KRUGER NATIONAL PARK

NXANATSENI SOUTH

A POPULATION ASSESSMENT OF LIONS IN THE NXANATSENI SOUTH REGION OF KRUGER NATIONAL PARK (SOUTH AFRICA): TECHNICAL REPORT ON A LION SURVEY CONDUCTED IN 2024

Version 1.1 — corrected 26 March 2026

Endangered Wildlife Trust



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Executive summary

Background

Following recent increases in the incidences of poaching and poisoning in the Nxanatseni South region of Kruger National Park, we conducted a survey to better understand the current status of lions.

Objective

Our primary objective was to obtain reliable estimates of lion density, abundance, sex ratio and spatial distribution.

Survey dates and area

Data were collected from 3 July to 29 September 2024. We surveyed the area known as Nxanatseni South, which consists of the following sections: Mooiplaas, Mahlangeni, Letaba, Phalaborwa, and Olifants. The combined area is ~4,482 km².

Field methods

An unstructured search-encounter approach was employed to maximize the number of individual lion identifications through the collection of high-quality photographs. All accessible roads within the study area were systematically driven to ensure comprehensive spatial coverage, and survey effort was explicitly recorded.

Upon locating lions, the following data were recorded using a customized Cybertracker application where possible: the number of individuals observed, demographic information (age and sex class), and the geographic location of the sighting. Where possible, high-resolution photographs of both right and left whisker spot patterns were taken for individual identification.

Analytical methods

It is not feasible to find every lion in the landscape. Therefore we used methods that enable us to estimate the number of lions based on a sample of that population.

In other words, we use information on the individual lions that we did see to estimate those that we did not see. To do this, we used advanced spatial capture-recapture models that are widely used for large carnivores globally.

Because lions less than one year old tend to suffer high mortality, we excluded them from analysis.



Members of the Nshawu Pride

Results

We drove 10,446 km in search of lions, which resulted in 182 detections of 74 individuals.

Using this dataset, we estimated there to be 155 lions in Nxanatseni South, at a density of 3.5 lions per 100 km². In addition, lion density was found to decrease with increasing distance from water.

Discussion

The most recent park-wide survey, from 2015, estimated 1,803 lions. With that survey now a decade old and reports of increased poaching—particularly in northern KNP—there is justified concern about the current status of lions in this region.

Our survey in Nxanatseni South therefore provides timely, updated information on lion abundance and distribution in an area subject to both ecological and anthropogenic pressures.

Lion densities varied across the study area, with the highest estimates in the Mooiplaas (4.55 lions/100 km²) and Letaba (4.12 lions/100 km²) sections, which support large herds of herbivores due to productive soils and grazing grounds.

Table 1. Results of a lion survey conducted in the Nxanatseni South region of Kruger National Park. Results are presented with posterior standard deviations in brackets. Estimates are for lions over 1 year old.

Estimates	
Estimated Lion Density	3.5 (0.4)
Estimated Sex Ratio	2.2 F : 1 M
Lion Abundance Estimates	
Letaba	23 (3.8)
Mahlangeni	32 (7.2)
Mooiplaas	47 (5.8)
Olifants	23 (5.9)
Phalaborwa	29 (6.2)
Nxanatseni South (all sections combined)	155 (18.4)

Lower densities were found in the western sections, Mahlangeni (2.76 lions/100 km²) and Phalaborwa (2.80 lions/100 km²), where mopane woodland, proximity to communities, and conflict with poaching may limit lion populations. The Olifants section had intermediate density (3.30 lions/100 km²), likely constrained by poor soils, low rainfall, and hilly terrain.



The overall sex ratio (2.2F:1M) and mean home range size (~341 km²) suggest a demographically balanced population.

The ongoing lion poaching pressure is cause for concern. During our study, five study subjects (one of which was collared) were found poached within Nxanatseni South, with additional incidents reported in the northernmost sections of the park and across the border in Limpopo National Park.

The observed trends highlight the urgent need for continued monitoring, strengthened anti-poaching efforts, and adaptive management to safeguard remaining prides. Further investigation into altered water management practices and other ecological drivers is also recommended. Regular surveys will be essential to track future trends and evaluate the effectiveness of ongoing conservation interventions.

Introduction

Kruger National Park (KNP) is one of the few remaining strongholds for lions (*Panthera leo*) in southern Africa (Riggio et al., 2013), with an estimated 1,803 individuals in 2015 (Ferreira & Funston, 2020). As a core component of the Greater Limpopo Transfrontier Conservation Area (GLTFCA), KNP functions as a key source population for neighbouring reserves such as Limpopo and Gonarezhou National Parks. Over the past decade, however, poaching—through bushmeat snaring and deliberate poisoning of carnivores, particularly lions—is thought to have increased markedly in the region (Hübschle, 2019), placing additional pressure on local populations. As large carnivores like lions are especially vulnerable to extinction owing to slow life histories, low densities, and high energetic demands (Ripple et al., 2014), it is essential to monitor not only small, threatened populations but also major strongholds such as KNP.

In the recent past, lion population monitoring efforts focused on using call-up methods to estimate lion density and abundance. In KNP, park-wide surveys in 2005/2006, 2008, 2015 and 2024 relied primarily on call-ups to derive lion population estimates (Ferreira & Funston, 2020). More recently, however, concern has grown that repeated use of playbacks has reduced and destabilised response rates as lions become habituated to the calls, undermining key detection assumptions.

These concerns have motivated the application of Bayesian spatial capture–recapture models, already tested on lion populations elsewhere in Africa (Elliot et al., 2020; Braczkowski et al., 2020; Western et al., 2022; Ball et al., 2023), to obtain more reliable and comparable estimates of



abundance and density under imperfect detection.

Objectives

Our main objective was to obtain robust estimates of lion density, abundance, sex ratio and spatial distribution in the survey area to support management decisions. For this, we used a Bayesian Spatial Capture Recapture (SCR) framework. This framework accounts for imperfect detection, and produces precise and statistically robust population estimates (Elliot & Gopalaswamy, 2017). Furthermore, this approach has been applied in several studies on lion density and abundance across Africa (Elliot & Gopalaswamy, 2017; Braczkowski et al., 2020; Western et al., 2022; Ngene et al., 2023), enabling direct comparisons of lion densities and contributing to the expanding body of knowledge on the species.

Methods

Survey Area

The survey area is in the northern half of KNP in South Africa and shares a border with Limpopo National Park (LNP) in Mozambique (Fig. 1). Data were collected from 3 July to 29 September 2024.

The area mostly consists of mopane dominated woodlands on granite to the west, open savanna grasslands with stunted mopane in the east, and a small region of Lebombo (low, arid rhyolite) hills at the border with Mozambique (Venter & Gertenbach, 1986).

Throughout the area, various seasonal rivers such as the Letaba and Olifants are supplemented by boreholes and dams to provide water to the wildlife throughout the year.

The area supports a variety of carnivore and herbivore species, including lions and several key prey species: buffalo (Syncerus caffer), greater kudu (Tragelaphus strepsiceros), southern giraffe (Giraffa giraffa) and Plains zebra (Equus quagga) (Davidson et al., 2013).

Field Methods

Observation teams in two vehicles (occasionally a third) actively searched the survey area during daylight hours using unstructured search-encounter methods following Elliot & Gopalaswamy (2017). Both tourism and management roads were driven, and we aimed to cover each road multiple times to reduce underrepresentation of remote or difficult sections. Opportunistically, tourist reports and information from park personnel were used to refine search effort. Drive effort for each search was logged in CyberTracker on Android phones (GPS fixes every 10 seconds), along with the location and demographic details of all lion sightings. Lions were individually identified using their distinctive whisker-spot patterns on both sides of the face (Pennycuick & Rudnai, 1970). Whenever possible, observers took systematic close-up photographs of both profiles of each lion so that images could be matched and sorted into individual-specific folders for subsequent data processing.

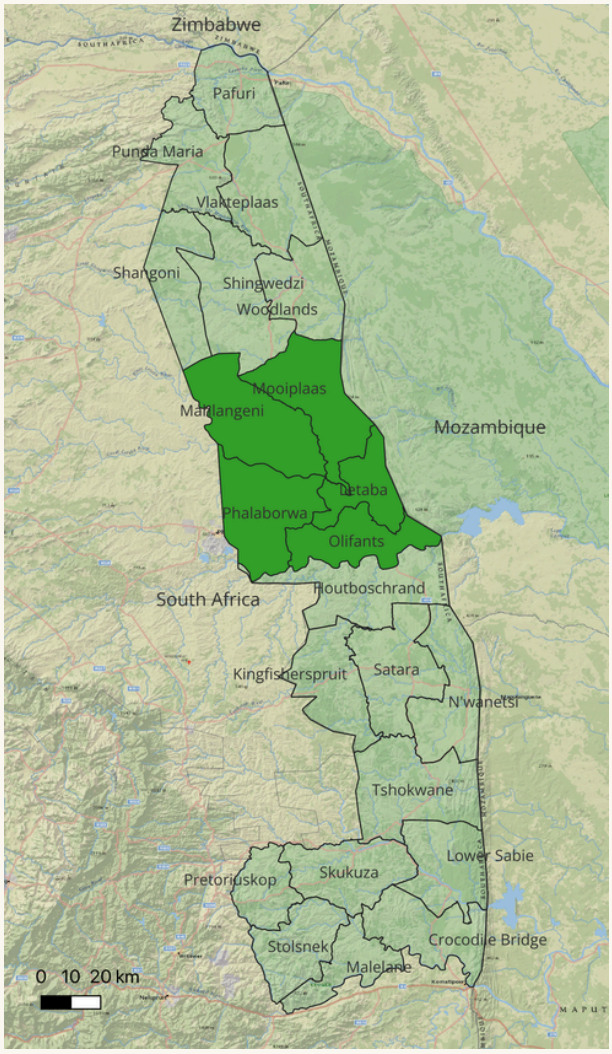


Figure 1. Survey area (Nxanatseni South) shown in dark green. The area is divided into five management sections—Mooiplaas, Mahlangeni, Letaba, Phalaborwa, and Olifants—covering a total of 4,482 km².

Data Processing

We classified lions as over or under one year old based on phenotypic traits (body size, shoulder height, nose pigmentation, and mane development).

Individuals estimated to be <1 year were excluded from analysis because of high mortality at this age (Miller et al., 2016).

Images from each sighting were stored in a date-labelled folder and then subdivided into individual-specific folders. For every new individual, we assigned sex and a unique ID using secondary sexual characteristics and whisker-spot patterns, and created an ID card for the catalogue.

Subsequent sightings were coded as recaptures if the whisker-spot pattern matched an existing ID, or as new individuals if no match was found; in cases where image quality or framing was poor (whisker spots were not visible) or viewing conditions prevented reliable identification (e.g. distance, vegetation), detections were recorded as “No ID” and excluded from the SCR analysis.

Initial sorting and ID assignment were done by the original observer, after which all detections (including “No ID” images) were independently reviewed by four additional observers to verify identifications and minimise loss of usable data.

The full ID protocol is described in Appendix I.

Analytical Methods

We used Bayesian SCR models to estimate key state variables. To model the spatial distribution of lions (state process) we generated a state-space by defining a 25 km buffer around the sampled area.

Next, we created potential activity centres, represented by equally spaced pixels (1 km²). Unsuitable habitat (e.g., agricultural areas, mining of natural minerals on the western fence as well as a high density human populated area) was masked out (Fig. 2). We assumed that lions whose activity centres were outside the state-space had a negligible chance of detection.

The value of M (the data-augmented value of abundance in the larger state-space) was set at 800 (comprising the number of individuals observed during the survey, and the number of individuals augmented for the analysis), which represents the maximum number of lions possible within the state-space.

The input file consisted of a standard SCR array consisting of individuals, trap locations (defined by pixels of 1 km²), and sampling occasions. Since highly sampled traps might increase the number of detections, we included an effort covariate (logarithm of kilometres driven) per trap per day.

We also included sex-specific covariates when defining the observation process. By explicitly accounting for sex-specific detection probabilities and/or spatial scales of movement, we were also able to estimate the sex ratio.

We ran the models in R (R Core Team, 2023), using the same priors as Davis et al. (2025) and adapted the code provided by Elliot and Gopalaswamy (2017). Each model was set to run 16,000 iterations across four chains, and initial runs were assessed for convergence using the Gelman-Rubin diagnostic (Gelman & Rubin, 1992), and by visually inspecting trace plots. For each model, we set 1,000 iterations as burn in, and discarded more iterations

if convergence was not achieved. We evaluated candidate models using: (i) Bayesian p-value based on individual encounters (Royle et al., 2009), (ii) Bayesian p-value based on the summed trap-level encounter variation (Gopalaswamy et al., 2012), (iii) the log marginal likelihood via the harmonic-mean estimator (Dey et al., 2019), and (iv) inspection of pairwise parameter correlations.

Candidate Models

We defined four a-priori models:

- Model1: N(.), λ0 (sex + effort), σ(sex) - assumes that basal encounter rate and the rate of decline in detection probability are sex-specific.
- Model2: N(.), λ0 (effort), σ(sex) - assumes that basal encounter rate is independent of sex and the rate of decline in detection probability is sex-specific.
- Model3: N(.), λ0 (effort), σ(.) - assumes that basal encounter rate and the rate of decline in detection probability are independent of sex.
- Model4: N(.), λ0 (sex + effort), σ(.) - assumes basal encounter rate is sex specific and rate of decline in detection probability is independent of sex.

Our field data was collected during the dry season and suggested a clustering of lions close to water sources.

While lions are not water dependent, many herbivore species are. This often results in a higher density of prey, and therefore lions, close to water, especially during the dry season in arid and semi-arid ecosystems, like KNP (e.g., Valeix et al. 2010). We therefore ran two additional SCR models that incorporated resource selection, with the expectation that lion density is influenced by distance to water.

A covariate representing water availability was derived from existing shapefiles of rivers, satellite imagery and waterbodies provided by the park and used to map the spatial distribution of surface water within the area. We used the resulting layer to create a raster that depicted the Euclidean distance to water from each pixel. This covariate was incorporated into the habitat file and used as a density predictor (Fig. 3).

In the original model set, all models shared the same assumption that each pixel was equally likely to contain a lion before fitting the data. By introducing the water-distance covariate, this assumption changed—the model no longer treated all areas as equally suitable, and instead weighted locations based on proximity to water, thereby modifying the prior probability of occurrence across the state space. Because adding this covariate changed the prior assumptions of the model, these models can not be compared directly with the original model set using standard Bayesian comparison tools and therefore had to be evaluated separately.

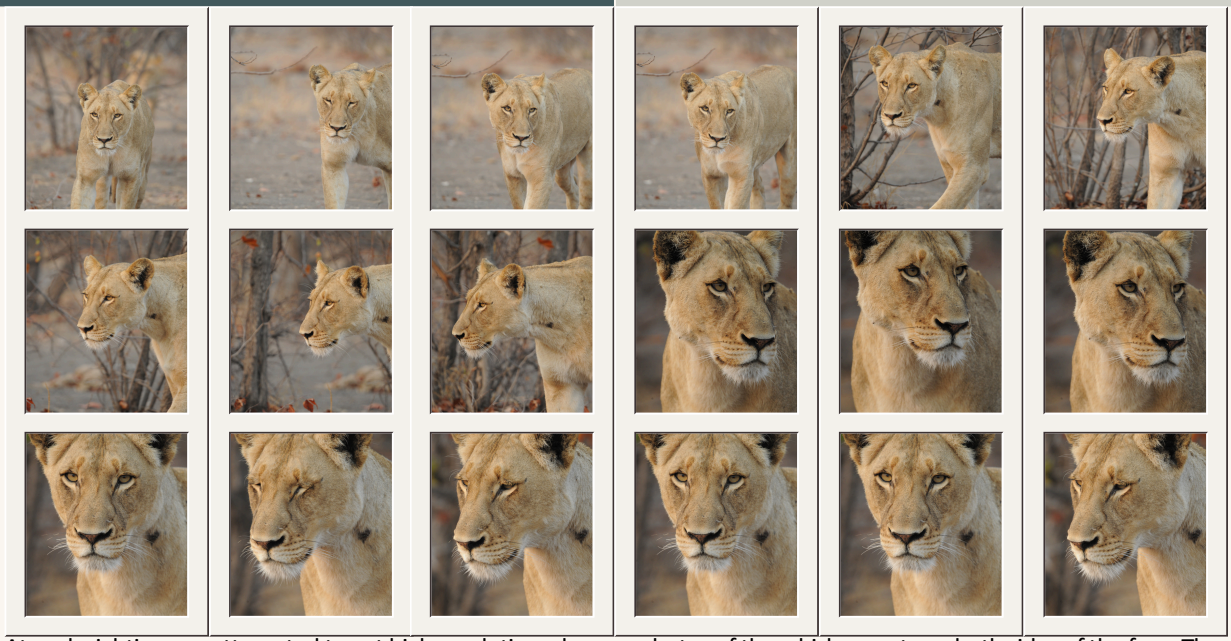
As described above, there was broad support for Model 4, and so we added resource selection to this model (Model 4.1) and additionally ran a competing model (Model 3.1) that contained no sex-specific parameters. Each model was set to run 310,000 iterations across four chains, and we set 1,000 iterations as burn in, discarding more initial iterations if convergence was not achieved. The models were identical to Model 3 and 4, but with a distance to water covariate on lion density.

- Model 3.1: N(water), λ0 (effort), σ(.)
- Model 4.1: N(water), λ0 (sex+effort), σ(.)

Data Summary

Table 2. Summary table of the raw data collected in the Nxanatseni South region of Kruger National Park, South Africa. These summaries relate only to lions over the age of one year. Note that only identified detections (where individuals were unambiguously identified using their whisker spots) were used in the analysis. Individuals were identified using their distinct whisker spot patterns using the protocol defined in Appendix I.

PARAMETER	VALUE
Survey Effort (search encounter protocol)	10,446 km
Total detections (with ID)	182
Discarded detections (Uncertain ID)	65
Number of individuals identified	74
Number of males identified	22
Number of females identified	52
Number of individuals recaptured	47
Number of males recaptured	13
Number of females recaptured	34
Number of individuals detected at more than one trap	47
Average spatial recaptures	2.3
Mean of the maximum distance moved (km)	6.6



At each sighting, we attempted to get high resolution, close up photos of the whisker spots on both sides of the face. These were later used to identify individual lions. At this sighting, 229 photos were taken of 5 the individuals that were present.

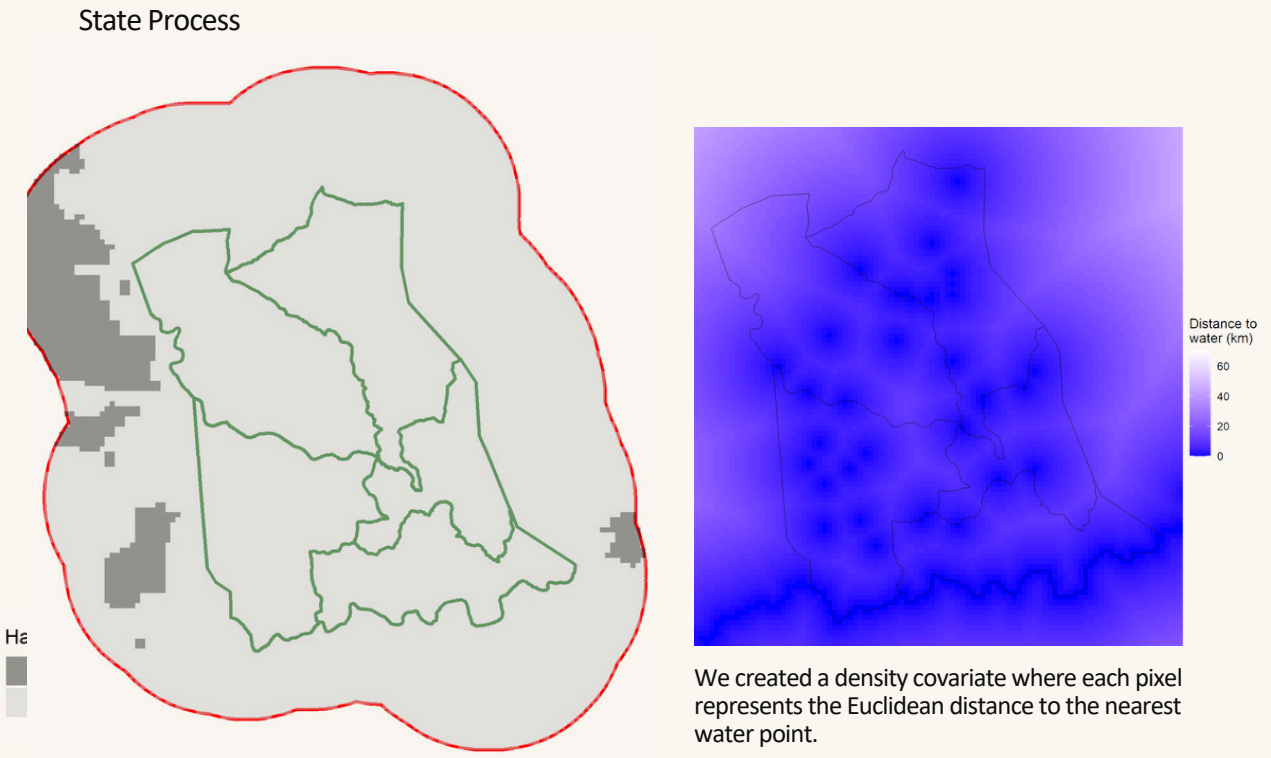


Figure 2. We created a 25 km buffer around the study area. Next, we discretised this area into 1km^2 cells, each representing potential activity centers of lions, and masked out cells of unsuitable habitat.

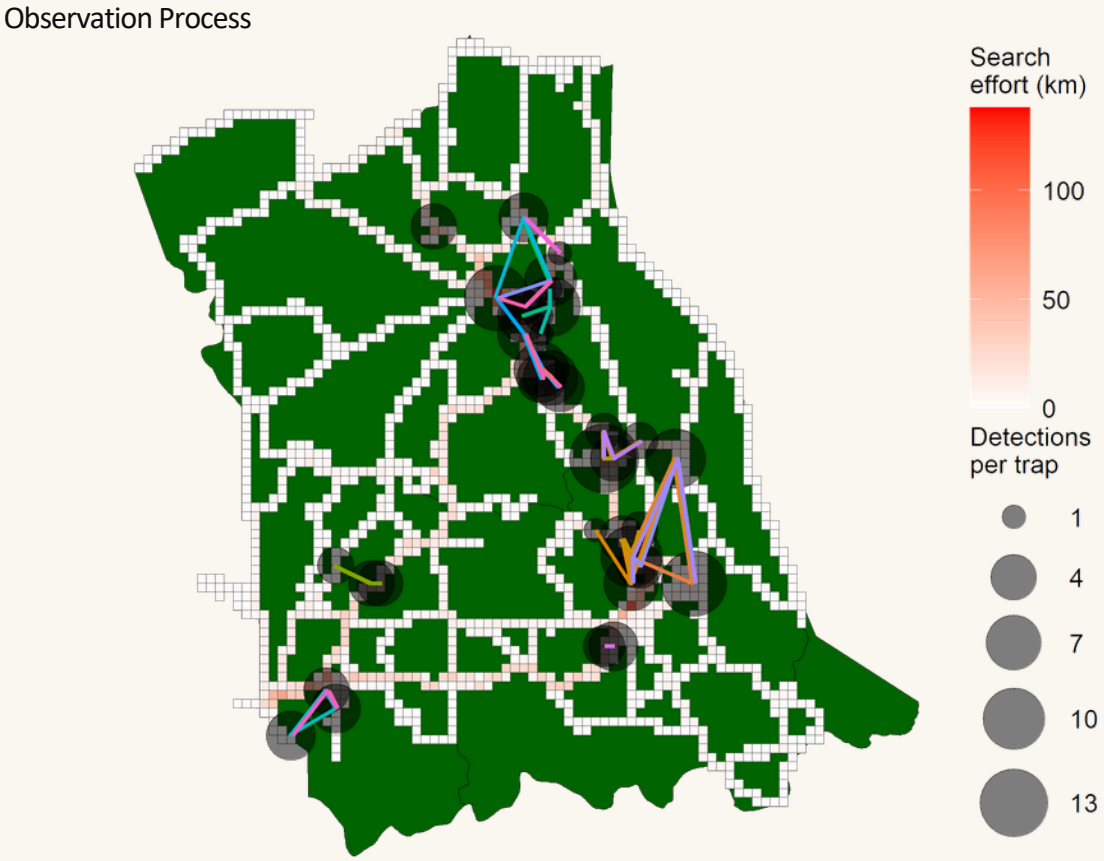


Figure 3. We created a grid (traps) of equal-sized cells (1km^2) around the drive effort. We then totalled up the km driven per trap per day. Next, we created a capture history detailing which individual lion was detected, in which trap, on which day (grey circles, where the larger the circle, the more detections in that trap). Coloured lines link recaptures of individuals and green squares are areas that were masked / not sampled during the survey.

Results

Model Diagnostics

All four base models converged satisfactorily (maximum potential shrink reduction factor (Gelman-Rubin diagnostic) ≤1.08). Bayesian p-values based on individual encounters (Royle et al., 2009) ranged from 0.67 to 0.74, within our a priori acceptable range (0.15–0.85), indicating adequate fit for all models.

Pairwise correlation plots revealed minor correlations involving the sex parameters in Model 1, and Model 2 had the highest marginal likelihood. However, there was no strong evidence for sex-specific σ (substantial posterior overlap and very similar density estimates across models), and overall parameter estimates were broadly consistent among candidates. We therefore selected Model 4 for inference, as it omits sex-specific σ while retaining a sex effect on λ_o and remains directly comparable to the model reported for Nxanatseni North (Roodbol et al., 2024).

Building on this, we fitted Model 4.1 to test for resource selection and, for comparison, the simpler Model 3.1, which omits all sex-specific terms. Both models showed satisfactory convergence and Bayesian p-values within 0.15–0.85, and pairwise correlation plots indicated minimal parameter redundancy. Model 4.1 had the higher marginal likelihood. Given the support for Model 4 as the preferred base structure and the relatively weak but negative estimated effect of distance to water on lion density ($\beta_{density}$; Table 3, Figure 5), we selected Model 4.1 for reporting the main results of this survey. Full estimates and model fit statistics for all models are provided in the Appendix.

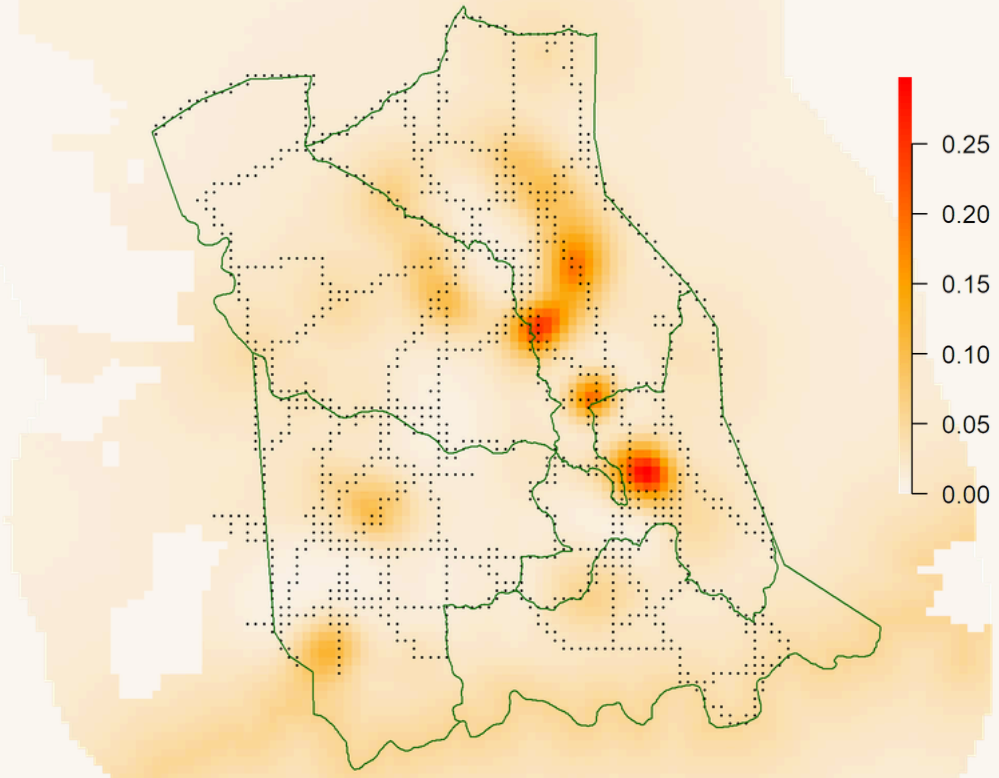


Figure 4. Pixel-specific (1 km²) lion density in Nxanatseni South region of Kruger National Park, South Africa. This output was obtainedfrom Model 4.1. Distance to water was included as a density covariate in a resource selection-based SCR model. The outputs provide a signal that lion density decreases with increasing distance from water. Posterior lion density ranged from 0.005 to 0.3 lions / km².

Model Estimates

Table 3. The results presented below are the product of an analysis of search encounter data using Bayesian spatial capture-recapture models that incorporated resource selection. Given the broad support for Model 4 and the strong signal (beta.density parameter) that distance to water has a negative relationship with lion density, we select Model 4.1 for reporting. Estimates are posterior means and include 95% Highest Posterior Density Intervals in brackets. All estimates are for lions over the age of one year. To aid clarity, we only report the results from the selected model (Model 4.1) in this table. Data descriptions, model diagnostics, and parameter estimates for all other models are provided in the Appendices.

Parameter	Definition	Estimate
σ	Rate of decline in detection probability (DP) with increasing distance between a lion's activity centre and the centroid of a sampled grid cell	4.2 (3.7 – 4.8)
λ0	Basal encounter rate of an individual (female for sex-specific models) lion whose activity centre is located precisely at the centroid of the grid cell	0.003 (0.002 – 0.004)
β1.eff	Rate of change in the complementary log-log value of DP as the (log) effort changes by one unit	1.68 (1.4 – 1.9)
βsex	Difference of complementary log-log value of detection probability between males and females	-0.2 (-0.7 – 0.3)
ψ	Ratio of true number of individuals in the population compared to the data augmented population M	0.4 (0.2 – 0.6)
ψsex	Proportion of lions that are male	0.3 (0.2 – 0.4)
Beta.Density	Relationship between lion density and distance to water (resource selection model)	-0.09 (-0.2 – -0.04)
Abundance		
Letaba	Number of lions over the age of one year estimated to be resident within the specified area	23 (16 – 30)
Mahlangeni		32 (19 – 46)
Mooiplaas		47 (35 – 57)
Olifants		23 (11 – 34)
Phalaborwa		29 (18 – 41)
Survey Area		155 (121 – 191)
Density		
Letaba	The estimated number of lions over the age of one year per unit area (individuals / 100 km²) within the specified study region	4.1 (2.9 – 5.4)
Mahlangeni		2.8 (1.6 – 4)
Mooiplaas		4.6 (3.4 – 5.5)
Olifants		3.3 (1.6 – 4.9)
Phalaborwa		2.8 (1.7 – 4)
Survey Area		3.5 (2.7 – 4.3)

Discussion

Contextualisation

Several parkwide call-up surveys for lions have been carried out in KNP over the last few decades, with the most recent estimating 1,803 (95% CI: 1,715 – 1,891) individuals in 2015 (Ferreira & Funston 2020). Due to an increase in poaching incidents in the last few years, especially in the northern half of KNP, there is significant concern over the status of lions in this area.

Conservation implications

Our survey estimated a density of 3.45 lions (older than 1 year) per 100 km^2 (95% HPD = 2.70 – 4.26) in the Nxanatseni South area. The lowest density estimates were found in the Mahlangeni (2.76 lions per 100 km^2 (95% HPD = 1.64 – 3.96)) and Phalaborwa (2.80 lions per 100 km^2 (95% HPD = 1.74 – 3.96)) sections, bordering the western boundary of the park.

These sections are comprised of predominantly mopane-dominated woodland habitat and border the communities living to the west of the park. Although the opening of additional waterholes to support large herds of buffalos in those sections have likely contributed to the retention of lion populations in the area, these sections are known as conflict hotspots as lions frequently leave the park—particularly in search of water and prey around the Phalaborwa mine—and are often among the first areas targeted by poachers entering to collect lion parts.

The Mooiplaas and Letaba sections support large herds of large herbivores throughout the year due to favourable soils and extensive, productive grazing grounds (Gertenbach 1983), making it a suitable habitat for lions. Therefore, it is not surprising that our results show they support the highest densities of lions in the study area (Mooiplaas : 4.55 lions/100km^2 (95% HPD =3.39 – 5.52), Letaba : 4.12 lions/100km^2 (95% HPD = 2.87 – 5.38)). Despite being named after a major river that provides water for much of the year, the Olifants section has a low game carrying capacity due to poor soils and low rainfall (Gertenbach 1983). The hilly terrain further limits their suitability for large herbivores such as buffalo and kudu, which are key prey species for lions, and prevented us sampling the whole section as thoroughly as the others. Consequently, our results indicate an intermediate density of lion (3.30 lions/100km^2 (95% HPD = 1.58 – 4.89)) in this section.

The estimated sex ratio was 2.2 females to 1 male, which is consistent with expectations for a source population and may reflect a stable demographic. Lions in this area had an average movement parameter (sigma) of 4.25, translating to a mean home range size of approximately 341 km^2. Furthermore, the effect of distance to water on lion density was relatively weak (β = -0.1), suggesting that water did not strongly influence lion spatial variation in density during the survey.

Although we often found lions near rivers or man-made waterholes, a relatively weak effect of distance to water likely reflects that water sources are relatively widespread across the ecosystem, including perennial rivers, pans, and artificial waterholes. The relationship between lion density and water availability will be investigated more

thoroughly in future analyses using remote sensing–derived water layers to provide an even more accurate representation of water.

In 2023, a survey was conducted in the Nxanatseni North area, using the same methodology described here and in the same season (dry) (Roodbol et al., 2024). Lion density is considerably higher in Nxanatseni South (3.5 lions / 100km^2) compared to Nxanatseni North (1 lion / 100km^2). The sex ratio in the north was 1.6 females to 1 male, compared to the south (2.2 females to 1 male). Although both values are still reasonable (lion populations typically have a 2 : 1 sex ratio), the sex ratio in the northern region is slightly skewed towards males.

The effect of distance to water on lion density was considerably stronger in the north (beta.density = -0.3) compared to the south (beta.density = -0.1). This likely reflects that water is more limiting in the northern section. Annual precipitation in KNP declines from south to north, with the northern most regions being the driest. In Nxanatseni North, surface water in the dry season is largely restricted to small pools in the rivers and a few localities where park management provides water, while artificial waterpoints are more prominant in the more southern sections (Gaylard, 2015).

The movement parameter (sigma) is considerably larger in Nxanatseni North (6.1) compared to Nxanatseni South (4.3) indicating lions have much larger home ranges in the north. Indeed, lions in the north have a mean home range of 700 km^2 compared to 341 km^2 in the south. This likely reflects the lower availability of resources such as water and prey in Nxanatseni North together with the lower lion density.

Although poaching was not directly assessed in this study, incidental observations suggest it remains a concern in the region. During our survey, we recorded five identified study lions that had been poached, along with additional reports from northern Kruger and adjacent Limpopo National Park (pers. comm. M. Roodbol). Given the conservation importance of the Kruger lion population, these observations are concerning. Future investigations should address factors such as water management and increasing anthropogenic pressures that may contribute to mortality from snaring and poisoning. Continued lion monitoring is needed to understand population dynamics, and we recommend regular surveys. If mortality rates are high, increased anti-poaching measures should be implemented to reduce the pressure currently facing lions in the area.

Insights from the field

The survey was conducted in mid-winter (July to September), an excellent period due to dry conditions that increased visibility, improved access to remote areas, and concentrated wildlife activity (and therefore lions) around water sources.

Not being able to drive off road severely limited our ability to obtain good ID photos during the search-encounter protocol, and required increased resources as more effort was neeeded. Out of 247 detections, 182 were retained because the lion could be identified, but 65 could not be used. Identifying more individuals would have improved precision without necessarily changing the estimates. Knowing this limitation beforehand allowed us to plan for increased survey effort and resources.

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