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Assessing the health of lions (*Panthera leo*) in a reserve: A study of Body Condition Score and Stomach Contents Index

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Key Words: Body condition score, Stomach contents index, Animal health, Camera trap, *Panthera leo*, lion, reserve management, Naankuse

Abstract

This research assesses the potential of the body condition score (BCS) and the stomach contents index (SCI) as indicators for monitoring the health status of lions within a fenced-off reserve in central Namibia. BCS is a non-invasive management tool that evaluates an animal's accumulation of fat and muscle, and SCI is the measure reflecting the saturation state of the stomach.

Using 3,700 camera trap pictures from November 2018 to August 2023, we firstly study BCS and SCI of five adult lions (*Panthera leo*), including two males and three females in a 7,500 hectare fenced-off reserve. Then, we investigate the potential correlation between BCS and SCI and analyse whether factors such as sex, moon phase, season, and time of day have an impact on BCS and SCI. Finally, we investigate the influence of BCS and SCI on the drinking behaviour of the lions.

We found that BCS assessments reveal an ideal health status among the lion population in this reserve, while SCI demonstrates a rapid and dynamic response to their feeding behaviour. Analysing the five lions simultaneously reveals a significant positive correlation between BCS and SCI. Concerning the males and females, BCS remains stable across sex but differs between long-term residents and newly introduced lions. In contrast, SCI is unaffected by sex or lion introductions. Our study found no significant variations in BCS and SCI according to the moon phases. While no significant difference in BCS distribution was observed across seasons, SCI varied between dry seasons (dry summer and dry winter) and humid seasons. BCS and SCI showed no differences during dawn, day, and dusk, but we found differences for both between night on the one hand and dawn, dusk, and day on the other. Both BCS and SCI influence their drinking behaviour.

The conclusion is that understanding BCS and SCI enhances the monitoring of lion health status, enabling action to be taken accordingly for the effective management of a fenced-off reserve.

Introduction

The lion (*Panthera leo*) is an iconic apex predator within African ecosystems (Henschel et al. 2016), playing an important role in maintaining the ecological balance by regulating diverse prey species (Funston & Mills 2006; Lima 1998) and influencing other carnivore populations (Périquet, Fritz, & Revilla 2015). Despite occupying the top of the food web, African lion populations almost halved during the last two decades (Abade et al. 2020). This decline can be primarily attributed to factors such as habitat loss and fragmentation, human-wildlife conflict, poaching, and diseases (Bauer et al. 2015; Everatt, Kokes, & Pereira 2019; Sargent et al. 2022; Trinkel 2013; Young 1975).

These essential animals typically live in prides comprising one to three males, several females, and their offspring (Kothe & Taffin-Jouhaud 2018). Being a social predator confers certain advantages, including heightened territorial competition and better prey capture rate (Hopcraft, Sinclair, & Packer 2005; Mosser & Packer 2009). However, this social structure may also entail disadvantages. Indeed, transmission of disease is accelerated among individuals within a group due to proximity, impacting their overall health (Ezenwa et al. 2016).

For reserve management or for conservation efforts it is essential to ascertain the size of the different populations, understand their ecological niche, and assess their health status (Massey, King, & Foufopoulos 2014; Welch & Parker 2016). Every species holds significance, even if some exert a more substantial impact on the ecosystem balance (Ellison & Degrassi 2017). This is particularly true for carnivores, given their role in regulating prey populations (Funston & Mills 2006; Lima 1998). When apex predators are in poor condition, the rest of the food web is more likely to be unbalanced, leading to major deregulation in the ecosystem and significant consequences (Davies et al. 2016; Yugovic 2015). Therefore, it is crucial to monitor and understand the health status of the lion population within a reserve, to recognise the natural cycles of their physical condition influenced by specific environmental factors and their influence on the drinking behaviour of lions.

In this context, the study will assess the potential of body condition score (BCS) and stomach contents index (SCI) as indicators for monitoring the health status of lions. The analysis encompassed BCS and SCI assessments of five adult lions from November 2018 to August 2023 using 3,700 camera trap pictures. The camera traps were distributed across the 7,500 hectare Zannier Reserve (-22.43723° latitude, 17.42623° longitude) in central Namibia. It is situated in the thornbush shrubland biome with annual rainfall of 250 to 300 mm.

BCS serves as a management tool devised to evaluate an animal's body reserves or fat and muscle accumulation (Coon et al. 2019; Daigle et al. 2015; Teng et al. 2018). SCI is the measure reflecting the saturation state of the stomach (Bertram 1975; Ogden et al. 2008). In the context of this research, BCS was divided into five categories (1 = emaciated / 5 = obese) and SCI into four categories (1 = completely empty stomach / 4 = completely full stomach). BCS functions as an indicator of an animal's health status (Coon et al. 2019; Ezenwa, Jolles, & O'Brien 2009; Teng et al. 2018), whereas SCI indicates length of time since the lion last consumed food, thereby serving as a proxy for feeding intervals (Bertram 1975; Ogden et al. 2008).

Firstly, this study will focus on a detailed elucidation of the body condition score and stomach contents index, providing clarity on their interpretation and significance in the context of reserve management. Subsequently, BCS and SCI values of the studied lions will be presented, facilitating a clear visualisation of their evolution. The next section will focus on the evaluation of a possible correlation between BCS and SCI. Following this, a detailed exploration of the influence of sex on BCS and SCI will be undertaken. Additionally, the impact of environmental factors such as moon phases, seasons, and time of day, will be analysed and interpreted. Finally, the impact of BCS and SCI on the drinking behaviour of lions will be analysed.

Hypothesis

Understanding BCS and SCI enhances the monitoring of lion health status, facilitating the determination of action to be taken for the effective management of a fenced-off reserve.

Research questions

This research addresses the following questions in relation to reserve management:

1. Can the analysis of BCS and SCI through camera trap pictures provide an indication of lion health within a reserve?
2. To what extent do factors such as sex, moon phases, seasons, and time of day have an impact on BCS and SCI?
3. Is the drinking behaviour of the lions influenced by the BCS and SCI?

Materials and Methods

Study site: Zannier Reserve

The study site is the Zannier Reserve, managed by the N/a'an ku sê Foundation, located 45 km east of Windhoek (-22.55941° latitude, 17.08323° longitude) in the Khomas region of Namibia. This 7,500 hectare reserve contributes to the conservation and protection of biodiversity by preserving the natural habitat of its diverse wildlife. The reserve serves as a relocation destination for animals involved in human-wildlife conflicts. A research team is working on the reserve to understand the behaviour, movement, and ecological dynamics of the resident wildlife. The anti-poaching unit ensures the security of wildlife. Several camera traps are placed in the reserve for research and monitoring of wildlife (Fig. 1). Situated in the savannah habitat with a main river on the south-eastern side, the reserve is home to a wide diversity of animals. This includes but is not limited to primary consumers such as white rhinoceros (*Ceratotherium simum*), common eland (*Taurotragus oryx*), impala (*Aepyceros melampus*), springbok (*Antidorcas marsupialis*), African savanna elephant (*Loxodonta Africana*), plains zebra (*Equus quagga*), and Angolan giraffe (*Giraffa angolensis*). Additionally, secondary and tertiary consumers such as leopard (*Panthera pardus*), brown hyena (*Hyaena brunnea*), cheetah (*Acinonyx jubatus*), and lion (*Panthera leo*), contribute to the rich ecological diversity of the reserve.

Population of the study: Lion pride

Considering that lions' home range can vary from 2,000 to 207,500 hectares across study areas (Lehmann et al. 2008), this 7,500 hectare reserve holds a single lion pride. This pride was studied from November 2018 until August 2023 and its composition, that has varied over time as illustrated in Figure 2, differs from a classic lion pride. The inception of the pride dates back to the first sighting on 20 November 2018, when a lion pride was introduced from the Brandberg area to the Zannier Reserve. The pride initially consisted of two female adults and three cubs (one male and two females). In this study, the cubs are considered adults from 17 September 2019, based on observable morphological changes and distinct patterns on their legs and belly. Subsequently, the lion pride evolved to consist of one male and three females, as one of the female cubs

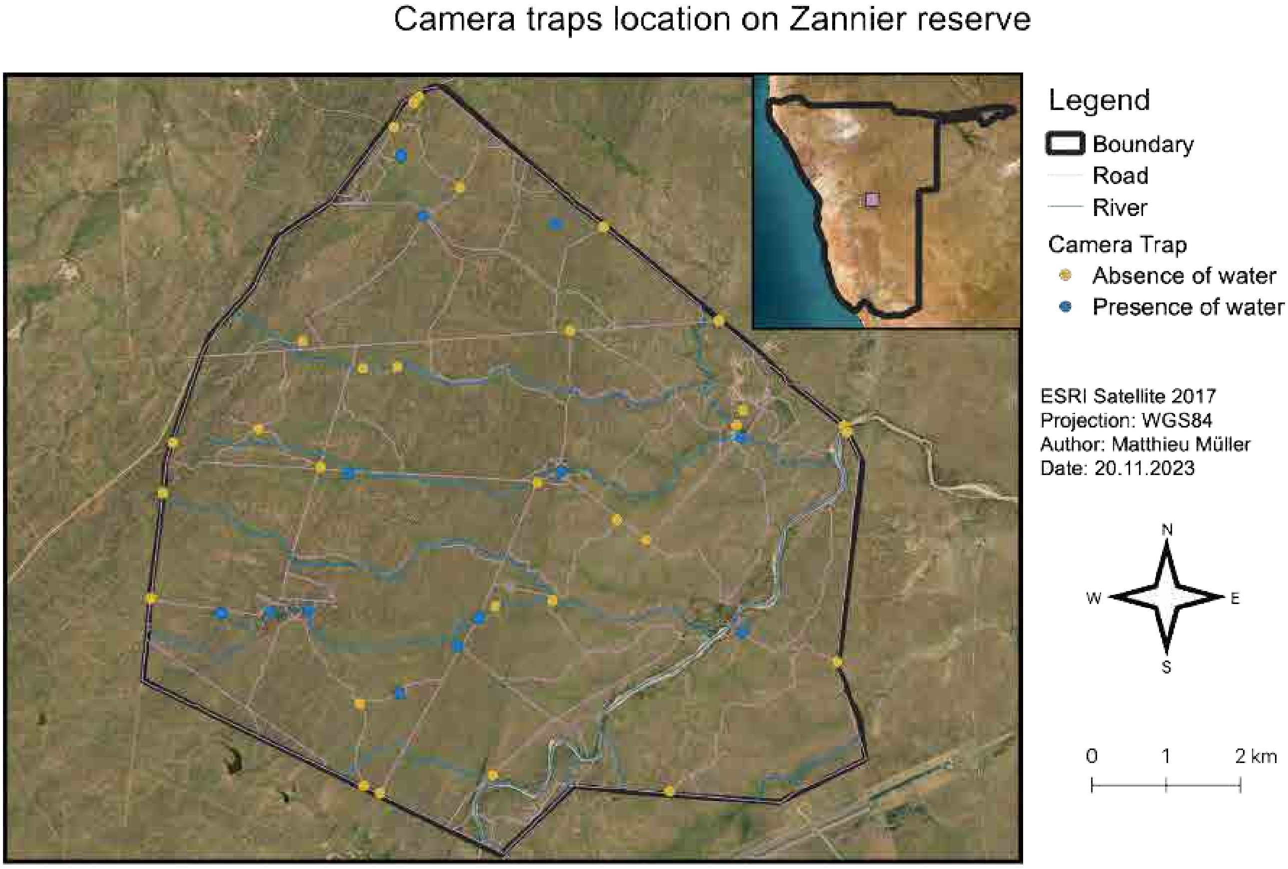

Figure 1: Map presenting the distribution of the camera traps on Zannier reserve

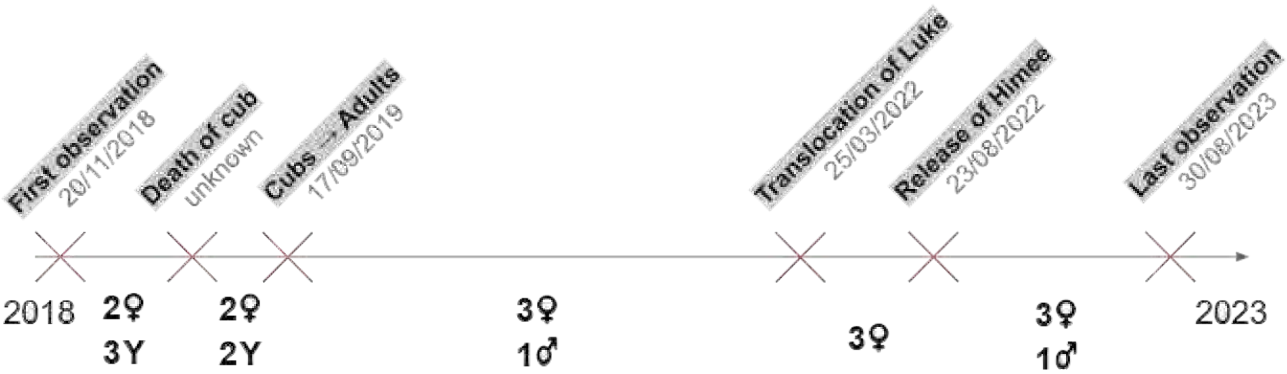

Figure 2: Timeline explaining the changes in the lion pride composition over the years

did not survive. On 25 March 2022 the initial male, Luke, was relocated to another reserve, resulting in the pride remaining without a male until 23 August 2022. At this point, a new male named Himezembi (also called Himee) was released on the reserve. From this time, the composition remained stable until the end of the observations for the research on 30 August 2023.

Body Condition Score / Stomach Contents Index

The body condition score (BCS) serves as a subjective and non-invasive management tool for evaluating the physical condition of an animal. It considers the quantity of fat and muscle material and the visibility of specific bones, providing insights into the long-term food consumption and overall health status of the animal (Daigle et al. 2015; Teng et al. 2018).

In the context of this study, BCS is divided into five categories, 1 indicating an emaciated lion, 3 an ideal animal and 5 an obese one (Fig. 3). BCS of 1 is characterised by the absence of muscles in the neck, shoulder, and tail base area, prominently visible vertebrae, ribs and pubic bone, and extremely thin limbs. BCS of 2 is identified by a slight presence of muscle in the neck, shoulder, and tail base along with slightly visible vertebrae, ribs, and pubic bone, with limbs still being somewhat skinny. BCS of 3 is defined by muscle definition in the neck, shoulder, and tail base, with vertebrae, ribs, and pubic bone mildly visible but not prominent, and strong limbs without excess fat. BCS of 4 is represented by a thick neck, shoulder, and an obscured view of vertebrae, ribs, and pubic bone, with fat limbs and tail base area. BCS of 5 indicates a fat animal on all levels,

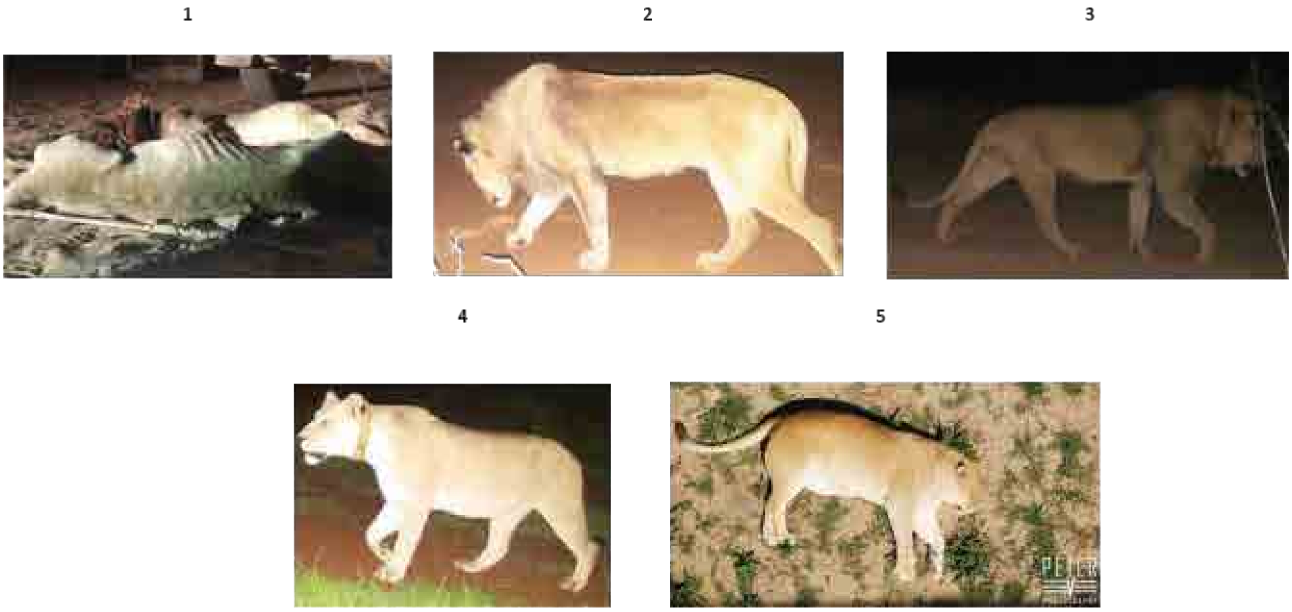

Figure 3: Five different categories of body condition score for the lion. (Pictures 1–4: N/a'an ku sê Foundation; Picture 5: Published with permission of Peter Van, pers. comm.)

with rolls sometimes visible on the neck and belly, and layers of fat covering the entire animal.

The stomach contents index (SCI) reflects how full the animal's stomach is (Bertram 1975; Ogden et al. 2008). It is a subjective and non-invasive method and reflects the food consumption over a short period. In the context of this study, SCI is split into four categories, with 1 indicating a completely empty stomach and 4 representing a completely full stomach (Fig. 4). SCI of 1 is characterised by a stomach well above the chest. SCI 2 is identified by a slightly lower position of the stomach, though not completely flat. SCI of 3 is recognised by a flat stomach, aligning with the chest level. SCI of 4 is characterised by the stomach positioned below the level of the rib cage.

Data collection

Camera trap data analysis

3,700 lion pictures were selected from camera trap data, in 44 locations between 20 November 2018 and 30 August 2023. To streamline the analysis, all pictures that were taken by one camera trap within a two-hour timeframe were considered as a single observation. Each lion in every observation was recorded, with a total of 380 observations. The following variables were recorded per observation: camera trap location, date, time, ID of the observation, number of pictures (for each observation), number of lions (for the observation), picture quality for the identification of BCS and SCI (useless; bad quality; medium quality; good quality), sex (Luke; Himee; female; juvenile), BCS (1–5), SCI (1–4).

Quality control for BCS and SCI involved a thorough process. The assessment and verification of all variables, including BCS and SCI, were repeated three times by the researcher. When BCS or SCI identification posed challenges, three additional researchers conducted further reviews. Additionally, 76 randomly selected pictures from different observations, corresponding to 1/5 of the total observations, were discussed with the research team to assess the assigned BCS and SCI categories. The consistency level achieved was 94.3% with differences of only one category, observed both in upward and downward trends.

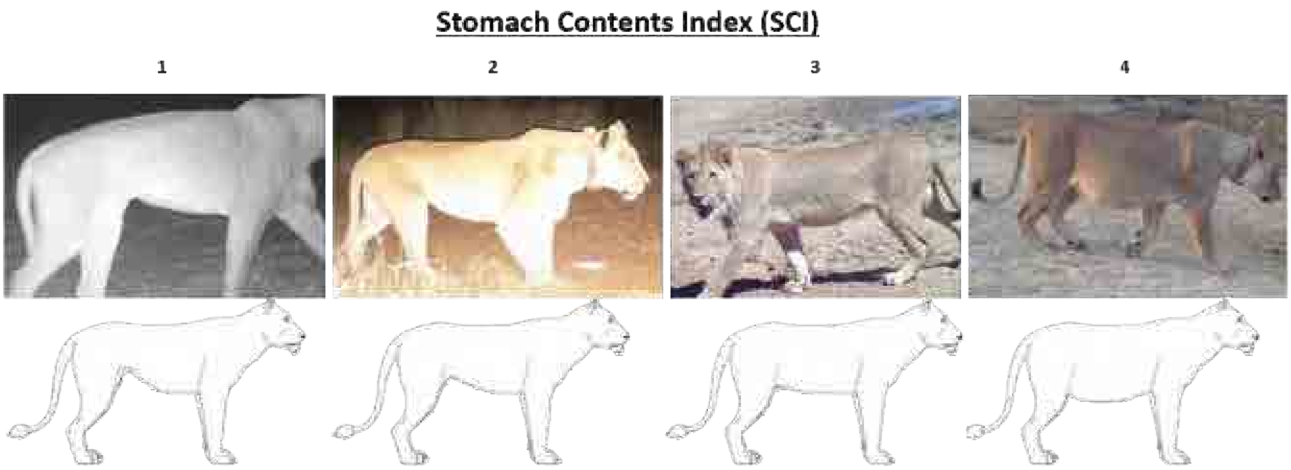

Figure 4: Four different categories of stomach contents index for the lion. (Pictures 1–4: N/a'an ku sê Foundation)

Environmental factors

Moon phase data, based on the date, was categorised into four main phases: new moon, first quarter, full moon, or last quarter, using the information from the web site "phasesmoon.com" (Moon Phases Today | Lunar Phase n.d.). A full cycle of the moon takes about 29.5 days, and each of these main phases lasts a little over a week (Jongbloet 1983). When the moon was in-between these main phases (waxing crescent, waxing gibbous, waning crescent, waning gibbous), they were divided into halves and attributed to the nearest main phase. In the case where the division resulted in an odd number, the previous phase was selected.

Seasons were divided into dry summer (October, November, December), humid summer (January, February, March, April) and dry winter (May, June, July, August, September).

A similar approach was used for the time of day classification: dawn (05:01 to 07:00), day (07:01 to 18:00), dusk (18:01 to 20:00), and night (20:01 to 05:00).

GPS location and drinking behaviour

The GPS location of each camera trap was recorded with decimal notation (DD.DDDDD°) and plotted on a map of the reserve. Each location was classified based on the presence or absence of a water point, with these water points being permanent. Camera traps in areas with water were focused directly on the water point, showing only animals drinking or staying a few meters from the water point. The camera traps in areas without water were used to monitor lion without a drinking behaviour. This is why areas with or without waterpoints were assumed to be related to their drinking behaviour.

Collar data

Lions' locations were studied using GPS collar data, which recorded their positions approximately every three hours. Unfortunately, technical issues with the collars prevented us from following the movement of an animal, as records were not regular enough. This is why, this data was only used to assess whether the lions were together following the introduction of new individuals.

Data analysis

Data preparation

Using RStudio (R Core Team (2022) v.4.2.0), the data underwent initial cleaning and verification to identify and exclude any mistakes or inconsistencies. The observations of the cubs were excluded from the dataset since only 41 observations were recorded, and no existing literature provided information on BCS and SCI for cubs.

General BCS and SCI

In RStudio, bar charts were generated to analyse the distribution of observations for BCS and SCI using the package ggplot2. A chi-squared goodness of fit test was performed to assess whether the number of observations in each BCS or SCI category differed significantly.

The distribution of BCS and SCI data was examined using a Shapiro-Wilk test. Since this test showed the non-normality of the data, a nonparametric Kendall correlation test was performed to evaluate the correlation between the two variables. The graph of a linear relationship between BCS and SCI and another bar chart showing the number of observations by SCI by BCS were generated. These visualisations were created to show the relation between SCI and BCS.

Sex

The temporal feeding patterns of the lions over the different months were investigated using a scatter plot. BCS and SCI of the males and the females were separately analysed on a timeline and a Chi-Squared test of independence was performed to identify differences of BCS or SCI between the sexes. A nonparametric Kendall correlation test was conducted separately for each sex category.

Environmental factors and drinking behaviour

The relation between BCS or SCI and the environmental factors (moon phase, season, or time of day) as well as their drinking behaviour were explored using a Chi-Square test of independence and illustrated with bar chart graphs. Even with some differences in the length of the three different seasons and four different times of day, the Chi-Square test of independence is adapted as it serves to compare the pattern of BCS and SCI, not considering directly the number of observations, but their proportion (Franke, Ho, & Christina 2012).

Map

A map showing the distribution of the camera traps in the Zannier Reserve was created using QGIS3 (QGIS Development Team (2020) v.3.14).

Results

BCS and SCI

Regarding BCS, no instances of category 1 or 5 were recorded. The distribution of category 2, 3, and 4 was uneven, with BCS of 3 being the most frequently observed assessment and BCS of 2 the least (Fig. 5). Highly significant differences in the number of observations across all BCS categories (χ^2=219.83, df=2, p<0.001) were noticed. In the cases where BCS estimations were uncertain due to the picture quality, they were classified as unknown (Unk).

For SCI, all categories (1 to 4) were documented, with the majority of observations belonging to category 3 or 4 (Fig. 6). A notable number of observations were classified as SCI of 2, while only a limited number were assigned as SCI of 1. The difference in the number of observations across SCI categories was highly significant (χ^2=153.62, df=3, p<0.001), except for the comparison between SCI of category 3 and 4 (χ^2=1.8113, df=1, p=0.1783). The quality of some observations did not

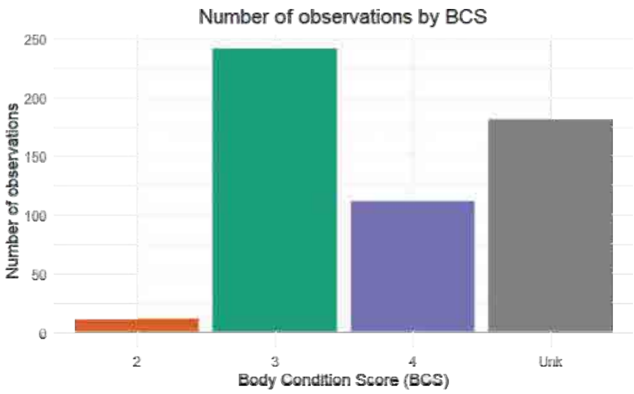

Figure 5: Bar chart showing the number of observations per BCS category

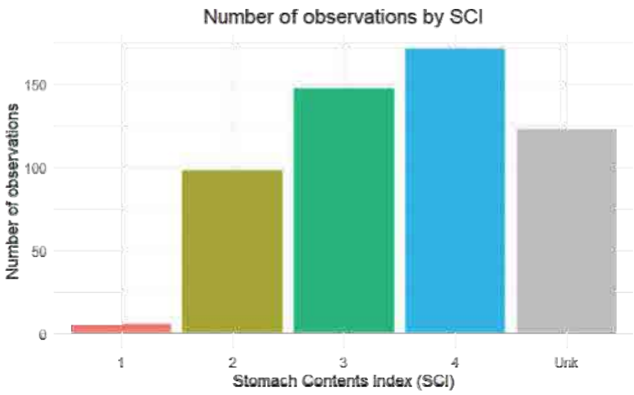

Figure 6: Bar chart showing the number of observations per SCI category

allow the precise identification of SCI, which were classified as unknown (Unk).

The correlation between BCS and SCI demonstrates high significance, with a *p*-value of 2.264e-11 and a Kendall's tau-b correlation coefficient of 0.3394741, indicating a weak positive correlation (Fig. 7).

The relationship between BCS and SCI is visually depicted in the bar chart in Figure 8. When BCS is 2, SCI is predominantly concentrated around 2. For BCS of 3, SCI is centralised mainly around 2, 3, and 4. In the case of BCS of 4 there is a predominant occurrence of SCI of 4, with fewer instances of SCI of 3.

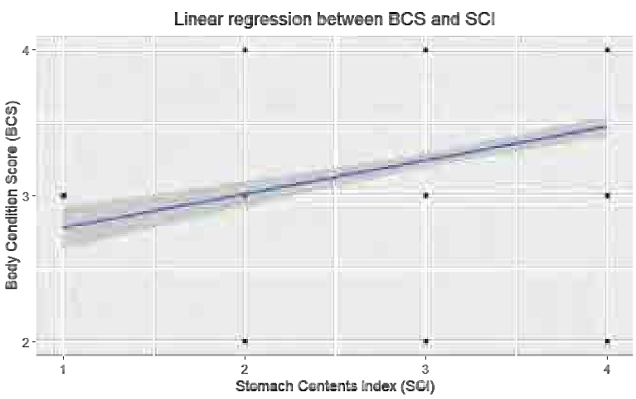

Figure 7: Linear regression between BCS and SCI

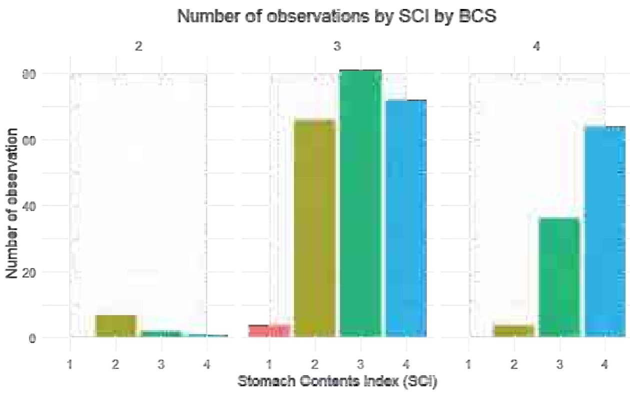

Figure 8: Bar chart showing the number of observations per SCI category and BCS category.

Sex

Fig. 9 illustrates the temporal progression of BCS for each male and all females. These timelines incorporate information about the individual (only available for the males) and depict the distribution of BCS over time.

Regarding the males, the gap from 25 March 2022 to 23 August 2022 represents the absence of a male in the reserve between the departure of Luke (male 1) and the introduction of Himee (male 2). This temporal hiatus can also be viewed in Fig. 10 when analysing the SCI. Examining BCS category for these males reveals that both are primarily around 3, fluctuating between 2 and 4. However, the distribution of observations across categories is significantly different (χ^2=7.7168, *df*=2, $p<0.05$) when comparing these individuals. Specifically, Luke is mainly around BCS 3 and 4 and Himee tends to be more around BCS 2 and 3 in the early stages of his introduction, reaching BCS of 4 just before the end of the observations. Collar data indicates that Himee first joined the females on 02 October 2022 (represented by the orange point in Figures 9 and 10), after a brief period of living alone.

Concerning the females, differentiating them with camera trap pictures is not possible, but an examination of the general trend of BCS is realisable. They exhibit BCS mainly around 3 and 4, with rare fluctuations to 2. The distribution of BCS is significantly similar to that of Luke (χ^2=4.6933, *df*=2, p=0.08846) but highly significantly different from Himee (χ^2=27.021, *df*=2, $p<0.001$). In the initial stages of observation corresponding to their release in the reserve, the females were never observed with a BCS of 4. Since July 2019, they have frequently been observed with a BCS of 4 and their distribution by category remained quite similar until the end of the observations in August 2023.

As presented for the BCS, Figure 10 illustrates the timeline of SCI for both males and females.

For both male lions, SCI fluctuates around 2 to 4, and the distribution is more widely spread than for BCS. The number of observations within SCI ranks for these two lions is similar, with no significant differences (χ^2=1.6138, *df*=3, p=0.4523).

Examining the females, SCI is mainly around 2 to 4 and fluctuates only for a period in 2020 to the category of 1. No significant variations between Luke or Himee and females were noticed (respectively χ^2=5.2988, *df*=3, p=0.1234 and χ^2=3.0465, *df*=3, p=0.3728).

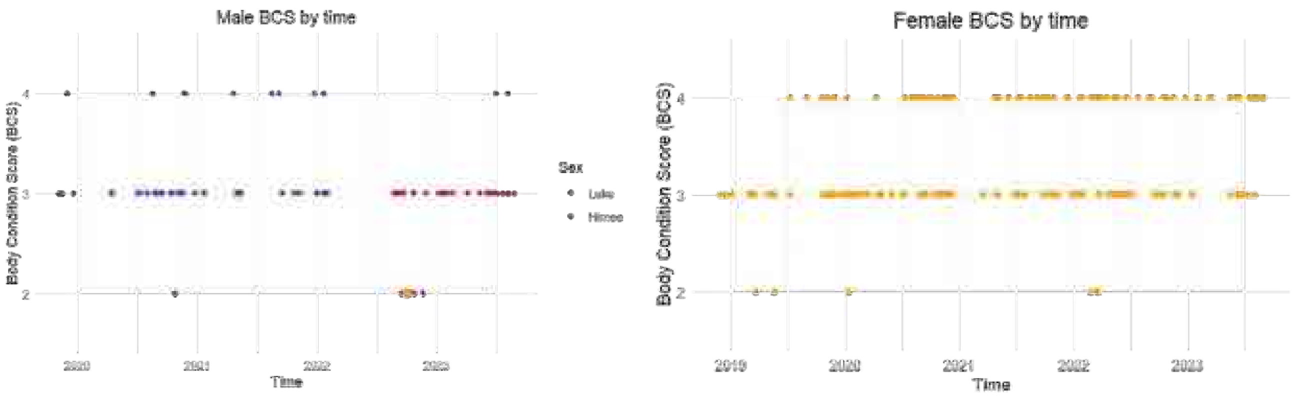

Figure 9: Timeline showing the evolution of BCS of the males and females over time

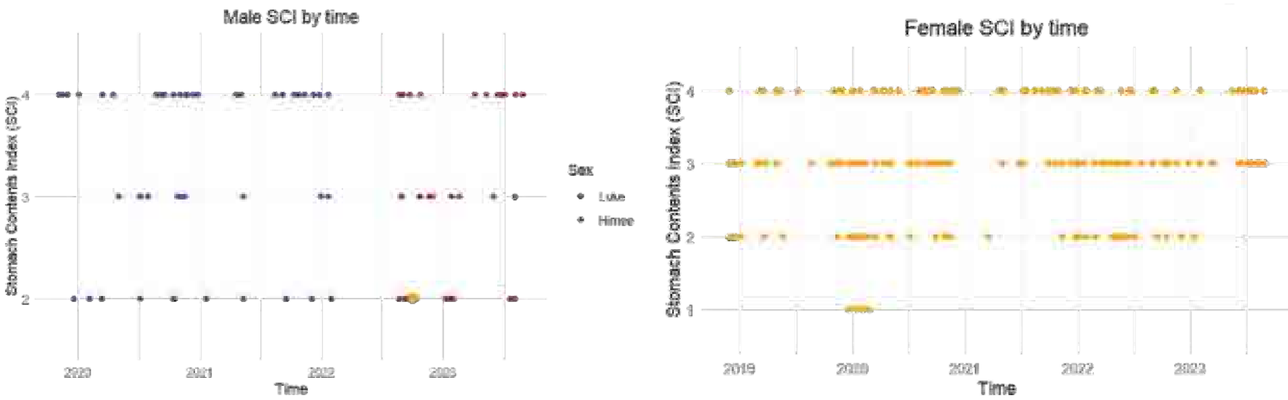

Figure 10: Timeline showing the evolution of SCI of the males and females over time

Regarding the association between BCS and SCI distinguished by sex, a remarkably strong correlation was observed for the females ($p<0.001$, $tau=0.3970833$), and a significant correlation was noticed for Luke ($p<0.05$, $tau=0.4085208$). However, no significant correlation was found for Himee ($p=0.2669$, $tau=0.1541067$).

Environmental factors

Moon phase

BCS and SCI did not vary significantly according to the phase of the moon (respectively $\chi^2=6.9318$, $df=6$, $p=0.3278$ and $\chi^2=4.989$, $df=9$, $p=0.8481$). Since these results are not significantly different, no graph is presented.

Season

There was no significant difference in BCS distribution between the seasons ($\chi^2=5.8995$, $df=4$, $p=0.2079$). For the SCI, no significant variation between dry summer and dry winter ($\chi^2=5.8995$, $df=3$, $p=0.2079$) was detected. However, there is a significant difference in the distribution of SCI between dry summer and humid summer ($\chi^2=9.0693$, $df=4$, $p<0.05$) and a highly significant difference between dry winter and humid summer ($\chi^2=18.256$, $df=4$, $p<0.001$). SCI varies therefore between dry seasons (dry summer and dry winter) and humid seasons. The data showed a higher SCI during the dry seasons than in the humid seasons, as presented in Figure 11.

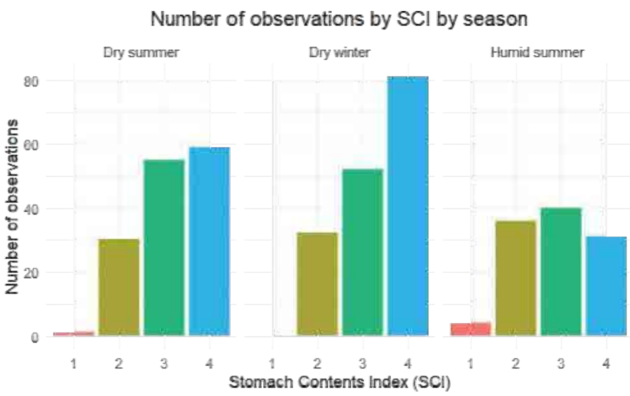

Figure 11: Bar chart showing the number of observations of the relation between SCI and season

Time of day

There were no significant differences in BCS distribution between dawn, day, and dusk (Tab. 1), but a significant difference was observed between night, and dawn and dusk (Tab. 1). A highly significant variation between the night and the day was detected (Tab. 1). Regarding BCS, it is therefore possible to categorise two groups: dawn-day-dusk, and night. The BCS was lower during night when compared with dawn, day, and dusk (Fig. 12), even if it cannot reasonably be expected on a daily timescale. This element is going to be discussed later.

Concerning SCI, similar results were found (Tab. 1). No significant differences were observed in the

Table 1: Results of the Chi-Squared test of independence on the time of day. The significant results are highlighted in grey

BSC Time of the day

	Dawn	Day	Dusk	Night
Dawn	x	χ^2=1.9321, *df*=2, *p*=0.4008	χ^2=1.8632, *df*=2, *p*=0.9245	χ^2=11.088, *df*=2, *p*=0.05
Day	χ^2=1.9321, *df*=2, *p*=0.4008	x	χ^2=2.8593, *df*=2, *p*=0.2034	χ^2=14.675, *df*=2, *p*=0.001
Dusk	χ^2=1.8632, *df*=2, *p*=0.9245	χ^2=2.8593, *df*=2, *p*=0.2034	x	χ^2=12.956, *df*=2, *p*=0.05
Night	χ^2=11.088, *df*=2, *p*<0.05	χ^2=14.675, *df*=2, *p*<0.001	χ^2=12.956, *df*=2, *p*<0.05	x

SCI Time of the day

	Dawn	Day	Dusk	Night
Dawn	x	χ^2=1.9046, *df*=3, *p*=0.6647	χ^2=3.9407, *df*=3, *p*=0.2544	χ^2=21.799, *df*=3, *p*=0.001
Day	χ^2=1.9046, *df*=3, *p*=0.6647	x	χ^2=5.361, *df*=3, *p*=0.07246	χ^2=28.422, *df*=3, *p*=0.001
Dusk	χ^2=3.9407, *df*=3, *p*=0.2544	χ^2=5.361, *df*=3, *p*=0.07246	x	χ^2=21.797, *df*=3, *p*=0.001
Night	χ^2=21.799, *df*=3, *p*<0.001	χ^2=28.422, *df*=3, *p*=0.001	χ^2=21.797, *df*=3, *p*<0.001	x

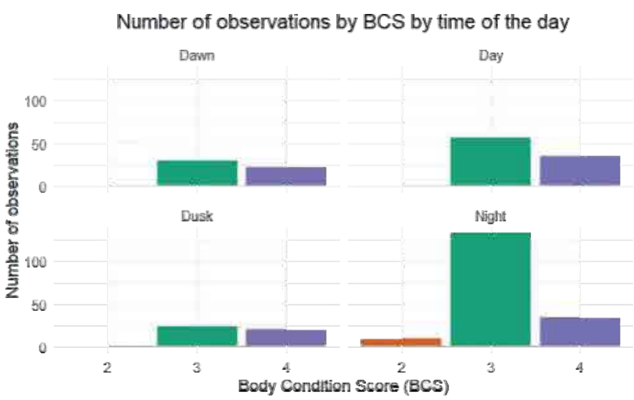

Figure 12: Bar chart showing the number of observations of BCS by time of day

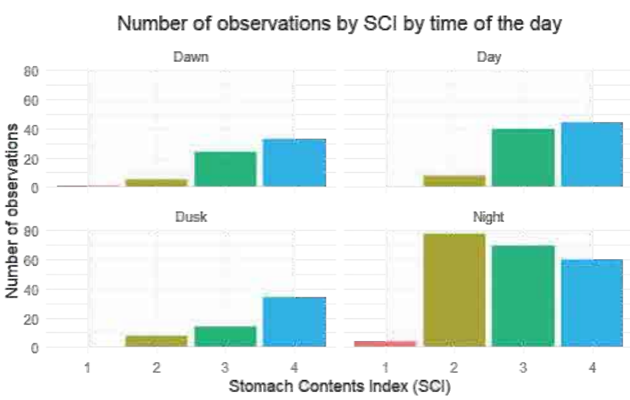

Figure 13: Bar chart showing the number of observations of the relation between SCI and time of day

distribution of SCI between dawn, day, and dusk, but the distribution at night was highly significantly different from that in dawn, day, and dusk. Regarding SCI, it is therefore possible to categorise two groups: dawn-day-dusk, and night. In the first group, the number of observations with SCI of 3 and 4 is high, and in the second group a SCI score of 2, 3 and 4 are dominant (Fig. 13).

Drinking behaviour

As aforementioned, the drinking behaviour was linked to the presence or absence of water due to the location of the camera traps. Regarding BCS between locations with or without water, a significant difference was noticed (χ^2=7.6723, *df*=2, *p*<0.05). We found lions with a higher BCS when they were at a water point compared to areas without water, although the distribution of BCS seems almost similar with a higher amount of BCS of 3, followed by a lower proportion of 4 and finally of 2 (Fig. 14).

As shown in Figure 15, the difference in SCI distribution between locations with or without water point is evident. Lions have a higher SCI score when they come to drink. The number of observations for SCI of 4 has more than doubled in locations with water point and SCI of 2 decreased almost twofold. The statistical test confirms this with a highly significant difference (χ^2=38.527, *df*=3, *p*<0.001).

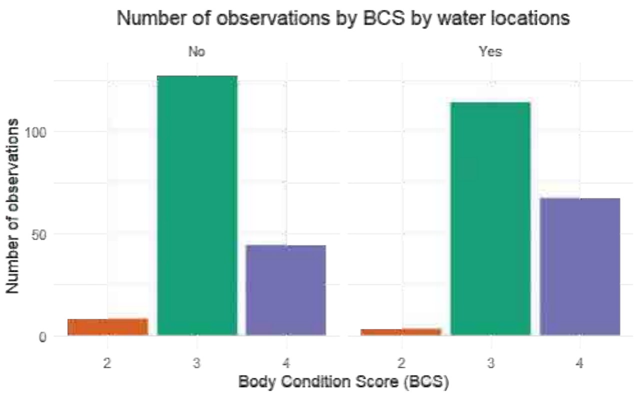

Figure 14: Bar chart showing the number of observations of the relation between BCS and the presence or absence of water

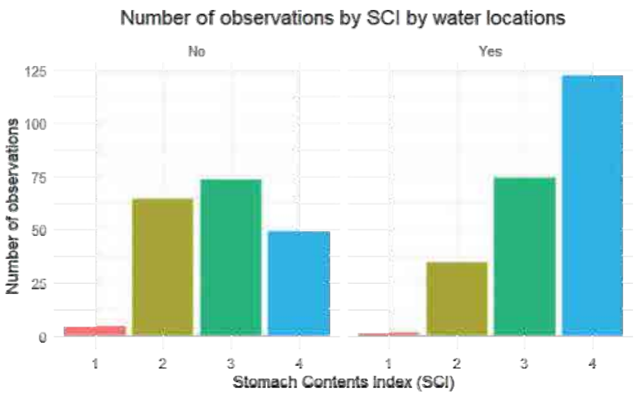

Figure 15: Bar chart showing the number of observations of the relation between SCI and the presence or absence of water

Discussion

BCS and SCI

Body condition score (BCS) assessments conducted on the lion population in the Zannier reserve reveal an ideal health status, with predominant BCS of 3, no observation of 1 (emaciated) or of 5 (obese). We assume that, in the wild, extreme BCS values could signal environmental changes or potential issues in the predator or prey population, such as territorial issues, inadequate number of prey, or disease.

Slight fluctuations (BCS of 2 and 4), observable in this lion population, are considered normal in a healthy population since external factors tend to be unstable, for example, abiotic factors or prey population numbers might vary. Concerning these slight fluctuations, it is recommended to have animals with slightly more fat material as it enhances their resilience (Bright Ross et al. 2021). Lions with a more robust body condition are better prepared during challenging times when competition is intense, and environmental factors undergo rapid changes.

Stomach contents index (SCI) demonstrates a rapid and dynamic response to their feeding behaviour, contrasting with BCS, which is more stable and changes more slowly. Indeed, lions can swiftly shift their SCI from 1 to 4 within a few hours. They consume large quantity of meat, and their digestion is highly efficient, resulting in quick filling or emptying of their stomach (Borstlap 2002). The observation of the four categories of SCI in our study reflects optimal feeding cycles: killing and eating their prey with optimal consumption and digestion. Maintaining a balance between occasionally having an empty stomach and infrequently a full one prevents obesity or emaciation.

Surprisingly, we primarily observed SCI category ratings of 3 and 4, as lions consume meals infrequently but in significant quantities (Borstlap 2002). They can have very full and very empty stomachs, with the latter being more common than the former. SCI values do not necessarily reach 1 between the two kills but decreases towards an SCI of 2. We would, therefore, have expected to find a predominant rate of SCI of 2 or 1 rather than 3 and 4. These unexpected results may be linked to the methodology, specifically the use of camera traps, and will be discussed in detail in the “drinking behaviour” section.

Analysing all lions simultaneously reveals a significant positive correlation between BCS and SCI, indicating the tendency that as SCI increases, BCS also increases. This outcome can be explained by the fact that a high SCI indicates recent feeding, and frequent feeding leads to weight gain due to the caloric content of the meat, stored as fat or muscle (Leaf & Antonio 2017). The same reasoning is valid the other way around. This expected result seems obvious but is essential to monitor in order to confirm that the lions generally live in a balanced, well managed ecosystem and are healthy. Nothing alters the link between eating correctly and being in good physical condition. With the presence of illness and unhealthy stress, the relationship between BCS and SCI would be less obvious because even when eating, the physical condition, and thus BCS, would show a lower category.

This correlation also holds potential for reserve management. When BCS reaches extreme categories, reserve management could strategically target the SCI to influence the BCS, allowing for adjustments to the lion’s health status when necessary. These adjustments could include increasing the number of prey, for instance, or additional feeding. This approach could offer a way to manage and improve the overall well-being of the lion population in the reserve. However, this remains to be proven with future studies since correlations do not establish causality. Indeed, BCS can be explained by many other elements such as diseases, environmental conditions, or natural disasters.

Sex

BCS does not fluctuate significantly because of sex, but significant differences emerge between the lions present for several years (Luke and females) and the more recently released lion (Himee).

Himee’s BCS consistently remained lower than that of Luke or the females, indicating a poorer physical condition. Over time, Himee’s BCS showed improvement, aligning more closely with the established members on the reserve. This change occurred a few months after the first grouping between Himee and the females (see the orange dot in Figure 9), showing that the stabilisation of BCS between 3 and 4 took time. Yet, the latter is not solely attributed to group dynamics but was influenced by various factors.

The impact of introducing Himee into the reserve was noticeable. Himee was living in a pride with three females before being released onto Zannier Reserve. The isolation from its pride and the introduction to a new environment induced significant stress, consumed a lot of energy and modified the lion's behaviour, increasing his tendency to move around to explore and establish his territory. These elements would tend to reduce its BCS.

Although Himee took several months after his first socialisation with females to increase his BCS, living in a group enhances the rate of hunting success and the competitiveness of the individual against other carnivore species. The BCS will therefore tend to decrease when a lion roams around alone rather than in a pride. Another explanation could be that Himee's initial body condition was simply low at the time of his release, and it took time to stabilise. However, this hypothesis was ruled out because Himee was released with an ideal BCS of 3 after being fed in the boma to increase the chances of success. BCS of 3 maintained stability for 23 days after the release before undergoing any deterioration due long-lasting effect of captivity (Skinner, Tuomi, & Mellish 2015) (Fig. 9).

A similar pattern was observed with the females: they did not show a BCS of 4 after their release in the reserve. However, this event is engulfed in the years for the females because this research considered data from the females over five years, while Himee's data covers only one year. The time before reaching a BCS of 4 was a couple of months longer for Himee compared to the females. This may be due to the females' being part of a pride during the release, a situation that did not apply to Himee. This reasoning does not apply to Luke because he was a cub during the release, and these data were excluded. In contrast, the SCI was not influenced by sex or the introduction of a new lion. Himee demonstrated a similar SCI to the other lions, indicating successful hunting, while its lower BCS suggested higher energy expenditure, possibly due to territory establishment, pride integration, and more energy used to kill prey due to his solitary behaviour at the beginning. In other words, there is high calorie usage but normal calorie intake, resulting in a lower BCS despite a good SCI.

When looking at the relationship between BCS and SCI considering sex, we observe a positive correlation between BCS and SCI for the females and Luke, indicating healthy lions with normal caloric intake and caloric usage. The absence of correlation with Himee explains the situation after a release with a good caloric intake but a high caloric usage, disrupting this relationship. SCI is not the only influencing factor for BCS.

To comprehend the dynamics of BCS and SCI in the studied lion population, it is essential to investigate it over several years. This approach enables the capture of the nuances of their feeding behaviour, considering the impact of external factors, which we will discuss in the next section.

Environmental factors

The investigation of the influence of the moon phase on BCS and SCI yields interesting results. Concerning the BCS, which exhibits variations over long periods, it remains unaffected by the relatively rapid changes in the moon phase. On the other hand, the moon phase could have influenced SCI. The very bright or very dark nights might have had impacted on the hunting behaviour and success of the lions and, consequently, on their SCI. This research proves that there is no influence of the moon phase on SCI in the lions within the Zannier Reserve.

The impact of seasons on BCS and SCI also provides interesting insights. Firstly, seasons do not show any effect on the BCS. Lions in the Zannier Reserve maintain a consistent and healthy BCS, indicating that the population resides predominantly in an ideal physical setting irrespective of seasonal variations. Secondly, SCI displays seasonal fluctuations. During dry summer and dry winter, SCI is similar, but differs from humid summer. SCI is higher during dry seasons (dry summer and dry winter) compared to humid summer, indicating better hunting success. This difference can be explained by four elements. Firstly, the prey population increases during the dry season due to the introduction of prey species, that occurs in every year of the study. A higher number of prey may have facilitated hunting. Indeed, more individuals equals increased hunting opportunities, especially considering that some individuals may have been injured or weakened during transportation. Secondly, during the dry season, the scarcity of water concentrates prey near water points, contributing to more successful hunting, as less time is spent looking for prey. Thirdly, the dry season is characterised by the absence of leaves, enhancing visibility. Improved visibility could contribute to the lions' effectiveness in catching prey. Additionally, reduced grazing and browsing opportunities may render prey weaker, further facilitating the lions' predatory success. Lastly, it is important to consider that the use of camera traps might impact the data collected. Indeed, lions tend to drink less at water points during the humid season following a kill, resulting in fewer pictures with high SCI during this period.

The analysis of the influence of the time of day on BCS and SCI reveals intriguing patterns. BCS exhibits fluctuations between daytime (dawn, day, and dusk) and night-time, with lower BCS observed at night. As discussed previously regarding moon phases, the inherent stability of BCS indicates that significant changes cannot occur rapidly, certainly not within a few hours. It is crucial to note that our observations rely on camera traps. This raises the possibility that skinnier lions may exhibit increased activity at night, possibly influenced by prey behaviour or environmental conditions. Another hypothesis would be that the quality of the pictures taken at night makes assessment of BCS less accurate, thus possibly making us underestimate the latter.

Concerning the SCI over the time of day, we observed a similar result: SCI was lower during night-time than daytime. Given the rapid variations in SCI, occurring within hours, this aligns with the nocturnal hunting behaviour of lions. At night, when lions hunt with an empty stomach, camera trap observations reveal lower

SCI as they actively search for prey. When they move to drink during dawn, day, or dusk after a successful kill, they have a full stomach, resulting in an increased SCI.

After examining the impact of environmental conditions on BCS and SCI, we will discuss whether the movement in relation to water proximity is influenced by the BCS and SCI.

Drinking behaviour

As previously mentioned, our method employing camera traps presents a bias since we only observe lions as they pass a camera trap. This bias can potentially influence our results and must be considered during interpretation. However, it is also possible to leverage this bias to analyse the impact of BCS and SCI on the drinking behaviour of the lions. Higher BCS near water points were observed because lions in good condition will stay for a longer time at the water points as they can drink easily and have less reason to move than skinnier lions that need to hunt. Lions exhibiting higher SCI are also observed in proximity to water points, and this observation can be attributed to the physiological response of needing water after a recent kill. Our observations reveal that the volume of water consumed by subjects does not appear to exert a significant influence on BCS and SCI as their category remains the same before and after drinking in a same observation.

Limitations

This study is subject to technological constraints that warrant consideration.

Firstly, the identification of BCS and SCI is subjective, leading to potential variations in interpretation and therefore results depending on the researcher. Additionally, the quality of the camera trap pictures was not consistently optimal for precise BCS and SCI assessments, which might lead to miscategorising. The limitations of camera traps become evident under suboptimal lighting conditions, such as weak light or over-exposure, which may compromise the image clarity and do not allow the accurate BCS and SCI assessment. Factors such as the lion's position in the picture and the presence of environmental elements such as vegetation or stones that obscure parts of the lion's body play a critical role in the examination of BCS and SCI. As a result, a significant portion of BCS and SCI observations have been classified as unknown due to various factors. While camera traps offer certain advantages, they present inherent challenges compared to direct observations, even if the animal can run or disappear quickly in the latter case. The use of infrared cameras and artificial intelligence for the identification of BCS and SCI may improve the process of data collection by making it faster, automatic, and perhaps even more accurate.

Secondly, using camera traps introduces an observational bias influenced by factors such as the camera's location, its orientation, the flash emitted at night, and the number of camera traps deployed. These factors might have a significant impact on the study's results.

Thirdly, with the technical issues encountered with the collars, only the location of the individuals at a certain time was usable. For future studies, it would be interesting to add lion movement to the study using fully working and reliable collars.

Fourthly, the inability to identify individuals among the females hindered the analysis of variations within this subgroup. We could imagine a Bluetooth system which would send information on the individual when the collar passes next to the camera trap or simply collars of different colours. Further research on BCS and SCI within female lions could explore factors such as the presence of cubs, which might influence the mother's BCS and SCI during the first months of the study.

Lastly, the small size of the studied population and its atypical composition, compared to the usual structure of lion groups, limit the generalisability of the findings. Future studies should be considered with larger samples sizes to enhance the robustness of conclusions drawn from the research.

Conclusion

The analyses of body condition score (BCS) and stomach contents index (SCI) in lions yield valuable insights into the health and behaviour within a fenced-off reserve.

To address our research questions, firstly, the study of long-term data on BCS and SCI through camera trap pictures can provide information about the health of lions. The findings reveal a stable BCS with no extreme across all lions, with a healthy broad distribution of SCI. The observed correlation between BCS and SCI suggests that the lions inhabit a balanced, well managed ecosystem and maintain good overall health. Secondly, it was observed that BCS is influenced by the lion's past condition rather than by sex differences. Additionally, we observed that seasons influence SCI. The results show significant differences for BCS and SCI depending on the time of day, which is aligned with the rapid changing nature of SCI but not accurate for BCS, which cannot vary so quickly. In the latter case, it is more likely to reveal a change of behaviour depending on BCS. Conversely, any impact of the moon phase on BCS or SCI was noticed. Thirdly, the drinking behaviour is influenced by BCS and SCI, with both exhibiting higher rates closer to water points.

These findings underline the importance of understanding these elements for effective reserve management, especially in the context of regulating prey populations.

Exploring BCS and SCI shows new opportunities for further investigation. Future studies could compare results across different reserves, with different species and/or add, with the help of new methods, injuries, lameness, etc. of animals, providing valuable information for conservation effort. The development of research in this field is crucial for optimizing reserve management practices.

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References

ABADE, L., CUSACK, J., MOLL, R.J., STRAMPELLI, P., DICKMAN, A.J., MACDONALD, D.W., & MONTGOMERY, R.A. 2020. The relative effects of prey availability, anthropogenic pressure and environmental variables on lion (*Panthera leo*) site use in Tanzania's Ruaha landscape during the dry season. *Journal of Zoology*, 310(2), 135–144. https://doi.org/10.1111/jzo.12731.

BAUER, H., CHAPRON, G., NOWELL, K., HENSCHEL, P., FUNSTON, P., HUNTER, L.T.B., MACDONALD, D.W., & PACKER, C. 2015. Lion (*Panthera leo*) populations are declining rapidly across Africa, except in intensively managed areas. *Proceedings of the National Academy of Sciences*, 112(48), 14894–14899. https://doi.org/10.1073/pnas.1500664112.

BERTRAM, B.C.R. 1975. Social factors influencing reproduction in wild lions. *Journal of Zoology, Lond.*, 177, 463–482.

BORSTLAP, D.G. 2002. *Intake and digestibility studies with captive African lions (Panthera leo), leopards (Panthera pardus) and cheetahs (Acinonyx jubatus).* http://hdl.handle.net/11660/6127.

BRIGHT ROSS, J.G., NEWMAN, C., BUESCHING, C.D., CONNOLLY, E., NAKAGAWA, S., & MACDONALD, D.W. 2021. A fat chance of survival: Body condition provides life-history dependent buffering of environmental change in a wild mammal population. *Climate Change Ecology, 2,* 100022. https://doi.org/10.1016/j.ecochg.2021.100022.

COON, C.A.C., NICHOLS, B.C., MCDONALD, Z., & STONER, D.C. 2019. Effects of land-use change and prey abundance on the body condition of an obligate carnivore at the wildland-urban interface. *Landscape and Urban Planning,* 192, 103648. https://doi.org/10.1016/j.landurbplan.2019.103648.

DAIGLE, C., BROWN, J., CARLSTEAD, K., PUKAZHENTHI, B., FREEMAN, E., & SNIDER, R. 2015. Multi-institutional survey of social, management, husbandry and environmental factors for the SSP African lion *Panthera leo* population: Examining the effects of a breeding moratorium in relation to reproductive success: Multi-Institutional Survey: African Lion SSP Population. *International Zoo Yearbook,* 49, n/a-n/a. https://doi.org/10.1111/izy.12073.

DAVIES, A.B., TAMBLING, C.J., KERLEY, G.I.H., & ASNER, G.P. 2016. Effects of vegetation structure on the location of lion kill sites in African thicket. *PLOS ONE,* 11(2), e0149098. https://doi.org/10.1371/journal.pone.0149098.

ELLISON, A.M. & DEGRASSI, A.L. 2017. All species are important, but some species are more important than others. *Journal of Vegetation Science, 28*(4), 669–671. https://doi.org/10.1111/jvs.12566.

EVERATT, K., KOKES, R., & PEREIRA, C. 2019. Evidence of a further emerging threat to lion conservation; targeted poaching for body parts. *Biodiversity and Conservation, 28.* https://doi.org/10.1007/s10531-019-01866-w.

EZENWA, V.O., GHAI, R.R., MCKAY, A.F., & WILLIAMS, A.E. 2016. Group living and pathogen infection revisited. *Current Opinion in Behavioral Sciences, 12,* 66–72. https://doi.org/10.1016/j.cobeha.2016.09.006.

EZENWA, V.O., JOLLES, A.E., & O'BRIEN, M.P. 2009. A reliable body condition scoring technique for estimating condition in African buffalo. *African Journal of Ecology, 47*(4), 476–481. https://doi.ORG/10.1111/j.1365-2028.2008.00960.x.

FRANKE, T.M., HO, T., & CHRISTINA, C.A. 2012. The Chi-Square Test: Often Used and More Often Misinterpreted. American Journal of Evaluation, 33(3), 448–458. https://doi.org/10.1177/1098214011426594.

FUNSTON, P. & MILLS, M. 2006. The influence of lion predation on the population dynamics of common large ungulates in the Kruger National Park. *South African Journal of Wildlife Research, 36,* 9–22.

HENSCHEL, P., PETRACCA, L.S., HUNTER, L.T.B., KIKI, M., SEWADÉ, C., TEHOU, A., & ROBINSON, H.S. 2016. Determinants of distribution patterns and management needs in a critically endangered lion Panthera leo population. *Frontiers in Ecology and Evolution, 4.* https://www.frontiersin.org/articles/10.3389/fevo.2016.00110.

HOPCRAFT, J.G.C., SINCLAIR, A.R.E., & PACKER, C. 2005. Planning for success: Serengeti lions seek prey accessibility rather than abundance. *Journal of Animal Ecology, 74*(3), 559–566. https://doi.org/10.1111/j.1365-2656.2005.00955.x.

JONGBLOET, P.H. 1983. Menses and moon phases, ovulation and seasons, vitality and month of birth. *Developmental Medicine & Child Neurology,* 25(4), 527–531. https://doi.org/10.1111/j.1469-8749.1983.tb13801.x.

KOTHE, H.-W. & TAFFIN-JOUHAUD, D. 2018. *Félins: Espèces, mode de vie, comportement.* L'IMPREVU.

LEAF, A. & ANTONIO, J. 2017. The effects of overfeeding on body composition: The role of macronutrient composition – A narrative review. *International Journal of Exercise Science, 10*(8), 1275–1296.

LEHMANN, M.B., FUNSTON, P.J., OWEN, C.R., & SLOTOW, R. 2008. Home range utilisation and territorial behaviour of lions (*Panthera leo*) on Karongwe Game Reserve, South Africa. *PLoS ONE,* 3(12), e3998. https://doi.org/10.1371/journal.pone.0003998.

LIMA, S. L. 1998. Nonlethal effects in the ecology of predator-prey interactions: What are the ecological effects of anti-predator decision-making? *BioScience, 48*(1), 25–34. https://doi.org/10.2307/1313225.

MASSEY, A.L., KING, A. A., & FOUFOPOULOS, J. 2014. Fencing protected areas: A long-term assessment of the effects of reserve establishment and fencing on African mammalian diversity. *Biological Conservation, 176,* 162–171. https://doi.org/10.1016/j.biocon.2014.05.023

Moon Phases today | Lunar phase. n.d. Moon Phases. Retrieved 11 December 2023, from https://phasesmoon.com.

MOSSER, A. & PACKER, C. 2009. Group territoriality and the benefits of sociality in the African lion, *Panthera leo. Animal Behaviour, 78*(2), 359–370. https://doi.org/10.1016/j.anbehav.2009.04.024.

OGDEN, M.B., FUNSTON, P.J., OWEN, C.R., & SLOTOW, R. 2008. Feeding behaviour of lions (*Panthera leo*) on a small reserve. *South African Journal of Wildlife Research, 38,* 66–78. https://doi.org/10.3957/0379-4369-38.1.66.

PÉRIQUET, S., FRITZ, H., & REVILLA, E. 2015. The Lion King and the Hyaena Queen: Large carnivore interactions and coexistence. *Biological Reviews of the Cambridge Philosophical Society, 90*(4), 1197–1214. https://doi.org/10.1111/brv.12152.

QGIS Development Team. 2020. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.org.

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

SARGENT, R., DEERE, N.J., MCGOWAN, P.J.K., BUNNEFELD, N., & PFEIFER, M. 2022. Room to roam for African lions *Panthera leo*: A review of the key drivers of lion habitat use and implications for conservation. *Mammal Review, 52*(1), 39–51. https://doi.org/10.1111/mam.12262.

SKINNER, J.P., TUOMI, P.A., & MELLISH, J.-A.E. 2015. The influence of time in captivity, food intake and acute trauma on blood analytes of juvenile Steller sea lions, *Eumetopias jubatus. Conservation Physiology, 3*(1), cov008. https://doi.org/10.1093/conphys/cov008.

TENG, K.T., MCGREEVY, P.D., TORIBIO, J.A.L.M.L., RAUBENHEIMER, D., KENDALL, K., & DHAND, N.K. 2018. Associations of body condition score with health conditions related to overweight and obesity in cats. *Journal of Small Animal Practice, 59*(10), 603–615. https://doi.org/10.1111/jsap.12905.

TRINKEL, M. 2013. Climate variability, human wildlife conflict and population dynamics of lions Panthera leo. *Die Naturwissenschaften, 100*(4), 345–353. https://doi.org/10.1007/s00114-013-1034-5.

WELCH, R.J. & PARKER, D.M. 2016. Brown hyaena population explosion: Rapid population growth in a small, fenced system. *Wildlife Research, 43*(2), 178–187. https://doi.org/10.1071/WR15123.

YOUNG, E. 1975. Some important parasitic and other diseases of lion, Panthera leo, in the Kruger National Park. *Journal of the South African Veterinary Association, 46*(2), 181–183.

YUGOVIC, J. 2015. Do ecosystems need top predators? A review of native predator-prey imbalances in south-east Australia. *Victorian Naturalist, 132,* 4–11.

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