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Manon Dehoorne/11

Comparing scat and kill-site methods for assessing the diet of Southern African lions (*Panthera leo melanochaita*) in Selati Game Reserve, South Africa.

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Summary

Lions are apex predators and can have substantial impact on their ecosystem. Investigating scat and kill site is a simple, non-invasive method to monitor lion diet. Kill sites are known to overrepresent large prey, while scat analysis is best at detecting small prey. Previous research on lion diet generally used a single method, potentially leading to a bias in prey detection.

This study compared scat and kill site analysis of the River Pride in Selati Game Reserve, with hopes of obtaining an accurate representation of their diet. This is especially important in the management of closed game reserves where movement of predators and prey is restricted, possibly increasing predator-prey interactions. The hypothesis states that scat analysis will detect a higher number of small prey compared to kill site analysis. During eight months, data was collected opportunistically, following known lion routes and GPS collar locations. Hairs were collected from lion scats for cross-section identification. Prey at kill sites were identified in the field when possible. When not feasible, prey hairs were collected from the kill site for cross-section identification.

Scat analysis revealed a broader spectrum in terms of estimated prey body weight. This method demonstrated a larger representation of small prey compared to kill site analysis. Kill sites revealed a predominance of medium-to large-bodied prey. These results reveal that relying on a single method would underestimate a lion’s diet. This highlights the importance of multi-method diet assessment as it provides a more detailed and accurate representation of a lion’s diet.

Introduction

Lion Ecology and Behaviour

The lion (*Panthera leo*) historically occupied Africa, parts of southeastern Europe, the Middle East, and Asia; their modern distribution has dramatically declined due to human expansion, causing habitat loss and prey depletion. Even with these negative human impacts, there are still lions living outside of game reserves; approximately 44% of Africa's lions occur in unprotected areas (Bauer & van der Merwe, 2004; Rippel et al., 2014; Lindsey et al., 2017b)

This investigation will focus on a subspecies of the lion, the Southern African lion (*Panthera leo melanochaita*), which is a social animal that typically forms prides of two to eighteen individuals, consisting of related females, their offsprings, and a coalition of males. Prides facilitate territorial defence as well as cooperative hunting, allowing them to exploit larger prey (Hayward & Kerley, 2006). Territories range from 20 to 500km^2 and are generally patrolled by dominant males. The size of lion prides, their territory and movement are strongly influenced by habitat structure. In more open prey-rich areas, prides may be larger and more stable compared to prey-limited landscapes, where prides and their territories tend to be smaller. This is because in open areas, the prey biomass is higher, and hunting success increases when lions cooperate. In contrast to prey-limited areas, where the energetic benefits of living in a large pride are reduced (Donkin, 2000).

Lions are apex predators that have an opportunistic foraging behaviour. They seem to have a preference for herbivores, large ungulates and mammals that have hooves, such as Plains Zebras (*Equus quagga*), Blue Wildebeests (*Connochaetes taurinus*) and African Buffaloes (*Syncerus caffer*). However, they also hunt on smaller prey, including Common Warthogs (*Phacochoerus africanus*), Impalas (*Aepyceros melampus*), Rodents (Rodentia spp.) and Birds (Aves spp.) when opportunities arise or during times of scarcity (Davidson et al., 2013; Hayward & Kerles, 2006).

Their dietary flexibility can be influenced by external factors such as prey availability, habitat type, rainfall, and pride dynamics. Prey availability has one of the strongest impacts on lion diet, as lions target prey species that are common and easily accessible within their territory.

Hunting abundant prey increases their likelihood of a successful hunt. When preferred prey species decline, lions are able to switch to alternative prey, allowing them to survive under changing ecological conditions (Hayward & Kerley, 2005). Additionally, habitat type affects what prey lions are able to hunt, as vegetation structure and landscape can influence hunting success. Different environments can enhance or limit their stalking ability by either providing cover or not, therefore leaving them exposed to prey detection (Donkin, 2000). Rainfall can indirectly affect a lion's diet, as it can lead to changes in vegetation and prey movements. In wet seasons grazing conditions improve and allow herbivores to disperse more widely, while in dry seasons, animals aggregate at water sources, leading to concentrated prey populations and predictable hunting areas for lions (Davidson et al., 2013). Pride dynamics can influence hunting behaviour, which in turn affects dietary flexibility. Although lions are capable of cooperative hunting, they do not always hunt as a pride. Hunting group size varies with habitat, prey type and local competition pressures. Cooperative hunts are advantageous when targeting large and dangerous prey such as buffalo because multiple individuals can improve capture success and decrease the risk of injury. However, lions frequently hunt alone or in small subgroups when pursuing smaller and more agile prey, thereby allowing them to remain stealthy and reduce carcass competition from other lions while feeding (Davidson et al., 2013; Donkin, 2000; Hayward & Kerley, 2006). This behavioural flexibility enables prides to exploit a wide range of prey species under changing environments. Additionally, pride hunting dynamics can shift seasonally or spatially. In denser habitats, lions use vegetation cover to aid in a small group ambush strategy, whereas in open savannas, larger coordinated groups are more frequently used. During drought, when prey are scarce, or there is higher competition, lions may broaden prey choice and alter their hunting strategy to maximise their success (Beukes et al., 2017; Yiu et al., 2022). Therefore, lion social structure is a dynamic cooperation with role variation, allowing prides to adapt and excel.

Adult females are typically the primary hunters and often cooperate with related females during stalk-and-ambush events. Adult males participate less frequently in hunts, especially in stable prides, as their main focus is on territorial defence. However, males can become important hunters in small prides when females are absent or when targeting large prey. Males contribute with their strength to take down large prey, while lionesses generally lead hunts using stealth and ambush (Davidson et al., 2013; Donkin, 2000).

Lion Feeding Ecology and Diet Importance

Lion digestion is adapted to a strictly carnivorous diet, with a short digestive tract and strong stomach acids that allow rapid breakdown of meat. Soft tissues of their prey are digested rapidly, while indigestible materials such as hair and bone fragments are passed in scats, poop (Hayward & Kerley 2006; Smith, Waal, & Kok, 2006). Larger carcasses attract a greater abundance of scavengers, which can accelerate carcass removal. However, larger prey are still detectable at kill sites as substantial skeletal materials are often left behind (Moleón et al., 2015). In contrast, smaller prey are often consumed more completely than larger carcasses, leaving fewer visible remains. This creates an important source of bias in dietary studies, as scat analysis can capture prey items that may be missed at kill sites and vice versa (Klare, Kamler & Macdonald, 2011).

Lions play an important role in the environment because they are located at the top of the food chain and regulate herbivore populations, thereby maintaining biodiversity. Lions are able to impact herbivores both directly and indirectly. Through predation they reduce herbivore numbers by targeting vulnerable individuals such as juveniles or weaker adults, which influences population growth rates. Removal of juveniles can lead to a loss of new breeding individuals, while the loss of weak adults can alter survival patterns and population structure, leading to an overall impact on population growth rates (Estes et al., 2011; Hayward & Kerley, 2006; Ripple et al., 2014). Lion presence can shape herbivore behaviour in a process described as "landscape of fear." Prey species avoid areas where they risk being attacked by lions, leading to changes in their movement patterns, habitat use and feeding activity. Together, these effects contribute to maintaining ecosystem structure and balance (Estes et al., 2011; Ripple et al., 2014).

Lion diet is important as it can give insight into prey overexploitation and potential trophic cascades in the ecosystem by top-down pressure on herbivore populations. When their preferred prey species decline due to overexploitation or habitat loss, lions will shift their focus to alternative prey (Tambling et al., 2011). This dietary shift may trigger trophic cascades, which can cause changes in vegetation structure due to herbivore abundance and behavioural changes. Therefore, monitoring lion diet is essential as it is able to provide early warnings about the health of the predator-prey system. Lion diet is also used in conservation to prevent irreversible damage to prey populations from overexploitation, as well as in management strategies. This is especially important for closed game reserves. As a closed game reserve, wildlife movement is restricted, and prey populations cannot disperse naturally in response to resource scarcity or predation pressure, meaning prey are limited in space, which can increase encounter rates with predators (Beukes et al., 2017; Davidsone et al., 2013). Due to lions' strong impact on herbivore abundance and structure, enclosed systems require active management to prevent prey depletion and ecological imbalance (Estes et al., 2011; Ripple et al., 2014). Therefore, having an estimate of prey population size is essential for closed game reserves, as it can be used to detect overexploitation when comparing it with the researched lion diet.

Scat analysis and kill site investigations are two of the most commonly used methods for studying large carnivore diets. Scat analysis can detect prey remains that may leave few visible remains in the environment, whereas kill site investigations allow direct identification of prey through carcass remains. Both methods can produce different estimates of prey composition due to their differences in prey detection, carcass persistence and digestive processes. Understanding the methodological bias is necessary to accurately interpret predator diet studies.

Study Area

Selati Game Reserve, located in the Limpopo, the northernmost province in South Africa, spans 27,000 – 30,000 hectares, enough that the reserve contains diverse types of habitats, from open grasslands to dense thickets (bush), which support a wide variety of wildlife, including a lion population (Radloff, 2008). The habitat's diversity allows for large herbivores to thrive in open areas, while smaller, more cryptic animals are able to use the thick bush for protection from predators. These habitats not only provide suitable environments for prey species but also align well with lions' adaptable hunting strategies. As their behavioural flexibility allows them to exploit different prey across different environments, making them successful predators.

Selati Game Reserve is a closed game reserve, making it an ideal study location, as it is important to understand and have extensive knowledge of lions' diet for managing a diverse and balanced closed game reserve (Hayward & Kerley, 2005; Rapson & Bernard, 2007).

This investigation combined a range of different seasons from winter to early autumn in Limpopo, capturing the seasonal conditions that can influence lion foraging. For example, drier periods in winter and spring often lead to herbivore aggregations around water sources, facilitating lion hunts and easier diet collection via scat or carcass remains left behind by lions (Yiu et al., 2022). In summer, there is more precipitation, dispersing herbivores, thereby promoting more opportunities for lions on prey selection (Davidson et al., 2013). Rainfall can also lead to faster scat decomposition and washing away of tracks, or evidence of lion activity at kill sites, potentially limiting detections of small prey (Tambling et al., 2011).

Lions of Selati Game Reserve

This study focused on a single lion pride, the River Pride, in Selati Game Reserve. The pride consisted of a single dominant male, three female adult lions and five subadults - three females and two males. In early February, the dominant male lion died, causing pride fragmentation and changes in social dynamics. Male loss is common in open systems; however, in closed reserves, natural male immigration is restricted and managed, therefore occurring less frequently and can have high-impact disturbance (Ferreira & Hofmeyr, 2014; Miller et al., 2013).

Research Gap and Study Purpose

Unlike previous research, this investigation will compare and test the limitations of both scat and kill site analysis within an ecologically diverse closed reserve setting. Valuable information has been published from single-method approaches, such as only using scat analysis (Ogara et al., 2010) or kill sites (Tambling et al., 2011). These methods have shown different prey selections. A limitation for scat analysis is that this method detects a higher proportion of smaller to medium-sized prey, while kill sites often over-represent larger prey, due to differences in detection and consumption duration between prey species (Tambling et al., 2011). Despite these biases, few studies have directly compared both methods during the same time period or with the same lion population.

This study addresses potential methodological biases by combining two types of analyses: scat analysis, examining undigested hair in faecal sampling, and kill site data, observing predation events and carcasses. This will provide a representative diet of lions with digestion variability in scat as well as the possible underdetection of small prey due to rapid consumption in kill sites (Beukes et al., 2017; Ogara et al., 2010; Tambling et al., 2011). This research approach aims to fill in critical knowledge gaps in lion dietary composition, particularly in closed systems where prey dynamics may differ from unfenced parks (Rapson & Bernard, 2007; Tambling et al., 2011).

The specific research questions addressed are:

1. How do prey species identified at kill sites compare to those identified in lion scat?
2. Does the inclusion of lion scat analysis provide a more comprehensive dietary overview by increasing the detection of small prey species that may be excluded in kill site observations?

Previous studies on lion diet have shown that prey size influences detection probability, with larger prey detected at kill sites often and smaller prey detected in scat (Tamblin et al., 2011). Based on these previously established methodological biases, the hypothesis for this investigation is that smaller prey will be detected more frequently in scat analysis than in kill site observations.

The objectives of this research are to:

1. Identify and compare the prey species detected by both methods.
2. Outline the limitations and biases of scat analysis and kill site observations.
3. Provide a more comprehensive view of lion diet that includes prey species that may be missed when using a single method.
4. Collect sufficient data to avoid an unbalanced dataset and to ensure robust comparison.
5. Improve ecological understanding of lion diet in an enclosed reserve.
6. Deliver practical recommendations for management strategies and lion conservation in closed game reserves in South Africa.

Key Concepts

To ensure clarity, several key concepts important to this study are defined below:

- **Game reserve:** Game reserves are areas of land that are protected for the conservation of wildlife, where animal populations are monitored, and human activities are regulated to maintain ecological balance. Reserves can have different management, with some reserves including anti-poaching, population control and habitat restoration (Bauer & van der Merwe, 2004; Lindsey et al., 2013a).

- **Apex Predator:** An apex predator occupies the top of the food chain in an ecosystem, having a critical role in regulating prey populations and maintaining ecological balance. Additionally, they have no natural predators of their own (Hayward & Kerley, 2005).
- **Opportunistic Foraging:** Opportunistic foraging refers to a flexible hunting strategy where predators select prey based on immediate availability and a simple capture. This foraging strategy has no strict preferences and often shifts seasonally or in response to environmental conditions such as rainfall (Davidson et al., 2013; Hayward & Kerley, 2005).
- **Landscape of fear:** Landscape of fear is an indirect effect of predators, such as lions, which can affect prey populations and lead to wider ecosystem changes. It is a pattern of how prey animals view danger from predators across landscapes. It acts as a mental map, where prey must balance finding food with staying safe. This can lead to changes in where they go, how they feed, alertness, and how they move. Areas perceived as high risk are avoided or used carefully, whereas areas perceived as safer are used more often (Estes et al., 2011; Ripple et al., 2014).
- **Scat Analysis:** Scat analysis is a non-invasive research method involving collecting, storing and microscopic examination of faecal samples to identify undigested prey remains. This method provides insight into diet composition, but it may over-represent smaller prey due to quicker digestion. Additionally, smaller prey have higher proportions of indigestible materials compared to larger prey (Ogara et al., 2010; Rapson & Bernard, 2007; Tambling et al., 2011).
    - **Hair Cross-section:** Hair cross-section is an analysis method used to identify prey species using hairs found in scat or at kill sites. It involves collecting and examining the medullary, size and colouration of the hairs, often using a reference list.
- **Kill Site Data/Observations**: Kill site observations involve locating sites, often using old GPS coordinates from collared lions. Upon arrival, the prey species is either identified based on the carcass or hair samples are collected for hair cross-section analysis. This data method can under-detect small prey that can be quickly consumed (Beukes et al., 2017; Rapson & Bernard, 2007; Tamblin et al., 2011).

- **Bush**: Bush is used to refer to dense, thicket vegetation that provides cover for wildlife and can influence prey distribution and predator ambush strategies (Randloff, 2008; Rapson & Bernard, 2007).
- **Top-down pressure:** Top-down pressure refers to predator influence on abundance, behaviour and distribution of prey on a lower trophic level within their ecosystem. Top-down forces occur when predators limit prey populations or alter their behaviour in a way that it cascades through the food chain (Estes et al., 2011). Lions act as top-down regulators as they lower herbivore populations and affect prey behaviour, which in turn can cause vegetation patterns and ecosystem functions to change (Rippel et al., 2014).

Materials & Method

Data Collection

Data was collected between August 2025 and April 2026 by Selati guides. I was present for data collection from January 2026 until April 2026, which is the peak summer wet season. During this season, the average rainfall was approximately 104.9 mm per month (Metoblue, 2026), influencing vegetation density, carcass persistence and sample preservation. Due to the rain, scat samples from August to October were lost.

The aim for data collection was to produce a balanced dataset to facilitate comparisons between scat analysis and kill site observations. Target sampling was set at a minimum of 30 scats and kill sites. Data collection was done along known areas of lion activity, which were provided by GPS locations given by lions collar (Figure 1). Sampling designs were structured to directly test the hypothesis that scat analysis detects small prey more often than kill sites. This was done by collecting scat and kill site data from the same lion population in Selati, during the same time period, and then comparing the frequency of small prey species identified by each method.

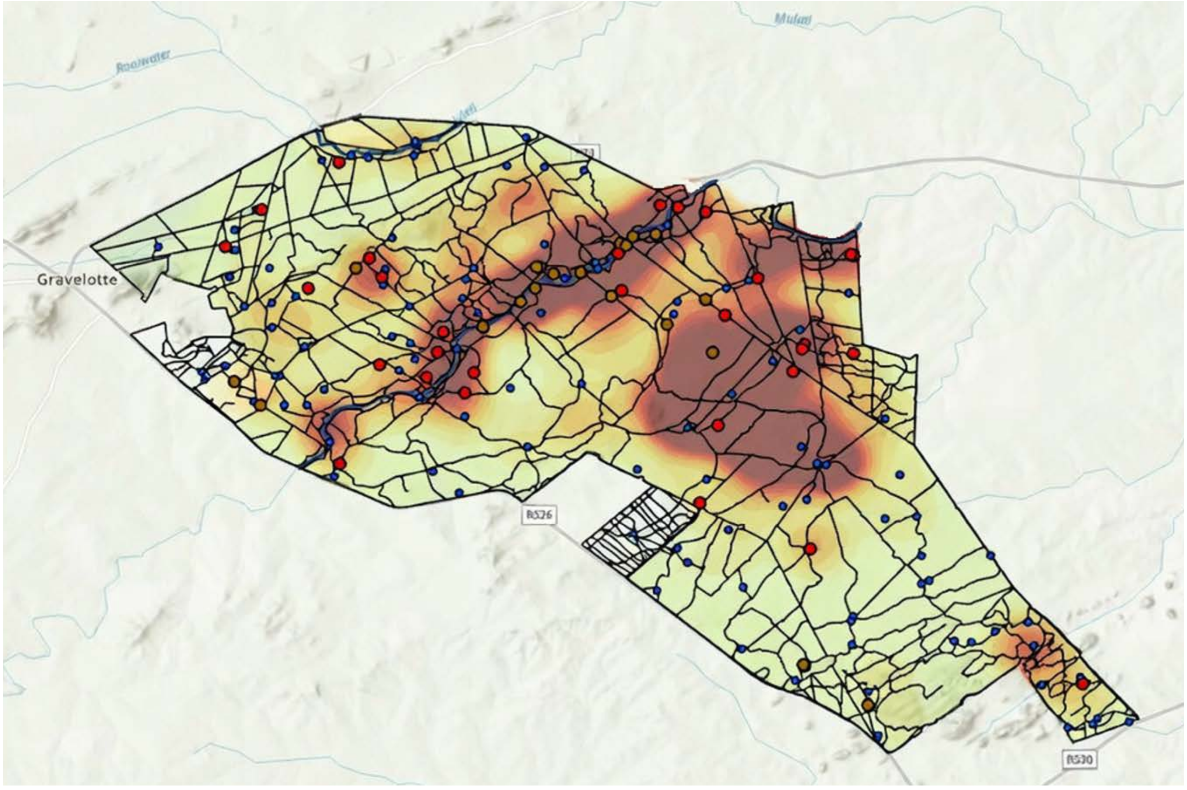

Figure 1: *Spatial density heatmap of lion activity, with GPS information provided by Selati Game Reserve. Colour gradient indicates relative density, from brown (high density) to yellow (low density). Red dots represent kill sites (n = 37), brown dots represent scat collection sites (n = 30, 28 are shown due to two missing coordinates), and blue dots represent water sources. Black lines indicate borders and roads; background shading shows topography and vegetation (green).*

Kill Site Observations

Kill sites were found through GPS coordinates that were a maximum of eleven days old, showing the lions had been in a particular area for a prolonged period of time. A site was classified as a confirmed kill site if the carcass remained or drag marks were present, with lion involvement verified through tracks, scat, direct observations or GPS coordinates.

Kill sites were documented during the eight-month study period. For each kill site data recorded included prey species and when possible, gender, age, horn measurements, GPS coordinates, and identification of which individual lion or lions were responsible for the kill. If there were any prey hairs present, they were collected and stored in a plastic bag containing the information of the kill site location. These hairs were then used in a hair cross-section to identify or confirm the prey species of the kill site.

Scat Sampling

Scats were collected over eight months, opportunistically during daily game drives, which happened twice a day – once in the morning and again in the evening. The drives were done around the reserve, focusing on areas of high lion activity, which we were able to find based on GPS locations. Scats were identified as lions based on their size, colouration, smell, and with the confirmation of guides. Scats were further confirmed during the hair-cross section, when lion hairs were present.

Upon collection, each scat was placed in a sterile paper or plastic bag labelled with GPS coordinates, date of collection, and, when possible, date of approximate defecation as well as individual lion identification. Once back at camp, the scat was taken out of the bag and placed on a table to air dry for easier hair extraction.

Hair Extraction and Storage

Hair extraction combined direct removal of visible strands with a washing process for embedded hairs. Tweezers were used to carefully extract large visible hair strands from the dry scat. For the smaller, more embedded hairs, the scat was placed in a sieve and washed with water and a rock to break the scat apart. Extracted hairs were dried using paper towels and then stored in dry and labelled envelopes. The labelled envelopes contained the same information as the scat bags. When possible, at least 20 – 30 hairs per scat were collected to ensure the randomisation of hairs for the identification of prey through hair cross-section. When samples had fewer than 20 – 30 hairs, all hairs were collected for cross-section.

Hair Cross-section

Hair cross-sections were done for hairs identified in scat as well as from hairs collected at kill sites. The methodology followed that of Lasis (2020), with a modification of using a glue gun mini 7mm instead of polycaprolactone as the embedding medium to secure the hair fibres. Samples containing long hairs, a minimum of 3cm, had two cross-sections prepared, with each set containing four hairs. These four hairs were selected randomly from the sample. A small amount of hot glue was dispensed in a line about 3cm long on parchment paper. The four hairs were then placed parallel and separate from each other for efficiency across the partially cooled glue using tweezers or gloved hands. A new layer of hot glue was applied over the hairs, and a piece of parchment paper was placed on top, along with a weight of approximately 1kg to flatten and fuse the two layers together. After about one minute, the glue had solidified at room temperature, and the embedded samples were cut into four rectangular pieces, 20 x 10mm, using a sharp scalpel. This was done twice, to have eight hairs for cross-section analysis. However, when the hairs were very short, such as dorsal hairs, all eight randomly selected hairs were embedded in separate hot glue portions.

Hair Analysis and Identification

After the hair cross-section was prepared, the rectangular cuts were placed on a microscope slide and analysed using a Bosma light microscope equipped with a Hayer HY-500B HDMI Microscope Camera. Analysis was done at 10× and 40× magnification. Identification was based on characteristics of the hair's internal structure, such as its shape, colour, size and medulla structure. These features were compared with a cross-section key guide made by Selati Game Reserve to identify the prey species (Figure 2). For hair cross-section analysis, prey were recorded as a single occurrence regardless of the number of hairs from that prey identified within the same sample. This means that when multiple hairs from the same sample showed the same species, they were counted as one recording of prey rather than multiple.

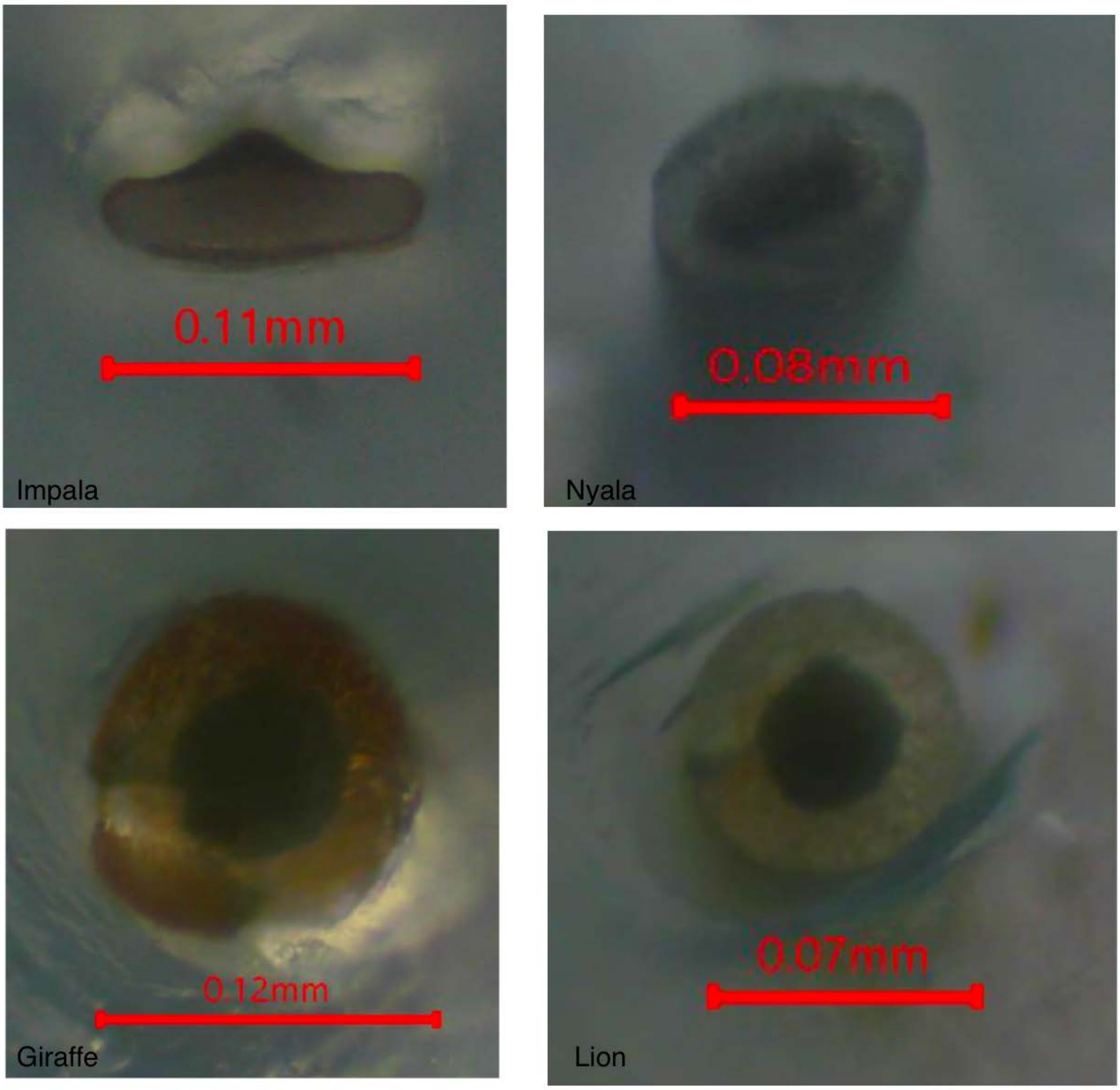

Figure 2: *Example of the microscope cross-section key guide provided by Selati Game Reserve, containing animal identification and scale with corresponding images.*

Ethical Considerations

This study ensures minimal impact on the lions and the ecosystem. All fieldwork, including kill site observations, was conducted under the supervision of experienced guides from Selati Game Reserve to ensure safe, non-invasive data collection and minimal disturbance to lions and other wildlife. Most lion kill observations were made after the lions had left the kill site, and no invasive methods were used. If researchers were present during a kill event, they maintained a non-invasive approach by keeping a distance recommended by the guides to avoid disturbing the natural behaviour of the lions and their prey. Scat was defecated by lions without any of the researchers' encouragement or interference.

Data Analysis

Assignment of Prey Body Mass

As this investigation's hypothesis and second research question are regarding prey size, a species-specific mean adult body mass (kg) was assigned to each prey recorded (The MammalBase community, n.d.). Body masses were log_{10} transformed prior to statistical analysis to improve normality and allow direct comparison of size distributions between the two methods, scat and kill site.

Statistical Analysis and Visualisation

Percentage occurrence (%) was calculated separately for each prey species documented in either scat or kill site, using the following formula:

$$\% = \left(\frac{number\ of\ occurrence\ of\ a\ species}{total\ number\ of\ prey\ records\ detected\ in\ that\ specific\ method}\right) \times 100$$

In order to determine the consistency of prey detection between both sampling methods, a Pearson's correlation coefficient test was done using RStudio (Version 2026.01.2+418) with R (Version 4.5.3). The analysis compared the percentage occurrence (%) of each identified prey species from scat (n = 31) and kill site (n = 37). A high correlation would indicate that both methods provide the same view of lion diet, while a low correlation would suggest that the methods capture different ecological information regarding lion diet.

For visualising prey body-size distribution, two complementary plots were generated in RStudio with R. A mirror back-to-back density plot was used to compare the kernel density of log_{10} (body weight) for scat and kill site samples. To show the full shape, median, interquartile range and data range of body size for both scat and kill sites, a violin plot with embedded boxplots was used.

Bayesian Analysis

A Bayesian robust two-sample t-test was done in R to evaluate differences in log10-transformed prey body weight between prey detected using scat analysis and kill site observations. Bayesian inferences were done because it calculates the likelihood of a difference between groups rather than solely relying on null-hypothesis significance tests. Posterior distributions were summarised using posterior mean differences, directional probabilities (pd) and 95% highest-density intervals (HDIs). Evidence of prey-size differences between both methods was evaluated based on the posterior probability that prey detected at kill sites were larger than prey detected in scat samples.

Results

Raw Data

A total of 30 scat samples and 37 kill sites were collected and used to investigate lion diet at Selati Game Reserve, South Africa. In total, 12 prey species were identified, with only six species detected by both methods: Giraffe, Impala, Greater Kudu, Lowland Nyala, Blue Wildebeest and Plains Zebra. Scat analysis detected a total of seven prey species, while kill sites recorded a broader prey range than scat analysis, with 11 species detected. There were some prey species detected by only one method; for example, Common Warthogs were only detected in scat samples twice. In contrast, kill sites had multiple species detected once: Aardvark, Bushpig, Common Eland and Leopard Tortoise, as well as Waterbuck, detected three times. From the 12 prey species identified, body masses ranged from small prey, with the leopard tortoise, 16.5 kg, being the smallest, to giraffes, 103.8kg, having the highest body weight (Table 1).

Table 1: *Summary of prey species identified in lion diet via scat analysis (n = 30) and kill site analysis (n = 37). Data includes mean adult body weight (kg), raw record counts (n), and percentage of occurrence (%) for each prey found in both sampling methods.*

Name	Species	Weight (kg)	Scat (n)	Scat (%)	Kill (n)	Kill (%)
Aardvark	*Orycteropus afer*	56.2	0	0.00	1	2.70
Bushpig	*Potamochoerus larvatus*	81.0	0	0.00	1	2.70
Common Eland	*Taurotragus oryx*	460.8	0	0.00	1	2.70
Giraffe	*Giraffa camelopardalis*	1038.3	4	12.90	6	16.22
Impala	*Aepyceros melampus*	49.2	6	19.35	4	10.81
Greater Kudu	*Tragelaphus strepsiceros*	221.0	5	16.13	1	2.70
Lowland Nyala	*Tragelaphus angasii*	82.2	7	22.58	2	5.41
Warthog	*Phacochoerus africanus*	77.2	2	6.45	0	0.00
Waterbuck	*Kobus ellipsiprymnus*	200.9	0	0.00	3	8.11
Blue Wildebeest	*Connochaetes taurinus*	199.2	2	6.45	9	24.32
Plains Zebra	*Equus quagga*	252.2	5	16.13	8	21.62
Leopard Tortoise	*Stigmochelys pardalis*	16.5	0	0.00	1	2.70

Comparison of Methods

Percentage of Occurrence

A taxonomic comparison of prey occurrence revealed noticeable differences between the two sampling methods (Figure 3). There is a clear mismatch between the prey species detected by both methods. Scat detects smaller-to-medium ungulates as primary dietary components, with Lowland Nyala (22.58%) and Impala (19.35%) having the highest percentage occurrence. In contrast, for kill sites, Lowland Nyala and Impala had low occurrences (5.41% and 10.81%). Instead, kill sites were dominated by larger species, specifically Blue Wildebeest (24.32%) and Plains Zebra (21.62%; Table 1, Figure 3).

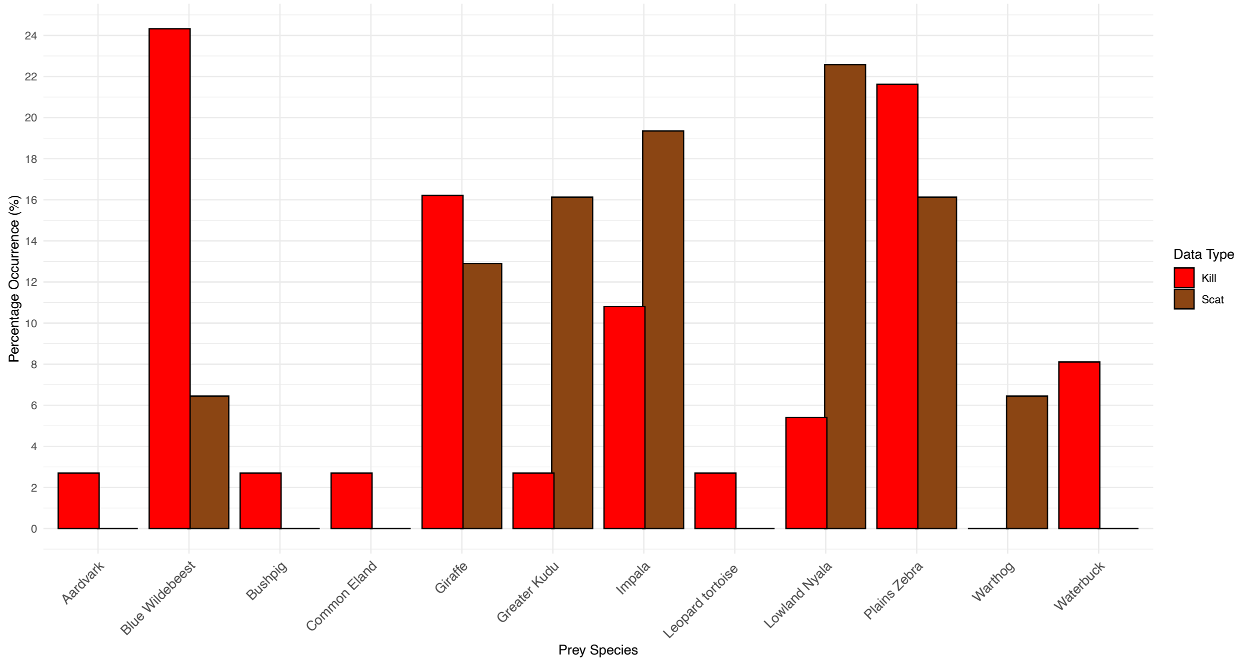

Figure 3: *Comparison of prey species percentage of occurrence (%) between detections at kill sites (red) and scat samples (brown). Species are ordered alphabetically along the x-axis, and bars represent the percentage of occurrence for each species across the study period.*

A Pearson's correlation analysis revealed a weak and non-significant correlation between the percentage occurrence of species in scat and kill sites ($r = 0.33$, $p = 0.296$; Table 2). Because the relationship was not statistically significant, the analysis does not provide sufficient evidence to conclude that prey occurrence estimates are correlated. However, the observed differences in species composition and prey-size distribution suggest that both methods may capture different components of lion diet.

Table 2: *Results of Pearson's correlation comparing the percentage occurrence of prey species detected via scat and kill site. The table shows the correlation coefficient (r), t-statistics, degrees of freedom (df), and P-value (p < 0.05 considered significant).*

Metric	Value	Interpretation
Pearson's r	0.330	Weak positive correlation
t–statistic	1.104	Test statistic
Degrees of Freedom	10	n–2
P–value	0.296	Non–significant
95% CI Lower	–0.301	Includes zero
95% CI Upper	0.760	Upper bound

Body Size Differences Between Scat and Kill Samples

The mirrored density plot (Figure 4) is a back-to-back density plot, allowing for comparison of where the mass of data lies. The scat data (brown, top) has the highest peak close to 0 log_{10} (body weight), showing a preference for detecting small prey. In contrast, the kill data (red, bottom) has its peak shifted slightly to the right, showing a preference for larger body weights, while still having some preference for small prey.

The mirror graph can also be used to see where the two methods detect the same body weights. Both graphs have a significant peak at the far left, showing that both scat and kill surveys are able to detect small prey 0.00 to 1.51 log_{10} (body weight).

Furthermore, the graph can also show sampling bias by having asymmetry between the two sampling methods. Scat data shows a bias for smaller-bodied prey, as seen between 1.01 and 2.5 log_{10} (body weight), which indicates that scat is more sensitive to smaller prey items. Kill site surveys have the opposite bias, toward larger-bodied prey, 6.06 to 8.58 log_{10} (body weight), as these carcasses are visible for longer, making them easier to find compared to smaller prey carcasses.

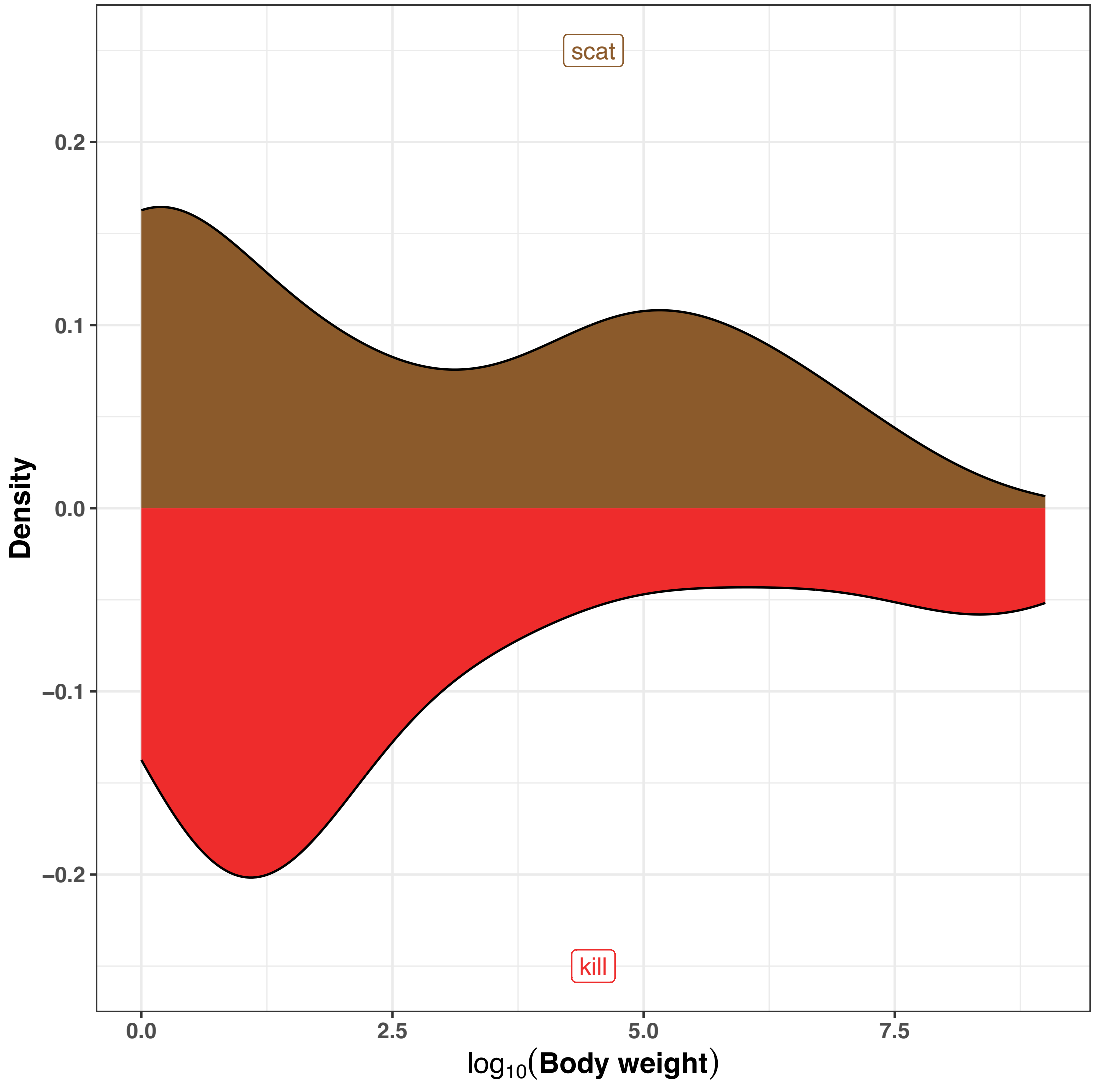

Figure 4: *Mirrored density plot comparing the relative probability density of prey body weights (log_{10}) between scat samples (top, brown) and kill sites (bottom, red). This graph highlights the specific weight ranges where each sampling method shows higher detection sensitivity.*

The violin plot (Figure 5) illustrates the distribution of data; the width represents how many prey counts were found at specific weights. Scat sampling shows a "stretched" distribution where there are many small prey, but there are also some large prey, with the maximum weight being around 3.5 $\log_{10}$ (body weight). Kill site has a different distribution, which is more clustered, with both small and large body weights being detected. However, the widest part for kill site is around 2.3 $\log_{10}$ (body weight), meaning that most prey detected at kill sites are medium-sized. Comparing both sampling methods shows that there is a clear difference in prey size detected.

Continuing on this, the violin plot contains box plots that show a difference in median. Kill site median is slightly higher than scat samples, meaning that larger prey are more likely to be detected at kill sites. The interquartile range shows body weight detection, and it is noticeably wider for scat than kill sites, meaning that scat samples exhibit greater body weight detection.

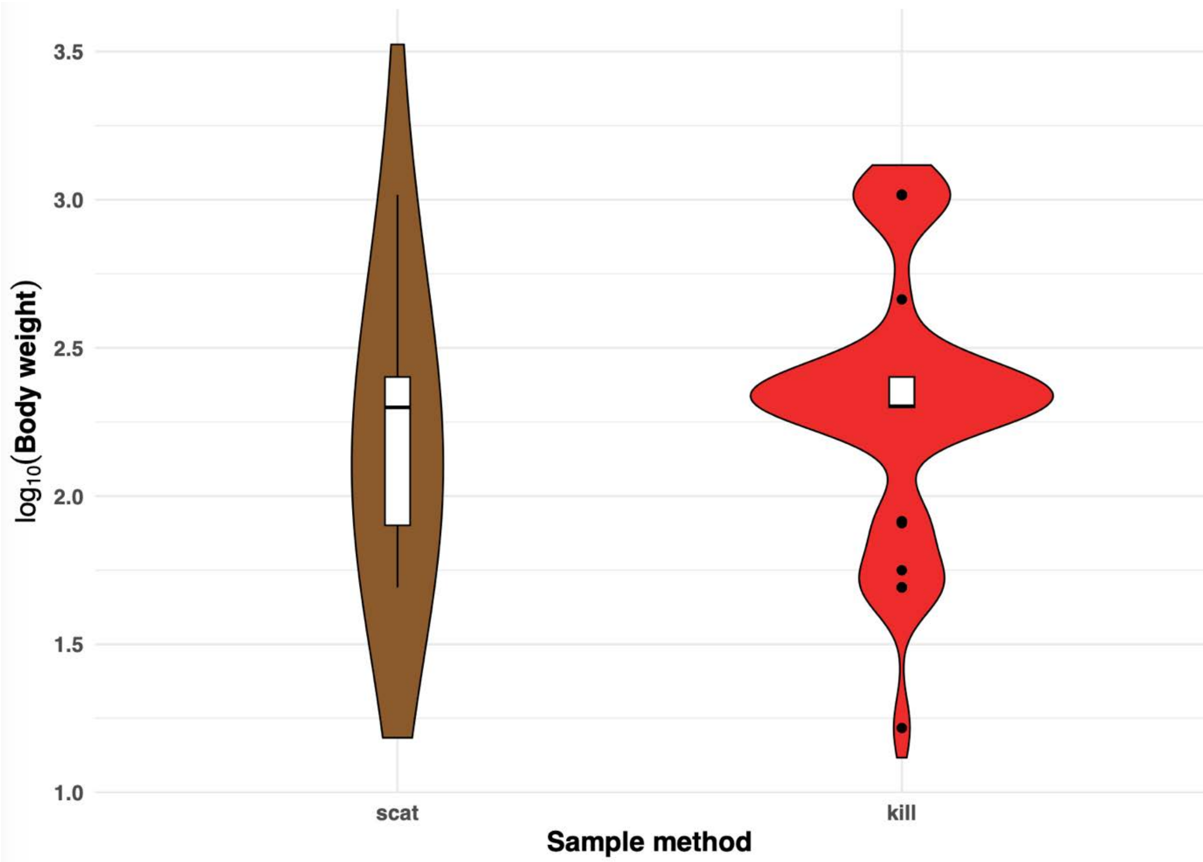

Figure 5: *Violin plot showing the distribution of log_{10} prey body weight across the sampling locations, scat (brown, left) and kill (red, right). The width represents how many prey items were found at that specific weight, while the internal box plot displays the median (horizontal line) and interquartile range (white box). Individual black dots indicate potential outliers in the kill site data.*

To detect weight-based sampling bias between the two methods, a Bayesian robust two-sample t-test was used, with results shown in Table 3. The posterior distribution showed that prey found at kill sites were, on average, heavier than those found in scat samples. When compared to the scat analysis, this high posterior probability indicates a persistent bias towards larger prey items in carcass-based surveys. This analysis result is also supported by the Pearson correlation test (Table 2) and the box plot in the violin graph, as the kill sampling location has a higher median than scat (Figure 5).

Table 3: *Summary of Bayesian robust two-sample t-test comparing log_{10} prey body weights between scat and kill site sampling methods. Parameters include posterior mean difference (D), standardised effect size (eta), posterior probability (p) and directional probability (pd). Values in brackets represent the 95% high density interval (HDI).*

Parameter	Symbol	Value	95% HDI	Interpretation
Mean Difference (D)	D	–0.162	[–0.370, 0.064]	Weight gap
Effect Size (eta)	eta	–0.39	[–0.92, 0.13]	Small–medium effect
Posterior Prob (p)	p	0.930	–––	93.0% chance Kill > Scat
Directional Prob (pd)	pd	0.070	–––	7.0% chance Scat > Kill

Discussion

Comparison Between Scat and Kill Sites

The results of this investigation demonstrate a difference in prey detection between scat analysis and kill site investigations. This difference indicates that both methods do not detect the same dietary information; in contrast, they each capture different components of lion diet. Together, these findings reinforce the need to integrate multiple approaches to obtain a complete understanding of lion's diet.

Prey Composition

Addressing the first research question: *How do prey species identified at kill sites compare to those identified in lion scat?* The results confirm that while there is some overlap, the two methods demonstrate different taxonomic composition. Only 50% of the identified species were detected by both methods. The Pearson correlation coefficient ($r = 0.33$; Table 2) suggests that in this study, the dietary trends do not mirror one another.

Kill site records were strongly dominated by large prey, with Blue Wildebeest (24.32%) and Plains Zebra (21.62%) being the most frequent prey species recorded. Additionally, medium-large species like Waterbuck (8.11%) were recorded exclusively at kill sites. In contrast, scat analysis highlighted small to medium-sized antelopes, such as Lowland Nyala (22.58%) and Impala (19.35%), which were under-represented in kill site data. Together, these results show that lion diet interpretations are dependent on sampling methods. Therefore, to see the overview of lions' diet, both methods need to be used, otherwise only one aspect of their diet will be represented.

Detection of Small Prey

The second research question: *Does the inclusion of lion scat analysis provide a more comprehensive dietary overview by increasing the detection of small prey species that may be excluded in kill site observations?* In response to this question, the results show that scat analysis does indeed increase the detection of small prey. The mirrored density plot (Figure 4) shows a clear, significant peak in detection sensitivity for scat in lower weight classes 0.0 – 2.5 log_{10} (body weight), which is not shown in kill site data. Scat analysis detected Common Warthog exclusively; however, this species was only recorded twice. Consequently, this pattern should be interpreted cautiously because low detection frequencies may reflect sampling variation rather than consistent methodological differences. Nevertheless, the broader distribution of smaller-bodied prey detected through scat analysis supports the conclusion that scat sampling improves detection of prey that may be underrepresented at kill sites.

The hypothesis that smaller prey would be observed more frequently in scat than at kill sites is strongly supported by statistical evidence. Bayesian analysis indicated a 93% certainty that prey found at kills are heavier than those identified in scat. Statistically, the violin plot (Figure 5) confirms the "downward shift" in weight for scat samples. Confirming that small-to-medium-sized prey are more dominant in scat-based analysis. Overall, the bias arises because large carcasses are more conspicuous and last longer in the environment; therefore, they are easier to locate and record. In contrast, smaller prey are consumed more quickly, leaving fewer detectable remains at kill sites and appearing predominantly in scat, and sometimes exclusively in the case of Common Warthogs.

Comparison With Previous Studies

These findings align with and add to previous research on methods used to study large carnivore diets. Rapson and Bernard (2007) carried out a comparison study of several techniques for studying lion diet in South Africa. Their findings showed that kill site and scat analysis gave different prey profiles; therefore, they concluded that lion diet strongly depends on sampling methods. Their results showed that kill site surveys overestimate large prey, and scat samples detect a wider range of medium and small prey. This investigation's weak Pearson correlation supports the study's conclusion, as r = 0.33 (Table 2), suggesting that kill site and scat analysis detect different prey categories. Additionally, out of the 12 total species detected, only six prey species were detected by both scat and kill sites, further confirming that scat and kill sites detect different prey species and at different quantities.

Similarly, to kill site records, Tambling et al. (2011) used GPS-cluster data together with scat samples. Their results show that scat collected along known movement routes revealed a wider range of prey sizes, particularly smaller-bodied prey. In contrast, carcass observations were biased towards large prey, likely due to smaller prey being eaten more quickly and leaving less evidence in the field compared to larger prey. Therefore, the researchers stressed that both methods should be combined to avoid underestimating the true diet of carnivores. This pattern is also shown in this investigation’s mirrored density (Figure 4) and violin plot (Figure 5). The mirrored density plot (Figure 4) shows the same small-prey versus large-prey detection as Tambling et al (2011). The scat curve shows a peak at low !"#!" (body weight), in contrast to the kill site curve shifted towards higher body weights. Similarly, the violin plot (Figure 5) shows a broader prey-size spectrum for scat compared to kill site, which is clustered at low and high body weights. Beukes et al. (2017) found similar results. Scat analysis showed better detection of small prey species, while kill site data rarely detected small prey. Due to these different prey detection methods, they recommended that both methods be used together for an accurate diet estimate. Both Tambling et al. (2011) and Beukes et al. (2017) results closely match the second research question on the detection of small prey.

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The value of scat analysis for revealing dietary components that may otherwise go undetected is also supported by Rapson and Bernard (2007). This study showed that scat-based methods identified a broader range of prey species than kill site surveys. These findings, along with the results of this investigation, reinforce the importance of including scat analysis when assessing lion diet, particularly for medium-to-small-sized prey, which may leave little evidence at kill sites due to rapid consumption.

Overall, these previous studies strongly support my findings. The present investigation builds on previous work by applying Bayesian analysis alongside visual tools, mirrored density and violin plots to assess prey-size bias. This combined graphical and statistical approach offers ways of interpreting sampling bias and complements previous studies.

Methodological Insight

The integration of scat samples and kill site records collected from the same lion population allows for a clear picture of methodological sampling bias on lions' diets. This is different to previous studies that considered these techniques as separate and complementary approaches (Rapson & Bernards, 2007).

The mirrored density plot (Figure 4) and violin plot with boxplots (Figure 5) provide clear visual comparisons in prey-size patterns between the two methods. Bayesian analysis brings further support, as it shows a high probability that prey found at kill sites were larger than those detected in scat samples. Therefore, these visuals and statistical methods help show similarities and differences between the two methods.

In order to get a realistic and full comprehension of a lion's diet, both methods should be used as neither method is sufficient on its own. This investigation's results, as well as previous studies, show that kill site records can overestimate the importance of large prey, while scat data can underestimate them (Beukes et al., 2017; Tambling et al., 2011).

Implications for Closed Game Reserves

In open landscapes, lion diet varies seasonally with prey movement (Davidson et al., 2013), but in fenced reserves, both lions and prey are limited in their movement, increasing predator-prey interactions. Having an accurate diet assessment is essential in closed game reserves to prevent overpopulation and an unbalanced ecosystem. Therefore, closed game reserves should use both scat and kill site analysis for a more accurate diet overview that includes a wide range of prey species.

Limitations

In January 2026, there was heavy rainfall leading to flooding, which influenced sampling locations and collection because roads were inaccessible, and the rain accelerated carcass and scat decomposition. Additionally, 17 scat samples were unusable, as samples collected prior to January were stored in a box that got wet, leading to the bags breaking and the scat being cross-contaminated. This led to a temporal mismatch between sampling methods. Most kill site data were collected prior to January 2026, whereas scat samples were predominantly collected from January until April 2026. Consequently, some of the differences between the two methods may be due to temporal variation in prey availability rather than methodological bias alone.

Further Research Directions

Methodological Recommendations

Further studies should address the limitations noted above and build on this preliminary work in several ways. To test method bias changes over time and across seasons, future studies should use a larger sample size collected over a longer duration.

Using full DNA metabarcoding of scat samples, rather than morphological analysis of hairs alone, would improve taxonomic resolution for highly digested prey items. Additionally, including species-specific detection probabilities for both scat and kill sites would account for more accurate estimates of lion diet, as prey differ in how likely they are to be detected by each technique.

Fitting GPS collars to more lions, as well as including individuals from several prides, would provide more representative scat and kill site data, allowing for direct comparison between prey choices of individual lions and the overall population diet pattern.

Ecological Recommendations

Further studies could investigate the effect of social instability in prides on lion diet by comparing the diet before and after the loss of a dominant male. The loss of dominant males may lead to pride fragmentation, altering how they use the landscape and access prey resources. These social disruptions may influence hunting group size and coordination, thereby affecting the type of prey lions are able to capture (Hayward & Kerley, 2006). Changes in territorial boundaries can expose prides to different prey communities, further shifting diet composition (Bauer & van der Merwe, 2004). Prey availability and selection are closely linked to pride stability and behaviour; therefore, the removal of a dominant male can lead to changes in prey profile, hunting patterns and overall diet (Beukes et al., 2017; Davidson et al., 2013).

Conclusion

This study demonstrates that combining scat data with kill site observations provides researchers with a more detailed and reliable estimate of lion diet than either method alone, since they generally detect different species. Kill site data tend to over-represent large-sized prey due to differences in detectability and carcass preservation duration. In contrast, scat analysis captures a wider range of medium-to-small prey that are regularly underrepresented in field-based surveys, such as kill sites.

Both statistical and graphical results show that there is a consistent size-based difference between the two methods. Bayesian analysis (Table 3) indicates a high probability (93%) that prey recorded at kill sites are heavier on average than those detected in scat samples (7%). This confirms that the two methods provide complementary and different views of the lion's diet.

These findings are particularly important in fenced game reserves, where prey populations are limited and actively managed. Relying on a single method may lead to a biased interpretation of prey use and affect management decisions. The results suggest that scat analysis and kill site observations provide partially overlapping but non-identical information regarding lion diet. Scat analysis improved detection of some smaller-bodied prey while kill site observations identified a broader range of prey species overall. Therefore, combining both methods may provide a more complete dietary assessment than relying on either method alone.

Although prey-size related differences were evident, the presence of large-bodied species such as giraffe in scat samples indicates that methodological bias cannot be solely explained by prey body mass. Future studies could investigate additional ecological and behavioural factors influencing prey detection.

Practical Management Recommendations

Game reserves should incorporate both scat analysis and kill site monitoring as part of their wildlife management strategy. Using both methods provides a more comprehensive understanding of lion diet and predation patterns. This combined monitoring can improve estimates of prey population and carrying capacity by revealing which species are most frequently targeted by lions and whether predation pressure is evenly distributed across prey species or communities.

Dietary monitoring can also be used to maintain ecosystem balance through habitat interventions and prey species reintroduction. Dietary monitoring can show areas of high predation pressure, allowing for the reserve managers to evaluate habitat quality to make sure it supports a diverse prey base, to maintain ecological balance and prevent trophic disruptions (Estes et al., 2011). If a particular species is heavily targeted, managers can take steps to reduce the risk of population decline by reintroducing it, thereby maintaining ecosystem balance.

Regular diet assessment is important for long-term lion conservation. Changes in pride structure, such as the loss of dominant males, can influence hunting behaviour and prey selection. Repeating diet studies allows for detecting potential shifts in prey use following a change in pride structure, thereby allowing the managers to respond accordingly. Therefore, integrating scat and kill site analysis as routine monitoring can help ensure stable predator-prey interactions and long-term ecological balance of the reserve.

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