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Seasonal and Habitat-Specific Density of Sambar (*Rusa unicolor*) in Achanakmar Tiger Reserve, Chhattisgarh, Central India

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Abstract

The sambar (*Rusa unicolor*) is the largest Indian cervid and a principal prey species of the tiger (*Panthera tigris*), yet it is listed as Vulnerable on the IUCN Red List because of widespread population declines. Reliable, season- and habitat-specific density estimates are needed to evaluate prey availability in tiger reserves. We estimated the density and group density of sambar in Achanakmar Tiger Reserve (ATR), Bilaspur, Chhattisgarh, using line transect distance sampling over one complete annual cycle (April 2025 to March 2026). Twenty-five 2-km transects (five in each of five habitats: mixed forest, sal forest, bamboo forest, teak plantation and grassland) were walked in three seasons (post-monsoon, winter and summer). Detection functions were fitted with a uniform key function with cosine adjustment, which was selected for all seasons. Density increased from 2.18 ± 0.59 individuals/km² in the post-monsoon season to 2.87 ± 0.38 in winter and 3.01 ± 0.48 in summer; group density followed the same pattern (1.59 ± 0.19, 1.82 ± 0.21 and 1.86 ± 0.17 groups/km²). Mean group size was small (1.37–1.61 individuals), and effective strip width ranged from 28.33 m (winter) to 34.50 m (post-monsoon). Habitat strongly influenced density: grasslands supported the highest annual mean density (4.21 individuals/km²), followed by mixed forest (3.44), sal forest (2.53), teak plantation (2.21) and bamboo forest (1.07). Summer density exceeded post-monsoon density in every habitat. High densities were recorded in the grassland and mixed forest of the Achanakmar, Lamni, Surahi and Chapparwa areas, while the Koechi, Kota and Lormi buffer areas held very low densities. Our results show that sambar in ATR occur at moderate densities with pronounced seasonal and habitat-level heterogeneity, and they emphasise the importance of protecting grassland–mixed forest mosaics and water sources for sustaining the tiger's prey base.

1. Introduction

Large herbivores shape vegetation structure and nutrient cycling and form the prey base that determines the carrying capacity of large carnivores. In South Asian forests, the tiger depends largely on medium- and large-bodied ungulates, and the abundance of these prey species is a primary determinant of tiger density (Karanth and Sunquist, 1995). Monitoring ungulate populations is therefore a core component of tiger reserve management, and national assessments in India rely on standardised protocols that combine line transect sampling with sign surveys (Jhala et al., 2020).

The sambar (*Rusa unicolor* Kerr, 1792) is the largest deer of the Oriental region and belongs to the family Cervidae. It was

originally described as *Cervus unicolor* by Robert Kerr in 1792. Hamilton-Smith treated *Rusa* as a subgenus of *Cervus* in 1827, Hodgson used it as a full genus for the sambar in 1841, and Grubb resurrected the genus in 1990, a treatment supported by Groves and Grubb (2011). On the basis of morphological and chromosomal evidence, the sambar complex was subsequently divided into a Southeast Asian species, *Cervus equinus* (2n = 60), and the Indian species *Rusa unicolor* (2n = 56). The nominate subspecies *R. u. unicolor* occurs across India, Bangladesh and Sri Lanka.

Sambar are large, robust deer with a shoulder height of 100–160 cm and a head–body length of 162–270 cm. Adult males reach about 225 kg and females about 135 kg. The adult pelage is coarse and varies from brown to dark or reddish-brown, juveniles carry faint pale spots that fade with age, and only males bear antlers, which in Indian populations typically measure 16–40 cm. The species is native to India, Sri Lanka, Nepal, Bhutan, southern China, Myanmar, Taiwan, Thailand, Laos, Cambodia, Malaysia, Indonesia, Sulawesi and the Philippines, and has been introduced to Australia, New Zealand, the United States and South Africa. Naaz and Mehrotra (2025) Sambar occupy a wider variety of forest types than most other cervids, from the thorny and arid forests of Gujarat and Rajasthan, through dry and moist deciduous forests of the peninsula, to pine and oak forests of the Himalayan foothills and the evergreen and semi-evergreen forests of the Western Ghats. They generally avoid steep terrain and prefer open habitat and dense shrub close to water and grassland. They are largely crepuscular and nocturnal, sedentary, and do not typically shift ranges seasonally. Their diet is mixed, comprising grasses, herbs, shrubs, young leaves of woody plants and fallen fruit, with bark consumed more heavily in the wet season for its calcium content. Shrivastava (2025) Adult males and pregnant or lactating females visit natural mineral licks intensively, often in darkness to avoid predators. Where sambar live near people they enter gardens, plantations and croplands, producing human–wildlife conflict.

The sambar is protected under Schedule III of India's Wildlife (Protection) Act, 1972, and is classified as Vulnerable on the IUCN Red List owing to an inferred population decline of more than 50% over three generations (Timmins et al., 2015). Despite this status, quantitative, season- and habitat-specific density estimates from many Indian tiger reserves remain scarce, particularly

from the forests of central India. Naaz and Mehrotra (2025) Where density has been estimated, detectability is rarely modelled explicitly, and results are therefore difficult to compare across sites and seasons.

Achanakmar Tiger Reserve (ATR) in Chhattisgarh is a heterogeneous landscape of mixed forest, sal (*Shorea robusta*) forest, bamboo forest, teak plantations and grasslands, and forms part of a larger forest corridor of the Maikal Hills. Its management relies on a healthy ungulate prey base, but season- and habitat-specific information on sambar density has been limited. The objectives of this study were to (i) estimate the density, group density, mean group size and effective strip width of sambar across three seasons using distance sampling; (ii) compare sambar density and group density among five major habitat types; (iii) describe seasonal variation within habitats; and (iv) identify the areas of ATR that support high and low sambar densities.

2. Study Area

Achanakmar Tiger Reserve lies in the Bilaspur region of Chhattisgarh, central India, and covers roughly 914 km² of core and buffer forest. The reserve lies between latitudes 22° 17′ N to 22° 38′ N and longitudes 81° 31′ E to 81° 57′ E. The altitude varies from 305 meters to 1,080 meters (approx. 1,000 to 3,540 feet) above mean sea level across its rugged Maikal hills terrain.. The reserve supports a tiger and leopard population together with a diverse ungulate community that includes chital (*Axis axis*), sambar, gaur (*Bos gaurus*) and wild pig (*Sus scrofa*). The vegetation was stratified for this study into five habitats: mixed forest, sal forest, bamboo forest, teak plantations and grasslands. The climate is seasonal, with a monsoon, a cool winter and a hot, dry summer; data were grouped into post-monsoon, winter and summer seasons. Surface water becomes limited in the dry season, when ungulates concentrate around the few remaining water sources.

3. Methods

3.1 Survey period and permissions

Data on the population structure and ecology of ungulates were collected for one complete year, from April 2024 to March 2025, after permission was granted by the Principal Chief Conservator of Forests (Wildlife and Biodiversity Conservation) and Chief Wildlife Warden, Chhattisgarh. Both direct and indirect methods were used, but the density estimates reported here derive from line transect distance sampling.

3.2 Transect design

Five habitats (mixed forest, sal forest, bamboo forest, teak plantations and grasslands) were evaluated. Within each habitat, five supervised transect lines were established, giving 25 transects in total, each standardised at 2 km in length. Five replicate transects per habitat were used to ensure spatial representativeness and adequate statistical power, and the layout covered almost all of the reserve. Existing transects laid by the forest authority for tiger and prey monitoring were also used where they coincided with the study design.

3.3 Field protocol

Transects were walked by trained ATR field staff and the research team in the early morning (approximately 06:30–10:00 h), when ungulate activity is at its peak, following the all-India tiger monitoring protocol (Jhala et al., 2020). Observers walked at a slow, steady pace (about 0.75–1 km/h). For every sighting the observer recorded species, number of individuals (cluster size) and the perpendicular distance to the animal or group centre. Yedahoun and Morkoyunlu (2025) Surveys were repeated through the year and grouped into post-monsoon, winter and summer seasons. Because dense vegetation and the presence of tigers and leopards restrict walking transects in parts of the reserve, road surveys (vehicle speed below 20 km/h, with a full headcount of each group using binoculars) and hide-based waterhole monitoring (fixed 4-h morning and evening sessions) were used as complementary checks on species composition and group size. These methods are subject to road-related bias and were not used for density estimation.

3.4 Distance sampling analysis

Perpendicular distances were analysed in distance-sampling software to fit detection functions and estimate density (D, individuals/km^2), group density (groups/km^2), mean group size, and effective strip width (ESW). Observations were right-truncated at 60 m (post-monsoon) and 55 m (winter and summer) to remove unreliable detections at large distances and to satisfy the assumptions of line transect analysis. Analyses were run separately for each season and survey year, and for the two years pooled. A uniform key function with a cosine adjustment term was selected for all seasons on the basis of Akaike's Information Criterion (AIC; Burnham and Anderson, 2002). Habitat-level densities were calculated for each of the five habitats and each season, and means and standard

deviations (SD) were calculated across habitats.

3.5 Indirect (dung) surveys

Circular plots of 10 m radius were laid at 200-m intervals along transects, 20 m from the line and alternating sides (125 plots, 25 per habitat), and additional random plots were laid across all habitats to record dung of chital, sambar and wild pig. Dung was classified by shape, size and colour. These data were collected to support density conversion with defecation and decay rates and are not reported in this paper.

4. Results

4.1 Survey effort and observations

Survey effort increased from the post-monsoon season to summer in both survey years (Table 1). In the post-monsoon season, 14 transect walks were completed in Year 1 and 25 in Year 2 (39 pooled); in winter, 16 and 27 (43 pooled); and in summer, 18 and 29 (47 pooled). Observation counts followed the same gradient. Post-monsoon sampling produced 12 pooled sambar observations (3 in Year 1, 9 in Year 2), winter produced 20 (6 and 14) and summer produced 25 (9 and 16). After truncation, 7, 10 and 15 pooled observations were retained for post-monsoon, winter and summer analyses, respectively.

Table 1: Distance sampling summary and density estimates (mean ± SE) of sambar in Achanakmar Tiger Reserve by season. Year 1 and Year 2 are the two survey years, and Pooled combines both.

Parameter	Post-monsoon Y1	Post-monsoon Y2	Post-monsoon Pooled	Winter Y1	Winter Y2	Winter Pooled	Summer Y1	Summer Y2	Summer Pooled
Survey effort (transect walks)	14	25	39	16	27	43	18	29	47
Total observations	3	9	12	6	14	20	9	16	25

Truncation distance (m)	60	60	60	55	55	55	55	55	55
Observations after truncation	2	5	7	3	7	10	4	11	15
Density (individuals /km²)	2.14 ± 0.76	2.23 ± 0.54	2.18 ± 0.59	2.87 ± 0.35	2.88 ± 0.42	2.87 ± 0.38	3.05 ± 0.44	2.98 ± 0.51	3.01 ± 0.48
Group density (groups/km ²)	1.57 ± 0.21	1.61 ± 0.13	1.59 ± 0.19	1.88 ± 0.24	1.76 ± 0.19	1.82 ± 0.21	1.83 ± 0.14	1.89 ± 0.19	1.86 ± 0.17

Table 2: Seasonal detection parameters and model selection (pooled data).

Season	Mean group size ± SE	ESW ± SE (m)	AIC	Model + adjustment
Post-monsoon	1.37 ± 0.37	34.50 ± 2.44	188.96	Uniform + cosine
Winter	1.57 ± 0.42	28.33 ± 2.82	193.28	Uniform + cosine
Summer	1.61 ± 0.29	34.02 ± 2.69	201.22	Uniform + cosine

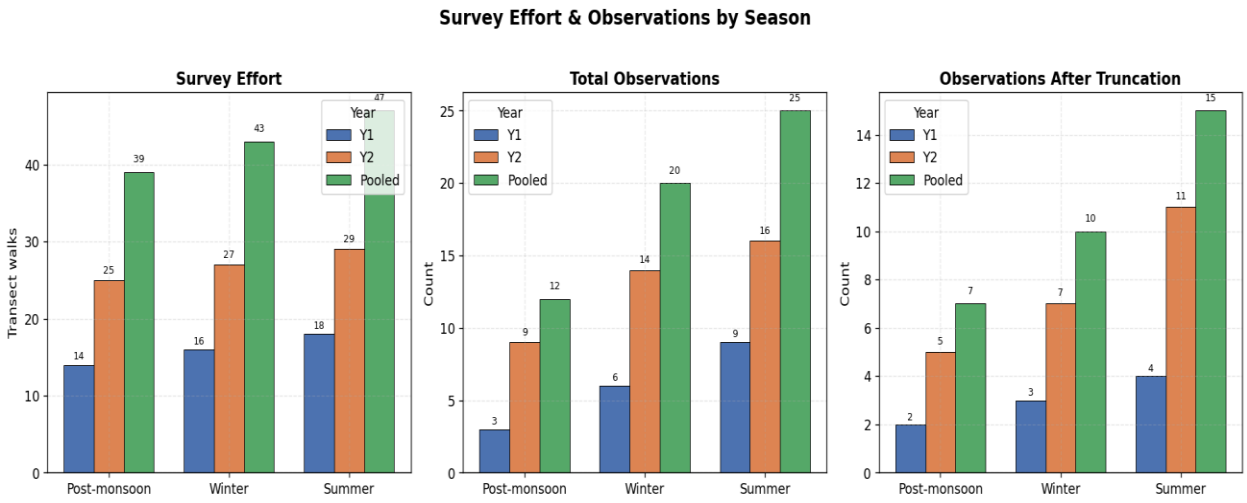


Figure 1: Survey Effort and Observation Counts by Season and Year

Grouped bar charts showing (a) survey effort (number of transect walks), (b) total observations, and (c) observations retained after truncation, for Post-monsoon, Winter, and Summer across Year 1 (Y1), Year 2 (Y2), and pooled data. Each panel compares the three survey years within each season. Effort was lowest in Post-monsoon (14–39 walks) and highest in Summer (18–47 walks), while observation counts increased consistently from Y1 to Y2 in all seasons.

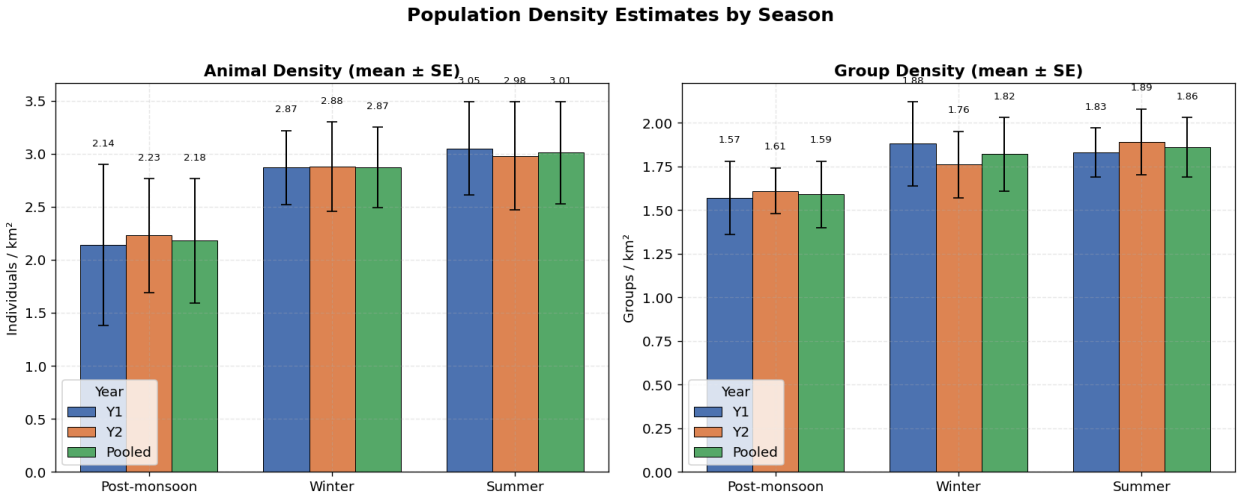


Figure 2: Animal and Group Density Estimates by Season (mean ± SE)

Grouped bar charts with error bars showing (a) animal density (individuals/km²) and (b) group density (groups/km²) for each season, comparing Year 1, Year 2, and pooled estimates. Error bars represent standard errors. Animal density was lowest in Post-monsoon (~2.2 ind/km²) and highest in Summer (~3.0 ind/km²), with group density following a similar seasonal pattern (~1.6–1.9 groups/km²). Estimates were consistent between years within each season.

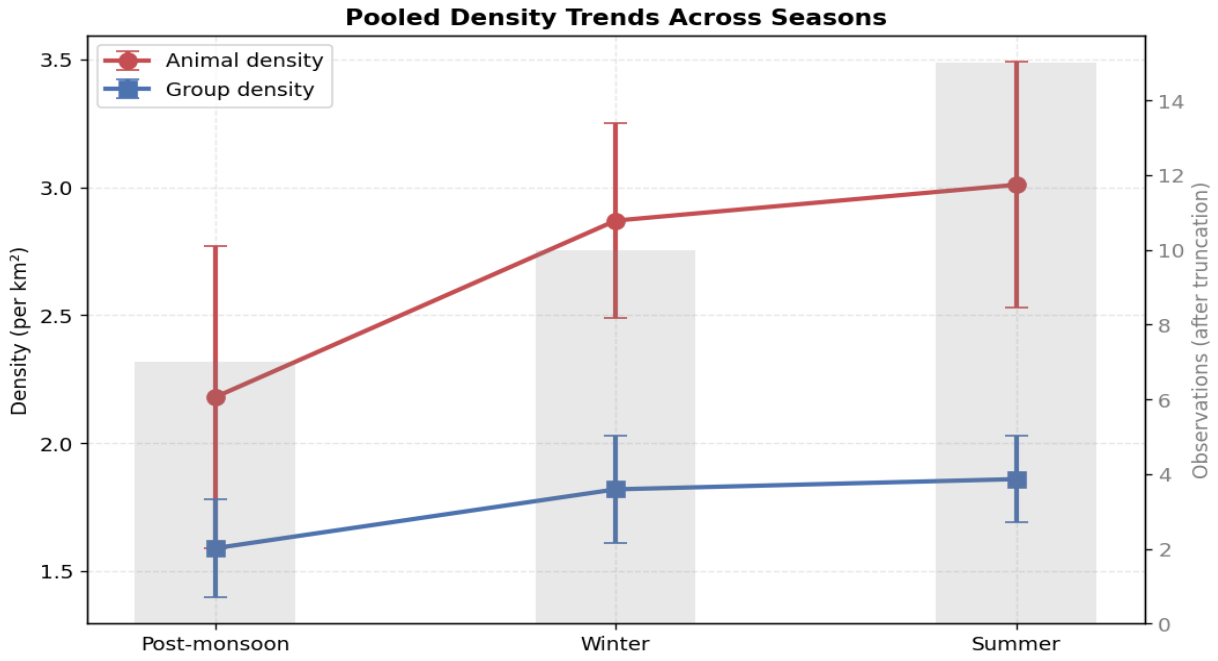


Figure 3: Pooled Density Trends across Seasons with Observation Effort Overlay

Line plot of pooled animal density (red circles) and group density (blue squares) across Post-monsoon, Winter, and Summer, with error bars (± SE). Observations retained after truncation are overlaid as light grey bars on a secondary axis to show the relationship between sampling intensity and density estimates. Both density metrics increased from Post-monsoon to Summer, paralleling the increase in retained observations (7 → 10 → 15).

4.2 Seasonal density and group density

Sambar density showed a clear seasonal gradient (Table 1). Pooled density was lowest in the post-monsoon season (2.18 ± 0.59 individuals/km²), higher in winter (2.87 ± 0.38) and highest in summer (3.01 ± 0.48). Year-specific estimates were very similar: 2.14 ± 0.76 and 2.23 ± 0.54 in the post-monsoon, 2.87 ± 0.35 and 2.88 ± 0.42 in winter, and 3.05 ± 0.44 and 2.98 ± 0.51 in summer. Group density showed the same pattern, rising from 1.59 ± 0.19 groups/km² (post-monsoon) to 1.82 ± 0.21 (winter) and 1.86 ± 0.17 (summer). Mean group size increased gradually from 1.37 ± 0.37 individuals per group in the post-monsoon season to 1.57 ± 0.42 in winter and 1.61 ± 0.29 in summer.

4.3 Detectability and model selection

The effective strip width was widest in the post-monsoon season (34.50 ± 2.44 m),

comparable in summer (34.02 ± 2.69 m), and narrowest in winter (28.33 ± 2.82 m; Table 2). The uniform key function with a cosine adjustment term was selected for all three seasonal analyses, with AIC values of 188.96, 193.28 and 201.22 for post-monsoon, winter and summer, respectively.

4.4 Density among habitats

Sambar density and group density differed markedly among the five habitats (Table 3). Grasslands supported the highest annual mean density (4.21 individuals/km²) and group density (2.84 groups/km²). Mixed forest ranked second (3.44 individuals/km²; 2.09 groups/km²), followed by sal forest (2.53; 1.32), teak plantations (2.21; 1.74) and bamboo forest, which had the lowest values for both parameters (1.07 individuals/km²; 0.84 groups/km²). Averaged across habitats, density was 2.69 ± 1.20 (SD) individuals/km² and group density was 1.76 ± 0.76 (SD) groups/km², and the high SDs indicate substantial spatial heterogeneity. In every habitat, density exceeded group density, indicating groups of more than one animal on average.

Table 3: Seasonal and annual mean density (individuals/km²) of sambar in five habitats of Achanakmar Tiger Reserve

Habitat	Post-monsoon	Summer	Winter	Annual mean
Grasslands	3.45	4.66	4.51	4.21
Mixed forest	2.85	3.81	3.66	3.44
Sal forest	1.88	2.93	2.78	2.53
Teak plantations	1.89	2.44	2.31	2.21
Bamboo forest	0.87	1.21	1.12	1.07
Mean across habitats	**2.19**	**3.01**	**2.88**	**2.69**
SD	0.99	1.32	1.29	1.20

Table 4: Seasonal and annual mean group density (groups/km²) of sambar in five habitats of Achanakmar Tiger Reserve

Habitat	Post-monsoon	Summer	Winter	Annual mean
Grasslands	2.61	3.05	2.86	2.84
Mixed forest	1.85	2.22	2.19	2.09

Teak plantations	1.61	1.81	1.79	1.74
Sal forest	1.11	1.42	1.43	1.32
Bamboo forest	0.75	0.91	0.85	0.84
Mean across habitats	**1.59**	**1.88**	**1.82**	**1.76**
SD	0.72	0.81	0.76	0.76

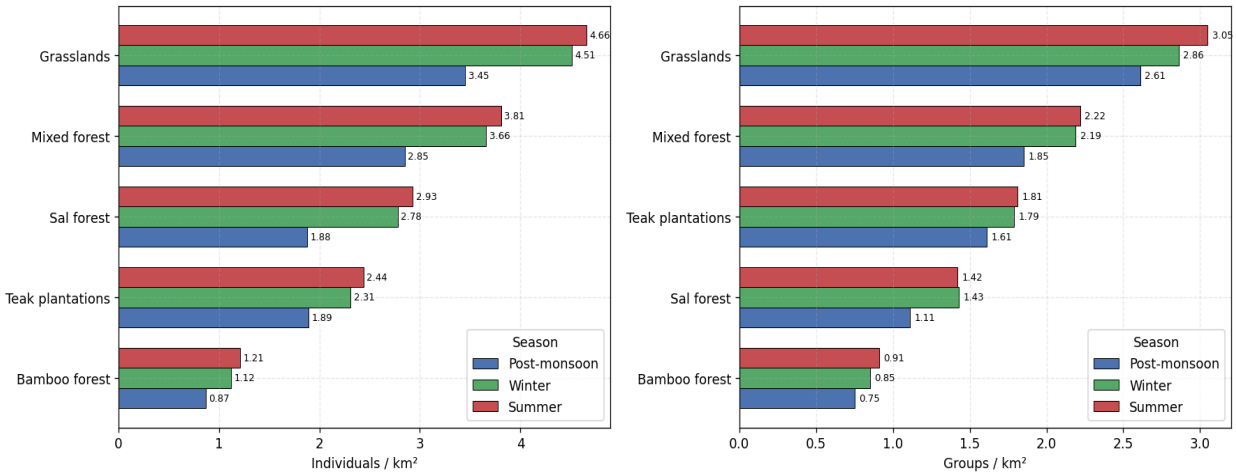


Figure 4. Habitat-wise seasonal density of sambar in Achanakmar Tiger Reserve

Grouped horizontal bar charts of (left) animal density (individuals/km²) and (right) group density (groups/km²) across five habitats for Post-monsoon, Winter, and Summer. Habitats are ordered by annual mean density; values are labelled on each bar.

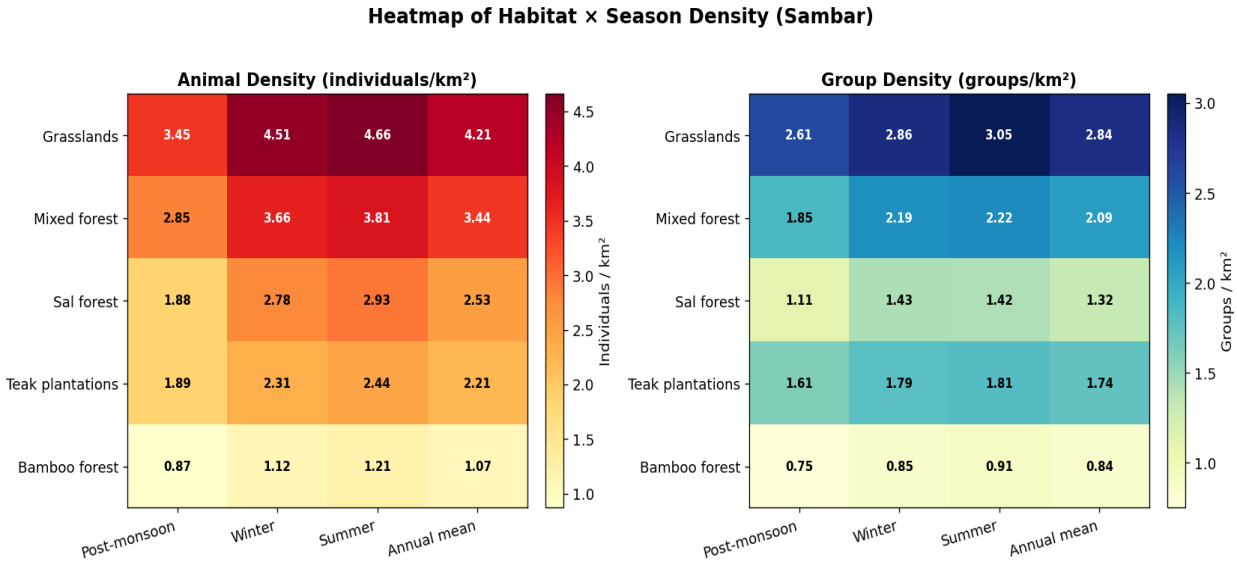


Figure 5: Heatmap of habitat × season density estimates for sambar.

Colour-coded matrices of (left) animal density and (right) group density across five habitats and three seasons, including annual means. Cell values are annotated; warmer colours indicate higher density.

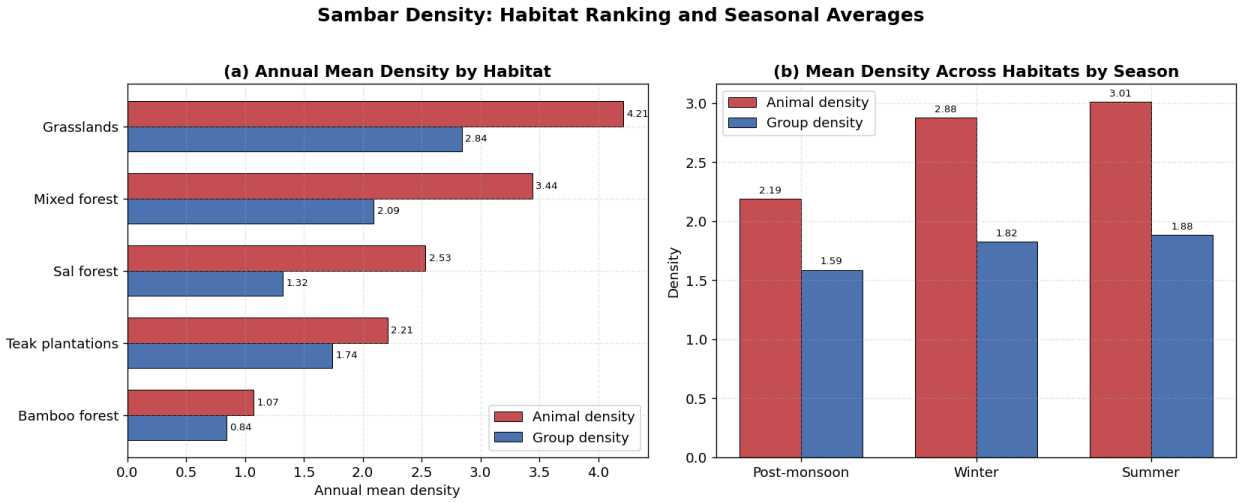


Figure 6: Habitat ranking and seasonal averages of sambar density.

(a) Annual mean animal and group density ranked by habitat; (b) mean density (± across habitats) for Post-monsoon, Winter, and Summer. Both metrics peak in Summer and are highest in Grasslands and lowest in Bamboo forest.

4.5 Seasonal variation within habitats

Summer supported the highest density in every habitat, followed by winter, with the post-monsoon season consistently lowest (Table 3). Grasslands peaked at 4.66 individuals/km² in summer, compared with 4.51 in winter and 3.45 in the post-monsoon season. Mixed forest followed a similar trajectory (3.81, 3.66 and 2.85 individuals/km²). Sal forest and teak plantations showed moderate densities (summer 2.93 and 2.44; winter 2.78 and 2.31), whereas bamboo forest remained lowest in every season (0.87, 1.21 and 1.12). Winter values were closer to summer than to post-monsoon values in all habitats. Group density mirrored these patterns (Table 4): the summer peak was 3.05 groups/km² in grasslands and 0.91 groups/km² in bamboo forest, and pooled seasonal means were 1.59 (post-monsoon), 1.88 (summer) and 1.82 groups/km² (winter).

4.6 Spatial distribution

Sambar density was highest in the core areas of ATR, followed by the buffer strips. The grasslands and mixed forest of the Achanakmar, Lamni, Surahi and Chapparwa areas held high densities, whereas other parts of the core, together with the Koechi, Kota and Lormi buffer areas, recorded very low densities.

5. Discussion

5.1 Overall density and seasonal pattern

Pooled sambar density in ATR ranged from 2.18 to 3.01 individuals/km² across seasons, which characterises the sambar as a relatively common and widely distributed ungulate in the reserve. The seasonal increase from post-monsoon to summer was accompanied by increases in group density and mean group size, and the year-specific estimates were closely similar, which suggests that the pattern is repeatable rather than an artefact of a single survey year.

Because sambar are sedentary and do not typically shift ranges seasonally, the seasonal differences we observed are best understood as changes in local distribution and detectability rather than changes in absolute population size. In the dry months, forage and surface water become localised and animals concentrate in habitats that offer both, notably grasslands and mixed forest, where visibility is also better. After the monsoon, forage and water are widely distributed, animals disperse across the landscape, and densities along transects fall. The mild increase in mean group size from 1.37 to 1.61 individuals is consistent with slightly larger aggregations when resources are scarce, although the groups remained small, as is typical of this largely solitary or small-group deer. Because group-size estimates have wide standard errors, we regard this trend as suggestive.

5.2 Detectability

The effective strip width differed among seasons, from 28.33 m in winter to 34.50 m in the post-monsoon season. A narrower strip in winter is plausibly linked to dense understorey growth that reduces lateral visibility, whereas reduced foliage in drier periods improves detection. This variation shows why detection probability should be modelled for each season, and why raw encounter rates would be misleading when compared across seasons. The selection of the same model form (uniform key with cosine adjustment) for all seasons supports consistent treatment of the data. AIC values are not comparable among seasons because

each season is fitted to a different dataset, so they indicate relative fit only within a season and should not be interpreted as evidence of seasonal change in density.

5.3 Habitat association

Habitat had the strongest effect on sambar density. Grasslands and mixed forest were the principal strongholds in all seasons. Open herbaceous cover with abundant forage and adjacent cover in mixed forest likely provide both feeding sites and refuge, in line with the known preference of sambar for grass–shrub–tree mosaics for feeding. Teak plantations and sal forest supported moderate densities, probably because their understorey is more limited in forage value. Bamboo forest consistently supported the lowest densities, which may reflect the dense understorey and poor visibility that make it less suitable for a large ungulate, and may partly reflect lower detection there. The ranking of habitats remained the same across seasons, indicating stable habitat preferences.

The high densities in the Achanakmar, Lamni, Surahi and Chapparwa areas and the low densities in the Koechi, Kota and Lormi buffer areas suggest that food, water and low biotic interference determine the distribution of sambar. Buffer zones are more exposed to livestock grazing, resource extraction and settlements, which can displace wild ungulates and compete for forage. Targeted habitat and disturbance management in these buffer areas could help to redistribute prey and to reduce the risk of conflict at the forest edge.

5.4 Implications for tiger conservation

Sambar are one of the principal large prey species of the tiger, and their density is a direct measure of the prey available to tigers in ATR. The concentration of sambar in grasslands and mixed forest highlights these habitats as critical for the prey base. Maintaining grassland quality, preventing woody encroachment and invasive weeds, ensuring year-round water sources, and limiting grazing and disturbance in the high-density zones should be priorities. The marked seasonal variation also indicates that monitoring programmes should be season-specific, so that density estimates are ecologically meaningful and comparable over time.

5.5 Limitations

Several limitations should be considered. First, the number of sambar detections per season was small (7–15 after truncation), and the year-specific estimates rest on only 2–11 observations; distance-sampling

guidelines generally recommend larger samples for reliable detection function fitting (Buckland et al., 2001). Estimates should therefore be viewed as indicative, and pooling across years and habitats is recommended where possible. Second, sampling effort differed among seasons, which may affect precision. Third, we report standard errors only; confidence intervals and coefficients of variation would improve interpretation. Fourth, habitat-level estimates are descriptive and were not tested statistically. Finally, the dung-based and road-based data were not used for density estimation and should be integrated in future work for cross-validation.

6. Conclusions

Sambar occur in Achanakmar Tiger Reserve at a moderate density of about 2.2–3.0 individuals/km², with density, group density and group size all increasing from the post-monsoon season to summer. Grasslands and mixed forest are the key habitats, whereas bamboo forest and parts of the buffer zone hold few animals. Season-specific, detection-corrected surveys are essential for accurate monitoring of this Vulnerable cervid and for assessing the prey base of the reserve's tigers. We recommend continued long-term monitoring, increased sampling effort to improve precision, and habitat management that conserves grassland–mixed forest mosaics and water availability.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The data supporting this study are available from the corresponding author on reasonable request.

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