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**Cover: Digital illustration of Smooth-coated Otter *Lutrogale perspicillata* by Dupati Poojitha. Reference from the picture taken by Rana & Sugandhi.**

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COMMUNICATION

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# Assessing nutritional status of Chital *Axis axis* (Erxleben, 1777) (Mammalia: Artiodactyla: Cervidae) through bone marrow condition of predated individuals in Kanha Tiger Reserve, India

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**Abstract:** Monitoring the body condition of ungulates is an important aspect of understanding their ecology as it provides information about habitat conditions, seasonality of nutritional stress, disease susceptibility, and prey selection by predators. Bone marrow condition at death provides a reliable indicator of body condition, as marrow fat is among the last energy reserves to be metabolized. Since big bones are often left intact by predators, the marrow condition of the femur is a standard measure. We examined 52 Chital carcasses from predated events to assess bone marrow condition in Kanha Tiger Reserve and found profound seasonality with monsoon having the poorest bone marrow condition while there were no differences between the body condition of predated male and female Chital.

**Keywords:** Carcass, central India, ecology, poor nutritional health, Satpura Maikal Hills, seasonal nutrition, Spotted Deer, ungulates.

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**Author details:** Shravana Goswami is a principal project associate involved in the long-term ecological monitoring program at Kanha Tiger Reserve. Her research focuses on wildlife ecology, ungulate ecology and large carnivore monitoring, and conservation science, with particular experience in population assessment and long-term field-based ecological studies. Ujjwal Kumar is a research scientist with the NTCA Tiger Cell, National Tiger Conservation Authority, Government of India. He supervises the ecological monitoring project at Kanha Tiger Reserve and works on tiger population monitoring, conservation planning, and implementation of scientific protocols for large carnivore conservation. Yadvendradev Jhala is a senior wildlife scientist and served as the PhD supervisor of Shravana Goswami and principal investigator of the Kanha monitoring project. He was dean of Wildlife Institute if India and currently senior scientist INSA at NCBS Bengaluru. His work focuses on carnivore ecology, population estimation, and the development of science-based approaches for wildlife conservation and management.

**Author contributions:** SG conducted the field data collection and, performed the data analysis. SG, UK, and YVJ wrote the manuscript. YVJ conceived, supervised, and procured the resources for the study. All authors approved the manuscript.

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## INTRODUCTION

The availability of resources directly influences individual health, behaviour, and population-level adaptations (Czyżowski et al. 2020). Assessing wildlife health is therefore critical for conservation, as it provides baseline data for managing ecological threats (Kophamel et al. 2022). A range of quantitative and qualitative methods exist for health assessments, using body condition scores, body mass, antler quality, and fat reserves (Riney 1955; Bonino & Bustos 1998; Majzinger 2004; Stokes et al. 2010). A decline in nutritional intake can result in reduced body condition, lower reproductive rates, disease susceptibility, increased mortality, and ultimately, population declines (Kie et al. 1983; Kie & White 1985).

In wild ungulates, body condition has been closely associated with factors such as nutritional status, health, reproductive success, and population density (Albon et al. 1986; Brunborg et al. 2004; Bender et al. 2008; Couturier et al. 2009; Santos et al. 2013; Risco et al. 2016). As such, monitoring body condition is a crucial component of wildlife management, providing insights into population performance and facilitating early detection of potential ecological imbalances (Morellet et al. 2007; Mattiello et al. 2009).

Various methods have been developed to assess body condition in wild ungulates, primarily by estimating fat reserves. Some of these techniques, such as the kidney fat index (KFI) (Riney 1955) and bone marrow fat content (Fuller et al. 1986) are invasive and applicable only to deceased animals but are extremely reliable. Among these, femur marrow fat (FMF) is particularly useful as it represents one of the last fat reserves to be metabolized, making it a reliable indicator of animals in poor condition (Cheatum 1949; Meyerholtz et al. 2011). The femur marrow fat method described by Cheatum (1949) is cost effective and provides a rapid assessment of nutritional status of the population. Moreover, Mørk et al. (2024) found a relation between the visual score of bone marrow with their fat content where with decreasing score, fat content of bone marrow also decreases.

In cervids, bone marrow fat depletion pattern as an indication of body condition is better documented than the fatty acid composition changes (Sugár & Nagy 1992) in blood. In the Indian subcontinent, Chital is widely distributed and the most abundant cervid which forms the major prey for most of the large carnivores. Ideally, to assess the nutritional health of a population, a random sample of bone marrow should be examined, however, this is not possible within the legal framework of Indian wildlife protection laws (Wildlife protection act 1972). Ambush predators like Tigers *Panthera tigris* and Leopards *Panthera pardus* are less selective of the body condition of their prey (Karanth & Sunquist 1995) compared to cursorial predators like Cheetah *Acinonyx jubatus*, Wolves *Canis lupus*, and Dhole *Cuon alpinus* that chase and test their prey (Hayward et al. 2006; Gable et al. 2021). We collected and examined the femur bone marrow condition of Chital predated by Tigers and Leopards in Kanha Tiger Reserve to assess the feasibility of using bone marrow as a marker to evaluate seasonality and gender differences in the nutritional body condition of the Chital population.

## MATERIALS AND METHODS

### Study area

Kanha Tiger Reserve (KTR), located in the Satpura Maikal Hill Ranges of the central Indian highlands, spans Balaghat and Mandla districts in Madhya Pradesh. Established in 1973 as one of India's first nine tiger reserves, it covers a total area of 2,051.82 km², with a core zone of 917.43 km² and a buffer zone of 1,134.39 km². The reserve features diverse landscapes, including flat hilltops, slopes, and meadows, creating varied habitats for a rich array of flora and fauna.

The tiger reserve is located within the dry deciduous zone, comprising of Sal forests, mixed forests, bamboo forests, and grasslands (Awasthi et al. 2016). Kanha experiences three distinct seasons: summer, monsoon, and winter. Seasonal variations in temperature, humidity, and precipitation influence vegetation and wildlife behaviour.

### Method

Chital carcasses were located opportunistically using predation records generated during routine forest patrol and field monitoring, and the femur bone marrow condition of the carcasses was examined (n = 52; males = 27, females = 25). As carcass detection was not systematic, sampling may be biased towards more detectable kills; however, the same protocol was applied consistently across seasons. Samples of bone marrow were examined only from very fresh kills; as older carcasses tend to dry out under environmental conditions. Marrow with high-fat content appears solid white, whereas low-fat marrow is gelatinous and often translucent to reddish (Cheatum 1949). Solid white marrow indicates good health at the time of death (Jhala 1991; Mørk et al. 2024). Based on

consistency, we categorized bone marrow conditions into three groups: good, medium, and poor (Image 1). In each case, we observed the femur bone marrow and recorded the animal's gender and the date of death to assess the potential effects of gender and season. Exploratory analysis and Fisher's exact test (Zar 1999) were conducted to examine and assess the statistical significance of the effect of gender and seasonal health status of predated Chital. Since these data are count data, the significance level can be tested either using chi-square test or Fisher's exact test. Since our sample size was zero in some categories, we used Fisher's exact test with Monte Carlo approximation to compute significance.

## RESULTS

Overall the bone marrow of 40.38% of the chital was in good condition, 46.15% was in medium condition, and 13.47% was in poor condition (Table 1; Figure 1). We found no significance difference between the bone marrow condition of predated males and females (Fisher's Exact Test, P = 0.56). Bone marrow condition differed across seasons (Fisher's Exact Test, P = 0.05; Table 1), indicating a borderline but biologically meaningful seasonal pattern.

## DISCUSSION

Our findings indicate that visual inspection of femur bone marrow in predated Chital can be a useful tool for monitoring their nutritional status. However, since the individuals available for such assessment are those killed by predators, it is important to consider potential biases in predator selection. While predators are generally known to target the young, old, or weak, this selectivity is less pronounced in ambush predators like the big cats (Annear et al. 2023). Therefore, though our assessment of body condition may be biased towards poorer condition Chital due to possible selection by Tigers & Leopards, this bias would be consistent between seasons, genders, and years. In the central Indian landscape, summer is the nutritional pinch period due to high temperatures and limited, poor-quality forage and water availability (Awasthi 2020). During this time, ungulates experience increased energy expenditure with reduced access to high-quality forage, leading to a decline in body condition. As the monsoon begins, habitat conditions gradually improve with increasing vegetation growth and water availability. As expected, we found the body condition of the Chital to differ between the seasons but contrary to our expectations we did not find any Chital carcass in good condition category during monsoon. Although no individuals in good bone marrow condition were recorded during the monsoon, the limited sample size for this season warrants cautious interpretation. Rather than definitive recovery dynamics, the observed pattern likely reflects delayed replenishment of fat reserves following prolonged nutritional stress during


**Image 1. Bone marrow condition of predated Chital: A—Solid white bone marrow denoting good body condition at the time of death | B—Semi-solid to jelly-like, having yellowish to pinkish-white coloration representing medium body condition | C—Semi-liquid translucent yellowish or reddish bone marrow with total fat depletion representing poor body condition. © Shravana Goswami.**

**Table 1. Seasonal distribution of bone marrow condition in predated Chital (n = 52).**

| Season | No. of good | | No. of medium | | No. of poor | | Percentage of good | | Percentage of medium | | Percentage of Poor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| Summer | 7 | 3 | 8 | 5 | 2 | 2 | 13.46 | 5.77 | 15.38 | 9.62 | 3.85 | 3.85 |
| Monsoon | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 3.85 | 5.77 | 3.85 | 0 |
| Winter | 4 | 7 | 5 | 1 | 1 | 0 | 7.69 | 13.46 | 9.62 | 1.92 | 1.92 | 0 |
| Total | 11 | 10 | 15 | 9 | 5 | 2 | | | | | | |

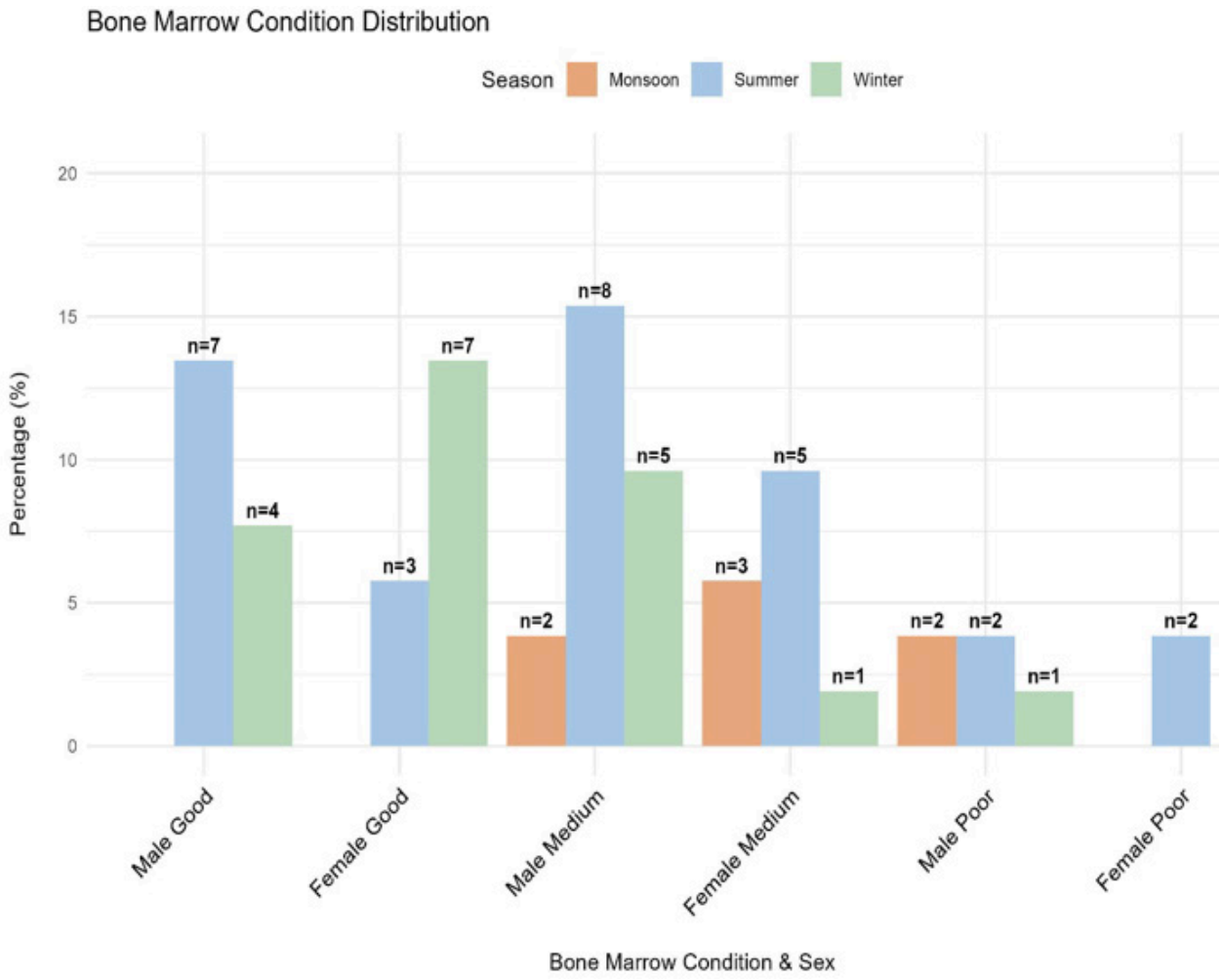


**Figure 1. Seasonal variation in bone marrow condition of predated male and female Chital in Kanha Tiger Reserve. Numbers above bars indicate sample sizes for each category.**

summer. However, given the borderline significance (P = 0.05) and uneven seasonal sample sizes, the seasonal trend should be viewed as exploratory and hypothesis-generating rather than confirmatory. Bone marrow fat depletion is a well-established indicator of an animal's overall nutritional status, as it is the last fat reserve to be utilized (Robbins 1993). Previous studies have documented that bone marrow fat is not significantly depleted until fat reserves from other critical areas such as subcutaneous, omental, renal, and pericardial depots decline to 15% (Sinclair & Duncan 1972; Watkins et al. 1991). Consequently, if an animal exhibits poor bone marrow condition, it implies that its overall body fat reserves have already been substantially depleted. Mech

& Delgiudice (1985) further suggested that individuals categorized as having a medium bone marrow condition might actually be considered in poor health when assessed within a broader ecological and physiological context. This perspective highlights the importance of using bone marrow condition as a key indicator of ungulate health, particularly in understanding long-term trends in population well-being. The predominance of medium and poor bone marrow condition among predated Chital likely reflects nutritional stress in a subset of the population, potentially compounded by predator selection bias. In the absence of comparable baseline data from other protected areas or non-predated individuals, these findings should be interpreted as indicative rather than diagnostic of population-wide nutritional status.

The health status of an individual animal is influenced by multiple factors, including pathogens, parasites, physical injuries, congenital abnormalities, and seasonal variations in resource availability (Franzmann & Arneson 1976; Ballard 1995). Seasonal changes play a crucial role in determining the health of ungulates, as fluctuations in food and water availability directly impact their ability to maintain adequate fat reserves. Seasonal variation in bone marrow condition has been observed in several other cervid species. Studies on Black Buck (Jhala 1997), White-tailed Deer (Kie et al. 1983), Roe Deer (Ratcliffe 1980), Moose (Ballard 1995), and Reindeer (Mørk et al. 2024) have reported that body condition deteriorates during periods of nutritional stress. This reinforces the idea that seasonal fluctuations in habitat productivity directly impact ungulate health. Given that nutrition plays a fundamental role in maintaining the health of wild herbivores, it is critical to assess habitat conditions and their capacity to support populations effectively. Understanding the nutritional value of available forage, seasonal shifts in plant phenology, and the spatial distribution of resources can provide insights into the ecological drivers influencing population health.

Our results are suggestive of poor nutritional health of Chital in KTR that needs management intervention and further study. To strengthen our findings, future research should focus on expanding sample sizes across seasons along with the assessment of the availability and nutritional value of forage. A larger sample would allow for assessing differences in body condition between age groups and differential selection by different predators. Moreover, the visual inspection of femur bone marrow is a field-friendly, cost-effective, and quick assessment method to evaluate the body condition of the animal as well as the habitat condition. Such data would be invaluable for informing conservation management strategies aimed at sustaining healthy habitat, ungulate and carnivore populations in the protected area.

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