsos.201155.

Purdon, A., M. A. Mole, M. J. Chase, and R. J. van Aarde. 2018. "Partial Migration in Savanna Elephant Populations Distributed Across Southern Africa." *Scientific Reports* 8: 11331. https://doi.org/10.1038/s41598-018-29724-9.

Purdon, A., and R. J. van Aarde. 2017. "Water Provisioning in Kruger National Park Alters Elephant Spatial Utilisation Patterns." *Journal of Arid Environments* 141: 45–51. https://doi.org/10.1016/j.jaridenv.2017.01.014.

R Core Team. 2023. *R: A Language and Environment for Statistical Computing*. R v4.4.1. R Foundation for Statistical Computing. https://www.R-project.org/.

Redfern, J. V., R. Grant, H. Biggs, and W. M. Getz. 2003. "Surface-Water Constraints on Herbivore Foraging in the Kruger National Park, South Africa." *Ecology* 84: 2092–2107. https://doi.org/10.1890/01-0625.

Rozen-Rechels, D., H. Valls-Fox, C. T. Mabika, and S. Chamaillé-Jammes. 2020. "Temperature as a Constraint on the Timing and Duration of African Elephant Foraging Trips." *Journal of Mammalogy* 101: 1670–1679. https://doi.org/10.1093/jmammal/gyaa129.

Ruggiero, R. G. 1992. "Seasonal Forage Utilization by Elephants in Central Africa." *African Journal of Ecology* 30: 137–148. https://doi.org/10.1111/j.1365-2028.1992.tb00487.x.

Sach, F., E. S. Dierenfeld, S. C. Langley-Evans, M. J. Watts, and L. Yon. 2019. "African Savanna Elephants (*Loxodonta africana*) as an Example of a Herbivore Making Movement Choices Based on Nutritional Needs." *PeerJ* 7: e6260. https://doi.org/10.7717/peerj.6260.

Shannon, G., W. S. Matthews, B. R. Page, G. E. Parker, and R. J. Smith. 2009. "The Affects of Artificial Water Availability on Large Herbivore Ranging Patterns in Savanna Habitats: A New Approach Based on Modelling Elephant Path Distributions." *Diversity and Distributions* 15: 776–783. https://doi.org/10.1111/j.1472-4642.2009.00581.x.

Shrader, A. M., S. L. Pimm, and R. J. van Aarde. 2010. "Elephant Survival, Rainfall and the Confounding Effects of Water Provision and Fences." *Biodiversity and Conservation* 19: 2235–2245. https://doi.org/10.1007/s10531-010-9836-7.

Sianga, K., S. W. Makhabu, V. K. Muposhi, et al. 2024. "Patterns of Spatial Dynamics and Distribution of African Elephants (*Loxodonta africana*) in the Central Kalahari Game Reserve, Botswana." *Global Ecology and Conservation* 56: e03284. https://doi.org/10.1016/j.gecco.2024.e03284.

Skarpe, C., P. A. Aarrestad, H. P. Andreassen, et al. 2004. "The Return of the Giants: Ecological Effects of an Increasing Elephant Population." *Ambio: A Journal of the Human Environment* 33: 276–282. https://doi.org/10.1579/0044-7447-33.6.276.

Smit, I. P. J., and C. Grant. 2009. "Managing Surface-Water in a Large Semi-Arid Savanna Park: Effects on Grazer Distribution Patterns." *Journal for Nature Conservation* 17: 61–71. https://doi.org/10.1016/j.jnc.2009.01.001.

Smit, I. P. J., C. C. Grant, and B. J. Devereux. 2007. "Do Artificial Waterholes Influence the Way Herbivores Use the Landscape? Herbivore Distribution Patterns Around Rivers and Artificial Surface Water Sources in a Large African Savanna Park." *Biological Conservation* 136: 85–99. https://doi.org/10.1016/j.biocon.2006.11.009.

Smit, I. P. J. 2013. "Systems Approach Towards Surface Water Distribution in Kruger National Park, South Africa." *Pachyderm* 53: 91–98. https://doi.org/10.69649/pachyderm.v53i.328.

Smit, I. P. J., M. J. S. Peel, S. M. Ferreira, C. Greaver, and D. J. Pienaar. 2020. "Megaherbivore Response to Droughts Under Different Management Regimes: Lessons From a Large African Savanna." *African Journal of Range & Forage Science* 37: 65–80. https://doi.org/10.2989/10220119.2019.1700161.

Smith, E., L. R. Brown, and A. S. Barrett. 2024. "Insights Into Artificial Waterhole Utilization Patterns by Elephants and Rhinos: Lessons From a South African Nature Reserve." *PLoS One* 19: e0312158. https://doi.org/10.1371/journal.pone.0312158.

Sutherland, K., M. Ndlovu, and A. Pérez-Rodríguez. 2018. "Use of Artificial Waterholes by Animals in the Southern Region of the Kruger National Park, South Africa." *African Journal of Wildlife Research* 48: 1–14.

Thaker, M., P. R. Gupte, H. H. Prins, R. Slotow, and A. T. Vanak. 2019. "Fine-Scale Tracking of Ambient Temperature and Movement Reveals Shuttling Behavior of Elephants to Water." *Frontiers in Ecology and Evolution* 7: 4. https://doi.org/10.3389/fevo.2019.00004.

Thomas, B., J. D. Holland, and E. O. Minot. 2012. "Seasonal Home Ranges of Elephants (*Loxodonta africana*) and Their Movements Between Sabi Sand Reserve and Kruger National Park." *African Journal of Ecology* 50: 131–139. https://doi.org/10.1111/j.1365-2028.2011.01300.x.

Thrash, I. 1998. "Impact of Water Provision on Herbaceous Vegetation in Kruger National Park, South Africa." *Journal of Arid Environments* 38: 437–450. https://doi.org/10.1006/jare.1997.0318.

Thrash, I., and J. F. Derry. 1999. "The Nature and Modelling of Piospheres: A Review." *Koedoe* 42: 73–94. https://doi.org/10.4102/koedoe.v42i2.234.

Thrash, I., G. K. Theron, and J. d. P. Bothma. 1993. "Impact of Water Provision on Herbaceous Community Composition in the Kruger National Park, South Africa." *African Journal of Range & Forage Science* 10: 31–35. https://doi.org/10.1080/10220119.1993.9638318.

Tshipa, A., H. Valls-Fox, H. Fritz, et al. 2017. "Partial Migration Links Local Surface-Water Management to Large-Scale Elephant Conservation in the World's Largest Transfrontier Conservation Area." *Biological Conservation* 215: 46–50. https://doi.org/10.1016/j.biocon.2017.09.003.

Valeix, M., H. Fritz, R. Sabatier, F. Murindagomo, D. Cumming, and P. Duncan. 2011. "Elephant-Induced Structural Changes in the Vegetation and Habitat Selection by Large Herbivores in an African Savanna." *Biological Conservation* 144: 902–912. https://doi.org/10.1016/j.biocon.2010.10.029.

Van Langevelde, F., K. Sianga, M. Van Telgen, J. Vrooman, and R. W. Fynn. 2017. "Spatial Refuges Buffer Landscapes Against Homogenisation and Degradation by Large Herbivore Populations and Facilitate Vegetation Heterogeneity." *Koedoe* 59: 1–13.

Venter, F. J., R. J. Scholes, and H. C. Eckhardt. 2003. "The Abiotic Template and Its Associated Vegetation Pattern." In *The Kruger Experience: Ecology and Management of Savanna Heterogeneity*, edited by J. D. Toit, K. H. Rogers, and H. C. Biggs. University of Pretoria, pp. 129.

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Verschueren, S., T. Hofmann, M. Kakove, H. Bauer, B. Cristescu, and L. Marker. 2024. "High Carnivore Richness Despite Human Pressure and Prey Depletion in the South-West of the Kavango–Zambezi Transfrontier Conservation Area." *Oryx* 58: 793–801. https://doi.org/10.1017/S0030605324000024.

Viljoen, P. J. 1989. "Spatial Distribution and Movements of Elephants (*Loxodonta africana*) in the Northern Namib Desert Region of the Kaokoveld, South West Africa/Namibia." *Journal of Zoology* 219: 1–19. https://doi.org/10.1111/j.1469-7998.1989.tb02561.x.

Wato, Y. A., H. H. Prins, I. M. Heitkönig, et al. 2018. "Movement Patterns of African Elephants (*Loxodonta africana*) in a Semi-Arid Savanna Suggest That They Have Information on the Location of Dispersed Water Sources." *Frontiers in Ecology and Evolution* 6: 167. https://doi.org/10.3389/fevo.2018.00167.

Węglarczyk, S. 2018. "Kernel Density Estimation and Its Application." ITM Web of Conferences, 23, p. 37. https://doi.org/10.1051/itmconf/20182300037.

Wigley, B. J., C. Coetsee, E. C. February, S. Dobelmann, and S. I. Higgins. 2024. "Will Trees or Grasses Profit From Changing Rainfall Regimes in Savannas?" *New Phytologist* 241, no. 6: 2379–2394. https://doi.org/10.1111/nph.19538.

Wijayanto, R. D., A. A. Condro, and D. A. Rahman. 2023. "Thermal Drone Technology Used to Capture Thermoregulation in Wild Sumatran Elephants." *HAYATI Journal of Biosciences* 30: 1061–1070. https://doi.org/10.4308/hjb.30.6.1061-1070.

Wilson, L. J., M. T. Hoffman, A. J. Ferguson, and D. H. Cumming. 2021. "Elephant Browsing Impacts in a Zambezian Baikiaea Woodland With a High Density of Pumped Waterholes." *Global Ecology and Conservation* 31: e01854. https://doi.org/10.1016/j.gecco.2021.e01854.

Woolley, L. A., J. J. Millspaugh, R. J. Woods, S. J. Van Rensburg, B. R. Page, and R. Slotow. 2009. "Intraspecific Strategic Responses of African Elephants to Temporal Variation in Forage Quality." *Journal of Wildlife Management* 73: 827–835. https://doi.org/10.2193/2008-41.

13652028, 2026, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/aje.70154 by Tatenda Dalu - John Carroll University , Wiley Online Library on [12/02/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License